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Convolutional Neural Network in Periodontology – Innovative Technology or New Era? – A Review

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ABSTRACT

Periodontitis is an inflammatory disease that affects the supporting tissues and bone around the teeth. In severe situations, it can result in tooth loss. This disease is most prevalent in rural and remote areas, where dental visits are few and far between. As a result, allied health practitioners will need a periodontal screening tool to diagnose periodontitis for early detection & also for prediction.

Clinical evaluation and radiograph examination by subject experts are two of the most common approaches used today to diagnose periodontal disorders. Due to numerous shortcomings of the traditional diagnosis paradigm — inaccuracy due to human error, inconsistent evaluations by individual examiners, and a lack of time to parse through vast volumes of data to arrive at accurate diagnoses — there is an increasing need for a more systematic approach to diagnose Periodontal conditions. As a result, computer-based technology will play a key role, as they provide a variety of diagnostic and detection methods for diseases like gingivitis, dental plaque, and periodontitis.

Dentistry has evolved from a very long time. Technologies tend to develop day by day, which tends to makes our everyday life easier and comfortable. Over the last decade, Convolutional Neural Networks (CNN) have opened the door to a wide range of applications, including facial and speech recognition, climate mapping, colorization of black-and-white videos, record analysis and preservation, and so on.

CNN can act as an unsupervised diagnostic tool in Periodontology, however, has been extremely limited, primarily due to hardware constraints, but also because of the lack of efficient interaction between the exclusive disciplines of AI and dentistry. It is safe to suppose that with the right algorithms and the skills of examiners trained in both dentistry and neural networks, transformative leaps in dental diagnostics and prognostics can be achieved, ushering in a new age in periodontology diagnosis.

Keywords:
Convolutional neural network, Artificial Intelligence, CNN, Periodontitis, Diagnocat, Diagnostic Aid

1. Introduction

Periodontitis is one of the most common diseases in the world, affecting billions of people and contributing to mobility of tooth and can lead to loss of tooth if left untreated. To treat periodontitis, early detection and active periodontal therapy, as well as routinely supportive periodontal therapy, are required. Clinical attachment loss assessments are used to detect and diagnose periodontal disease by assessing probing pocket depths and gingival recessions.

This clinical assessment, however, is unreliable, and periodontal disease screening is both a diagnostic endeavour and prone to discover localised periodontal tissue loss. As a result, automated assistance systems are needed.[1]

Day by day, technological advancements make our daily lives simpler and more relaxed. In dentistry, similar technological advancements have been made. In today's world of shifting trends, everything has gone digital, making work more easy, precise, and reliable, potentially increasing productivity and reducing time. Such automated technologies could enable for more exact and consistent periodontal condition.

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Convolutional neural networks (CNNs), the most recent, core form of artificial neural networks and deep learning in computer vision, have expanded significantly since around 2010. Because medical information is digitally processed and managed to accumulate quantitatively and qualitatively, deep CNNs with computer-aided detection (CAD) systems have global scale to be implemented in the medical field. This really fast-growing new field of research has produced promising results in terms of diagnosis and prediction in research.[2]

Convolutional neural networks (CNNs) are being effectively utilised in healthcare to diagnose breast cancer using mammography, melanoma during clinical skin screenings, and diabetic retinopathy with eye exams, for instances. In dentistry, CNN architectures that have been trained to identify carious lesions using bitewing and peri-apical radiographs. Convolutional neural networks (CNNs) are powerful image-processing techniques. As a result, the goal of this review would be to see how effective and accurate deep CNN algorithms are at diagnosing and detecting periodontal illnesses. [3]

2. WHAT IS CNN?

Artificial Intelligence has come a long way in bridging the gap between human and computer capabilities. A Convolutional Neural Network (CNN) is a deep learning method that can take an image as an input and assign importance (learnable weights and biases) to diverse components in the image, allowing them to be differentiated from one another. Multilayer perceptrons (MLPs) are regularised variations of CNNs. It usually refers to fully interconnected networks, in which individual neuron in one layer is coupled to all neurons in the following layer.[3]

