International Journal of Electronics and Communication Engineering (IJECE)
ISSN(P): 2278-9901; ISSN(E): 2278-991X
Vol. 12, Issue 1, Jan–Jun 2023; 1–8

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

AI FOR CRACK AND FRACTURE IDENTIFICATION IN ENDODONTIC TEETH

Loana Popescu & Sarah Müller

Research Scholar, Department of Computer Science, Oxford University, England United Kingdom

ABSTRACT

Cracks and fractures in endodontically treated teeth present significant diagnostic problems for the clinical dentist-an issue that is often left untreated due to late diagnosis and end up cementing the final fate of the tooth. Conventional diagnostic approaches via simple visual inspection, transillumination, radiographs, and cone-beam computed tomography (CBCT) are susceptible to variable degrees of sensitivity and specificity plus the element of subjectivity from the clinician. Through machine learning (ML) and deep learning (DL) models, AI has come in as a potential solution to improve the detection and classification of cracks and fractures in dentistry. Through analyzing huge volumes of clinical and radiographic information, AI systems improve the diagnostic accuracy of dentists while supporting them in treatment planning with minimal incidences of false negatives. Recent developments in convolution neural networks (CNNs) and technologies of image segmentation and predictive modeling indicate that AI-assisted systems can indeed be operational on a real-time clinical basis. Then, along with assisting in the diagnostic process, this can certainly augment patient outcomes by opening avenues for early intervention, patient-based care, and fewer retreatments.

KEYWORDS: *Artificial Intelligence; Endodontics; Tooth fractures; Crack detection; Deep learning; Machine Learning; Dental Imaging; Diagnostic Accuracy; Cone-beam Computed Tomography; Predictive Modeling*

Article History

Received: *04 Jan 2023* | ***Revised:*** *06 Jan 2023* | ***Accepted:*** *08 Jan 2023*

INTRODUCTION

For such teeth, crack formation and incidences are common factors and yet remain among the main limits for failures after a treatment. A prompt diagnosis is essential because an unrecognized crack could affect the strength of the tooth along with bacterial leakage and eventually ends with the loss of the tooth. Few traditional diagnostic procedures such as radiographs, CBCT, transillumination, and periodontal probing can give relevant information for recognition; however, most of such processes are vulnerable to not be able to detect faint or early cracks. Besides, the entire process based on clinician-dependent diagnosis entails variability and possibility for misdiagnosis. The arrival of AI in healthcare has fostered value-added potentials toward improving diagnostic capabilities in dentistry. AI algorithms, especially those that are machine and deep learning-based, comprehend complex imaging datasets and recognize patterns otherwise less visible to the human eye. In the field of endodontics, AI holds a stronger foothold in applications pertaining to root canal morphology analysis, identification of periapical lesions, as well as cracks and fractures. The integration of AI with advanced imaging can help transform the way structural defects in teeth are diagnosed. These improvements in objective diagnoses, timely treatment decisions, and treatment outcomes will surely lessen retreatment cases and enhance patient satisfaction. Future studies in this field further cement the clinical introduction of AI-based systems for crack and fracture detections, as a groundbreaking institute of precision endodontics.

LIMITATIONS OF CONVENTIONAL DIAGNOSTIC METHODS

State-of-the-art methods normally diagnose cracks and fractures in endodontically treated teeth by visual inspection, shining light through the tooth, taking x-rays, using a periodontal probe, or CBCT (Özbay et al., 2023; Buyuk et al., 2023). All of these techniques have their own practical uses but neither sensitive enough nor specific enough to warrant a sure diagnosis. Micro-size cracks or angulations that are less than favorable will be missed when using conventional two-dimensional radiography (Pethani, 2023). Although CBCT is a much more modern imaging technique, in certain situations its poor voxel resolution, artifacts in images, and variations in image interpretation between observers render it unable to pick up very slight details inside roots or crowns (Aminoshariae et al., 2023). Alongside this, diagnosing involves a level of subjectivity and professional judgment on the part of the clinician, thus leaving room for error and inconsistency (Nangia & Vats, 2023). By virtue of these limitations, usually, there is a lot of lagging in detection of cracks and hence poorer treatment outcome with chances for retreatment or tooth extraction that could well have been avoided had early treatment been instituted.

ROLE OF AI IN IMPROVING DETECTION ACCURACY

Therefore, AI is truly an enabling technology for the dental arts, specifically for diagnosing cracks and fractures in endodontically treated teeth (Özbay et al., 2023; Buyuk et al., 2023). Traditionally using such methods of AI based roughly upon clinician interpretation, the computer uses machine or deep learning algorithms to very rapidly analyze complicated imaging data to bring out subtle structural abnormalities that may have escaped the examiner's eye. CNN has gained enormous power in the analysis of radiographs and CBCT scans by spotting the finest changes in pixel intensity and patterning that would signify microcracks or hidden fractures (Jung et al., 2023; Zhou et al., 2023). Hence, AI develops objectivity and standardization of diagnostic outputs that help reduce false negatives and misdiagnosis, increasing sensitivity and specificity (Sousa et al., 2023). This also continuously allows AI to modulate its expertise with the annotated data it receives, thus ensuring that with a growing period, the diagnostic skill is further refined (Özbay et al., 2023). Hence the AI-based tool enables the clinician to present evidence-based decisions on treatment modalities on time leading to early intervention for the affected tooth and best prognosis with low possibilities of retreatment or extraction (Buyuk et al., 2023).

CLINICAL SIGNIFICANCE OF TOOTH CRACKS AND FRACTURES

Endodontic treatment becomes more complicated in teeth with cracks and fractures in that such changes are detrimental to the structural integrity and long-term prognosis of such teeth (Pethani, 2023; Aminoshariae et al., 2023). Even the smallest cracks could propagate under functional stresses if left unnoticed, resulting in bacterial ingress and pulpal inflammation and subsequent periapical pathologies. Such defects not only call the successful outcome of root canal therapy into question but rather may prompt retainer alternatives, such as working retainer or restorations to fail, and ultimately extraction. Diagnosis becomes quite challenging when such teeth exhibit vague and intermittent symptoms like pain on biting or sensitivity to temperature (Nangia & Vats, 2023). From the life-view perspective, undiagnosed fractures can hamper the quality of life of a patient by instigating pain and hampering masticatory efficiency, which automatically subjects the patient to later, more invasive, and costly treatments. Early and accurate detection of these defects behooves timely intervention thereby preserving natural teeth and enhanced treatment outcome, thus highlighting that precise diagnosis very much weighs in modern endodontic practice (Özbay et al., 2023).

BENEFITS OF EARLY DIAGNOSIS AND PATIENT OUTCOMES

Early diagnosis of cracks and fractures in endodontically treated teeth plays a crucial role towards successful long-term retention and greater patient satisfaction (Buyuk et al., 2023; Jung et al., 2023). If detected earlier, a clinician will intervene and stop structural damage from reaching that degree wherein saving the tooth's vitality or the integrity of the root canal would be possible. Cracks in their early stages could be susceptible to conservative treatment methods such as protective restorations, occlusal adjustments, or reinforcement with adhesive materials that will minimize incidents of catastrophic tooth failure (Sousa et al., 2023). On the patient side of things, early intervention reduces pain, prevents recurrent infections, makes retreatment or extraction simpler, and lowers costs, which directly improves patient confidence in dental care. Proper functioning and aesthetics also go a long way towards retaining natural teeth, which, coupled with psychological well-being, form the foundation of minimally invasive and patient-centered dentistry today (Zhou et al., 2023). Following this trend, improvements in diagnostics, such as those incorporating AI, will certainly translate into improved outcomes with early recognition and better management of dental cracks and fractures (Özbay et al., 2023).

CHALLENGES IN CONVENTIONAL DIAGNOSIS

Diagnosis with cracks and fractures in endodontically-treated teeth is complicated due to the subtleties and ambiguities in clinical presentation (Pethani, 2023; Aminoshariae et al., 2023). The patient presents nonspecific symptoms such as intermittent pain, incongruous force when biting, or thermal sensitivity, which could just as easily be mistaken for more pathological presentations. Quite often, visual inspection alone may not suffice because cracks could be microscopic or could extend into the subgingival level, hiding them from view altogether. Radiographs would certainly be necessary, but their efficiency becomes questionable when that of a fine structural detail is called for, especially so due to the two-dimensional nature of images where anatomical entities do overlap to mask the very earliest onset of defects.