2.1 MAIN ARCHITECTURE:

A convolutional neural network's core architecture consists of an input layer, hidden layers, and an output layer. The activation unit and final layers are often regarded as secret layers because they cover the inputs and outputs of the middle layers. Convolutional layers are found in the secret layers of a convolutional neural network. [4] Convolution develops a feature map, which is then fed into the input of the following layer. Other layers, like pooling layers, completely linked layers, or normalisation layers, are produced after that, eventually resulting to image output..(Figure 2.1)

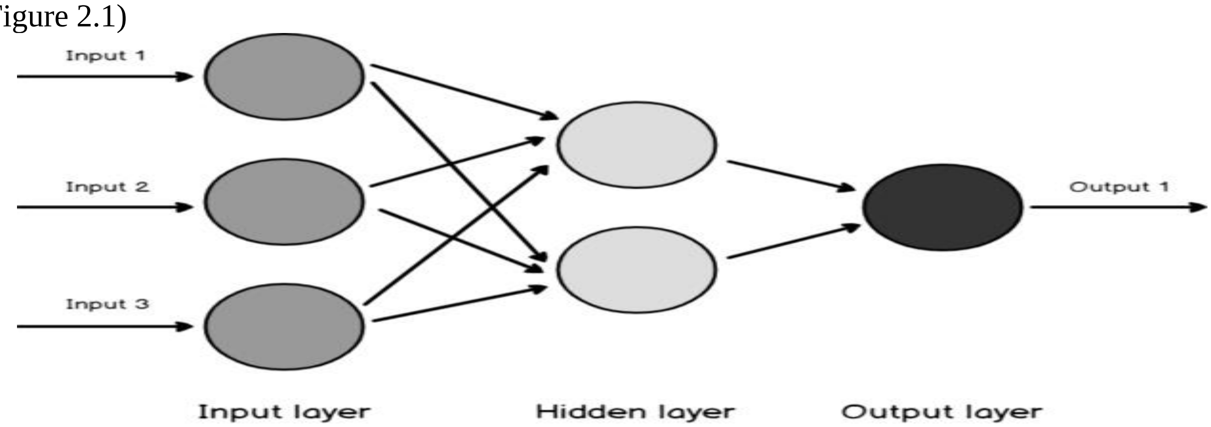

FIGURE 2.1

2.2 MECHANISM OF CNN

The input to a CNN is a tensor with a form: (number of inputs) x (input height) x (input width) x (input channels). The image is translated into a feature map, commonly known as an activation map, which organises all of the data after passing through a convolutional layer, when the algorithm's activation begins. These function maps, which have a pooling window, vectorize the

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data. Pooling layers minimise the dimensionality of data by mixing the outputs of neuron clusters at one layer into an one neuron at the subsequent layer.
The mathematical algorithms of the CNN extract minute characteristics, called features, from the pooled image datasets, and these stacked network layers learn from the continuous stream of input data. The information is then passed on to fully interlinked layers, which link each neuron from one layer to every neuron in a weighing layer. It functions similarly to a multilayer perceptron neural network (MLP). The flattened matrix runs throughout a fully connected layer to identify the images. Each neuron in a neural network generates output by applying a specified function to the input data collected from the preceding layer's receptive field..[4,5] (FIGURE 2.3)