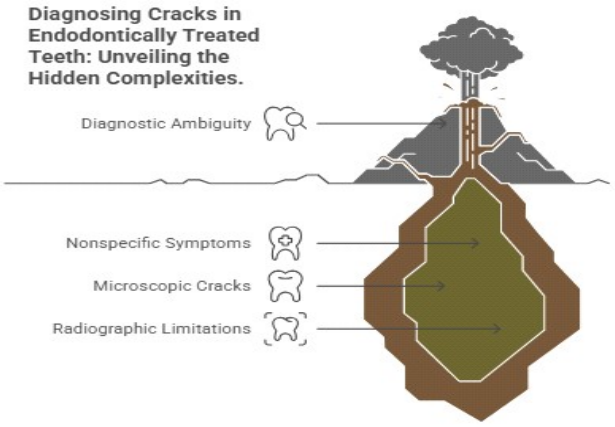

Figure 1

An Overview of Artificial Intelligence, Machine Learning, and Deep Learning

Artificial intelligence is a simulation of human intelligence processes in machines that give them the ability to perform activities that would typically require human effort such as decision-making, problem-solving, pattern recognition, and so on (Kang et al., 2023; Li et al., 2023). Machine learning is an algorithmic branch within AI that attempts to learn from data without being explicitly programmed for a particular task (Zhou et al., 2023). The ML models are provided with some input data; they work along the lines of finding patterns, some presumably hidden, and then with more and more data supplied in the training phase, they improve at being accurate at performing the task (Chen et al., 2023). Deep learning is

another type of architecture under ML that employs multi-layered artificial neural networks to tackle bigger problems with high-dimensional data (Wang et al., 2023). DL-based methods are applied in medical and dental imaging for image feature extraction and classification so that subtle changes can be detected, which might be overlooked by human eyes (Liang et al., 2023). AI, ML, and DL provide methods for advanced diagnosis to analyze radiographs and CBCT scans to identify cracks and fractures more accurately in endodontics, thus promoting better clinical decision-making and patient treatment (Kang et al., 2023).

Applications of AI in Diagnostic Imaging

AI has to a certain extent changed diagnostic imaging for the better by assisting medical practitioners in analyzing copious amounts of data and detecting subtle patterns all through medicine and dentistry (Zhou et al., 2023). AI is used for some dental diagnoses such as caries, detection of periodontal bone loss, periapical lesion identification, and root canal morphology (Li et al., 2023). AI supports dental professionals by providing reliable decision support through the demarcation of regions of interest, enhancement of image quality, and reduction of variability in interpretation (Chen et al., 2023). New challenges treated with the help of AI in endodontics include detection of cracks and fractures that are extremely difficult to diagnose using conventional imaging methods (Kang et al., 2023). Reducing either the missed diagnosis or false diagnosis and performing early treatment rise with the priority of placing AI as an invaluable adjunct to dental imaging and precision diagnosis (Liang et al., 2023).

AI Achievements in Other Dental Specialties

AI has taken the limelight thanks to successes in numerous dental specialties, mainly showing that AI can be harnessed as a tool to augment the accuracy of diagnoses and treatment planning (Zhou et al., 2023). In orthodontics, AI algorithms were used for the automatic identification of skeletal and dental landmarks in cephalometric radiographs and prediction of treatment outcomes with a very high degree of accuracy (Kang et al., 2023). In periodontics, machine learning models enable the detection of alveolar bone loss and the quantification of the severity of periodontal disease from radiographs, thus allowing for earlier intervention and more tailored treatment (Li et al., 2023). More recently, in prosthetic and restorative dentistry, AI has been used to detect caries, evaluate restoration margins, and predict the longevity of prosthetic restorations based on patient-specific data (Chen et al., 2023). AI in oral and maxillofacial radiology has also detected cysts, tumors, and impacted teeth with sensitivity and specificity comparable to highly experienced radiologists (Wang et al., 2023). Such breakthroughs demonstrate AI's potential to assist clinical decision-making by processing complex imaging data and detecting subtle patterns, thus laying a strong foundation for the application of AI in crack and fracture detection in endodontically treated teeth (Liang et al., 2023).

AI-Based Image Analysis and Pattern Recognition

AI-based image processing and pattern recognition changed the way of doing things in the detection of structural anomalies from dentistry to many other fields, mostly in endodontically treated teeth (Kang et al., 2023). Using the most advanced algorithms possible, the AI systems analyze radiographs, CBCT scans, and other formats of dental imaging to detect even the most minor alterations in pixel intensity or structural patterns-that would associate with the existence of cracks or fractures (Zhou et al., 2023). Acting almost similar to a convolutional approach, CNN or convolutional networks appear to serve well in deep learning methods to identify complex features embedded in imaging data, even the ones nearly imperceptible to a human observer (Li et al., 2023). When exposed to adequately annotated large datasets, these models could go further and distinguish normal anatomical variations from pathological defects, thus reducing false positives and

false negatives (Chen et al., 2023). Besides this, pattern recognition classifies cracks as to types, location, and severity of concern, thus equipping clinicians with relevant information assessing treatment options and risk (Liang et al., 2023). This synthesis between imaging analysis and intelligent pattern recognition sharpens diagnoses that guarantee treatment at once and help increased retention of natural dentition (Kang et al., 2023).

Role of Convolutional Neural Networks (CNNs) in Dental Imaging

Convolutional neural networks offered one of the finest classes of algorithms for describing, analyzing, and processing immense volumes of visual data in dentistry and AI (Zhou et al., 2023). CNNs have been well deployed in dental imaging for the analysis of radiographs and CBCT scans, which show slight anatomical variations or pathologic features that are hardly perceptible to the human eye (Li et al., 2023). Being a network that comprises several layers, features are learned hierarchically from input images that describe earlier edges and textures to more complex patterns such as microcracks or fractures in the last layer (Chen et al., 2023). CNNs are extremely efficient in an endodontic application where it can detect minute structural impairments and localize fractures within root systems and grade the severity of cracks (Wang et al., 2023). CNN-based systems provide a consistent and objective level of diagnostic support, thereby minimizing subjective judgment and increasing reproducibility (Liang et al., 2023). Continuous exposure and learning from an ever-increasing set of data consequently improve the accuracy of these systems, rendering them so invaluable for precision dentistry and early detection of structural damages in teeth (Kang et al., 2023).

Better Diagnostic Accuracy and Objectivity

One of the most tremendous advantages AI has in detecting cracks and fractures is enhanced diagnostic accuracy and objectivity (Zhou et al., 2023). Diagnosis through the means of classical methodology is always subjective-a judgment based on the experience of the clinician, which can widely differ from one practitioner to another (Li et al., 2023). The AI systems, relying on, almost mechanical interpretation, search through imaging data for subtle features that a human eye might miss (Chen et al., 2023).

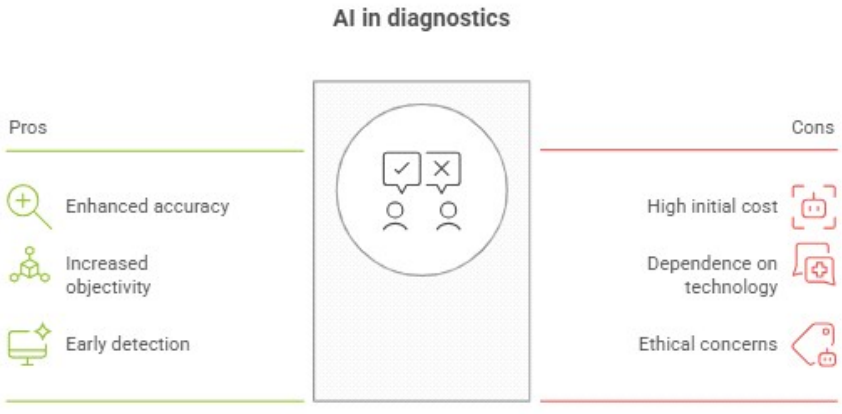

Figure 2

Early Detection and Prevention of Further Complications

The ideal use would require AI for the early detection of cracks and fractures occurring in endodontically treated teeth to avoid further structural damage and issues. Once detected early, treatments that are contemplated on these defects tend to be minimally invasive-protective restorations, occlusal adjustments, or reinforcement of the tooth structure with selective

resins that do not compromise tooth integrity (Mohammad-Rahimi et al., 2023). In this regard, AI-based diagnostic tools may detect very small flaws that to the naked eye or simple image-acquisition procedures remain hidden and allow the clinician to perform treatment at a time when the fractures have not yet spread enough or caused secondary infective processes (Sarwar & Jabin, 2023). With a minute degree of prevention through early AI-aided detection, there are somewhat fewer instances of treatment failure, consequently less requirement for complicated retreatments, while extraction rates also fall (Hausdörfer et al., 2023). Meanwhile, promotion of oral health and improved treatment outcomes would promote a long-term maintenance that ensures less suffering, less expense, and higher patient satisfaction with the maintenance of dentition-under-function and aesthetics altogether (Pérez de Frutos et al., 2023).