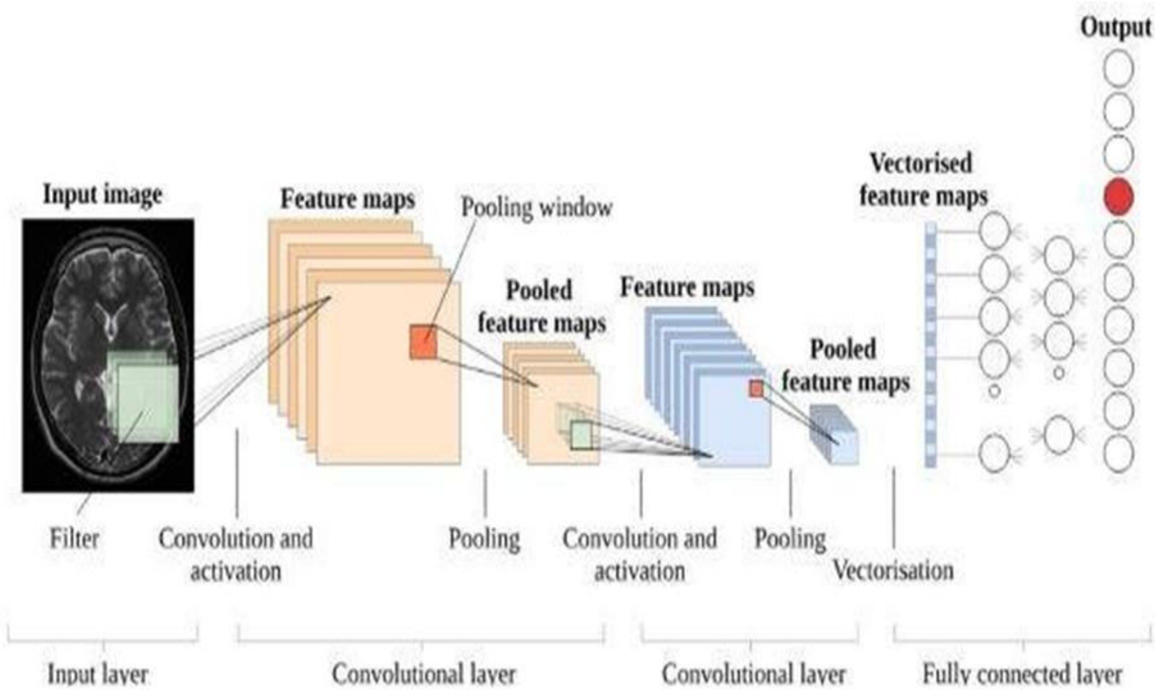

FIGURE 2.3

Multiple layers of neural networks, including disparate input and output layers of pooled modular data at either end, make up the functional mechanism of CNN. Several image datasets are fed into the network layers, along with a collection of weights, allowing CNN a more robust framework for detection than conventional shallow learning algorithms.
CNNs could be used to process high-resolution 2D or 3D radiograph images to locate, classify, and diagnose periodontally compromised teeth, overcoming. For example, for purpose of diagnosing periodontally compromised teeth, the input dataset would be multiple radiographs of teeth with and without Periodontal Bone Loss (PBL). The method to use CNN to understand radiograph can be explained in the following flowchart:

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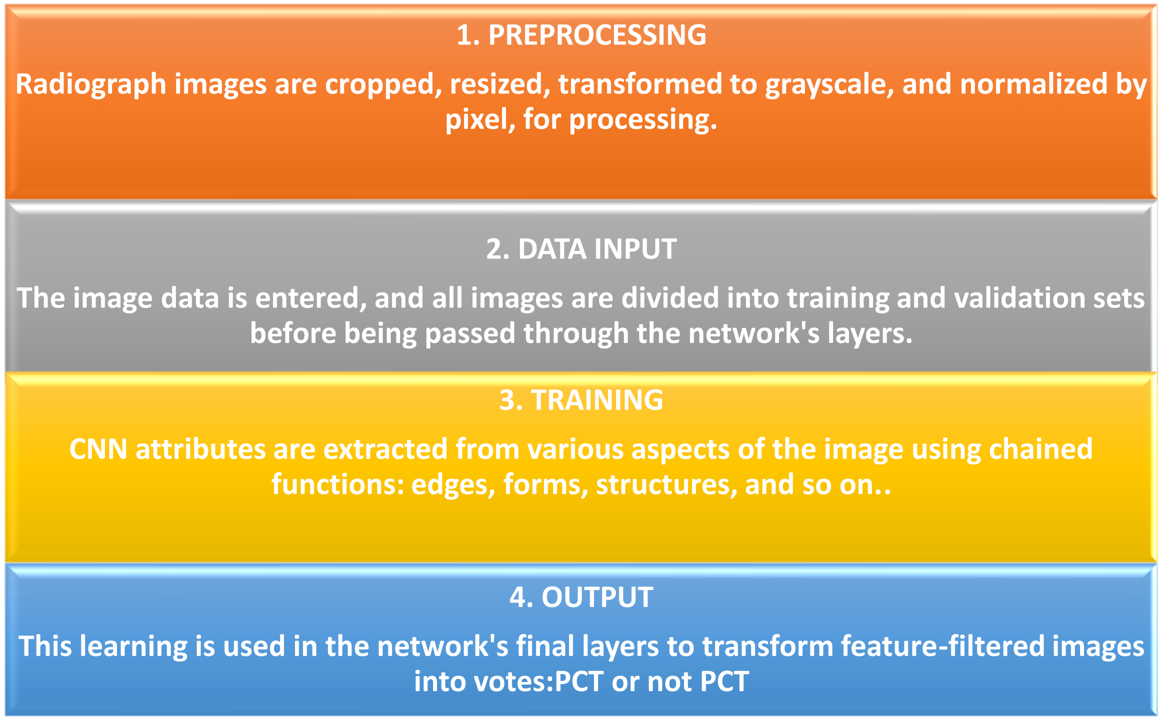

3. APPLICATIONS OF CNN

Neural Networks have been used with varying degrees of success in a variety of fields over the last decade. They aid in the recognition of distinct features of human or animal faces from photographs, correcting for parameters such as light, angle, stance, and so on. They play a critical role in understanding rapid climatic changes and modelling control and mitigation strategies.[6] In certain cases, CNNs have been used in data collection, such as :

- In handwriting identification, contrast, analysis, and digitization, with an error rate of 0.4 percent. Natural history collections, ecology, evolution, habitat destruction, and other studies are increasingly relying on AI reinforcements.
- In the field of medicine, CNNs are already being used to detect eye diseases, in addition to the promise of application in the prediction of ailments. Deep learning algorithms applied to OCT (Optical Coherence Tomography) scans can detect more than 50 different forms of eye diseases.
- Detect Cancer Early: Surpasses most conventional risk prediction models by detecting cancerous trends in mammograms of breast tissue that are too subtle for the human eye.[7]
- Diagnose Neurological Disorders: Use image processing to detect acute neurologic events, and connectome mapping to diagnose Alzheimer's, ADHD, and other autism spectrum disorders.[8]
- Evaluate Embryo Quality: Using time-lapse images, a CNN can distinguish between bad and good embryo quality with up to 97 percent accuracy, allowing for better IVF results.
- In dentistry, there have been fewer but more comprehensive attempts to use CNN to increase diagnostic accuracy .[9]

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4. APPLICATION OF CNN IN PERIODONTOLOGY

Periodontal diseases are a group of oral inflammations typically impair the gums as well as supporting components of the teeth. The use of artificial intelligence (AI) technology, such as automated systems like CNN, will aid in the accurate diagnosis and prediction of periodontal diseases. In Periodontology, CNN can be used as an unsupervised diagnostic tool. The applications of CNN can be as follows: [11]

4.1 DENTAL PLAQUE DETECTION USING CNN

Dental plaque is made up of bacterial components on the surface of the teeth; these masses are most often found on the gingival margins and interproximal areas.Commonly, a dentist would use an explorer or disclosing agents to discover dental plaque. Both of these evaluation processes are uncomfortable and time-consuming for the clinician. [12] According to the findings, developing a cost-effective and efficient system for detecting plaque is crucial in order to compare artificial intelligence's performance in plaque detection..[13]

Key Studies Using CNN to Identify Plaque

2020, Wenzhe You et al [14] did a study- On primary teeth, a comparative study of clinical assessments and deep learning in detection of dental plaque.