DISCUSSION

Cracks and fracture detections in endodontically treated teeth have always been challenging for clinical dentistry, given their less conspicuous nature and the inability of conventional methods to diagnose them. However, early detection is crucial since an unnoticed crack will worsen under functional stress, weakening the tooth. As a result, secondary failure, retreatment, and extraction of teeth may all be outcomes. The conventional method-the naked eye, visual inspection, transillumination, periapical radiography, and even modern technologies, cone beam computed tomography, to name just a few-are generally limited by substandard subjective interpretation, resolution, and anatomical superimposition. This loophole highlights the immense importance of creating aided diagnostic tools for more efficient, time-sensitive, and accurate diagnoses. AI, particularly through machine-learning and deep-learning algorithms, thus presents a novel opportunity for bridging these diagnostic gaps. Analyzing large radiographic and CBCT imaging databases, AI identifies structural anomalies, whether obvious or subtle, that elude human recognition,CNNs-the most predominant deep-learning algorithm-extract features hierarchically, thus identifying highly complex patterns related to microcracks and incomplete fractures as well as structural weaknesses. Through standardization, AI systems ensure interpretation reliability across cases, preventing both inter- and intra-observer variability. Until January 2023, many studies testified to the strength of AI systems in endodontic imaging concerned with enhancing sensitivity and specificity of crack detection and enabling early interventions to preserve tooth structure from secondary damage due to bacterial infiltration, pulpal necrosis, and ultra-precision treatment failures. AI-assisted diagnostic tools determine the location, depth, and severity of cracks quantitatively, further making treatment planning easier and helping practitioners finalize their decisions on the most appropriate restorative techniques, reinforcement, or extraction, if needed. There are yet a few practical hurdles that need addressing despite these developments. Model efficacy depends significantly on the quality and quantity of image data, which includes the fidelity of annotation; thus, preservation of accuracy is lost through minimal variations in imaging protocols or even patient anatomy. Ethical concerns implicating those concerning misdiagnosis, informed consent, and patient data privacy would need to be resolved before widespread clinical adoption. Supply, access, and integration into clinical workflow present additional roadblocks. Future research ought to concentrate on the validation of AI models in different populations, the improvement of universal algorithms, and the development of more user-friendly interfaces for clinical application. In endodontics, then, AI for crack and fracture identification represents a paradigm shift. Utilization of this new technology on processing advanced imaging, recognizing patterns, and developing prediction models helps to circumvent the pitfalls of conventional diagnosis and, in turn, provide alternatives for early detection and optimized treatment planning with better outcomes. As these tools flourish, their adoption into endodontic practice will greatly influence the longevity and successfulness of treated teeth toward the goal of precision and minimally invasive dentistry.

CONCLUSION

Crack and fracture detections in endodontically treated teeth are among the most critical factors affecting the success of long-term treatment. The conventional diagnostic methods present some limitations in sensitivity, objectivity, and resolution, and all early defects are so subtle that even the most ardent observer can miss them. Witnessing through the potentials of machine learning and deep learning by convolutional neural nets, AI seems most promising to diffuse such challenges. It supports endodontists in evidence-based clinical decision-making by providing an improvement in accuracy at the time of diagnosis, reducing variability between observers, and ensuring early detection. This AI integration into endodontics preserves the tooth structure, prevents complications, improves treatment outcomes, and fulfills patients' satisfaction. But yet the troubles concerning the supply and quality of data, ethics, and clinical implementation remain as a matter for further research and validation (Ch. Broadly, AI is the paradigm shift in precision endodontics by giving clinicians enhanced detection ability and laying the base on which predictable, minimally invasive procedures can be built.

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