- After adding disclosing agent, images for primary teeth were taken using an intraoral camera, as were photographs of the discoloured teeth. Plaque-infested areas on natural and discoloured teeth were labelled.
- From these pictures, the adopted plaque detection model gathered the features of dental plaque. The observations of AI model's dental plaque were compared to the real dental plaque areas.
- When compared to an experienced paediatric dentist, the established AI model had acceptable better performance levels clinically for identifying dental plaque on primary teeth. Accuracy rate was 100%.
- It is more effective in preventing plaque accumulation & periodontitis development, as well as assisting children in improving their oral health.[14]

4.2 DETECTION OF GINGIVITIS USING CNN

Gingivitis is the earliest and mildest stage in periodontal disease, even though it is not bone-destructive and treatable if identified early. When gingivitis is not treated and advances to periodontitis, it can lead to cancer, diabetes, and heart disease, among other serious health issues. With these kinds of severe effects it's crucial to detect the disease early to avoid further complications.

Key Studies That Used CNN to Identify Gingivitis

2020, Dima M. Alalharith et al Convolutional Neural Networks using a Deep Learning-Based Approach for Detecting Gingivitis in Patients who are undergoing orthodontic treatment.

- The model showed 100 percent accuracy, precision, recall of 51.85 percent, and mAP of 100 percent.
- According to the findings of the report, providing dentistry with an improved non-invasive way to diagnose gingivitis using intraoral images will help to minimise the complications of untreated gingival disease.

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- It also eliminates the need for clinical tests and saves patients from having to undergo expensive procedures to treat the disease in its advanced stages, making it a cost-effective option.[15]

4.3 DETECTION OF PERIODONTAL DISEASE USING CNN

Periodontal disorder is diagnosed and predicted using radiographic image analysis, which is a common practise. Various experiments have been performed using panoramic radiograph or IOPA to diagnose periodontal disorders using automated systems such as CNN.

Key studies that used CNN to identify periodontal diseases

Although many studies have attempted to use CNN to enhance diagnostic accuracy in other fields of medicine, few have successfully achieved it in dentistry.

1. 2019, Joachim Krois et al(TensorFlow and Keras)[13]: Compared the diagnostic performance of a CNN in detecting Periodontal bone loss from segmented panoramic radiographs with the diagnosis of six experienced dentists.
   - CNN did not prove to be significantly superior compared to examiners. Hypothesis that it would be, was rejected.
   - However, limited agreement between dentists was evidenced.
2. 2018, Jae-Hong Lee et al. (Keras framework in Python)[17]: A convolutional neural network with deep learning base algorithm was used to diagnose and predict periodontally compromised teeth. Based on a different review by the same team that used CNN to detect dental caries. 18
   - A prelabeled periapical radiographic dataset was used to perform unguided learning using the CNN system.
   - The findings were similar by those board-certified periodontists in terms of diagnostic precision.
3. 2017, (Shannah Therese A. Aberin et al (TensorFlow and Keras)[19]: Detecting Periodontal Disease Using Convolutional Neural Network
   - Deep CNN was able to correctly distinguish safe photos 98% of the time.
   - Its overall success in correctly classifying photographs of healthy and bad teeth was 75.5 percent accurate.
4. 2017, Asghar Tabatabaei Balaei et al [20]: To examine the use of computer algorithms in the identification and also in diagnosis of periodontitis, researchers used an intra-oral photographs of before periodontitis treatment and after treatment.
   - The rate of precision was 66.7 percent.
   - By quantifying the difference between "before" and "after" for periodontitis therapy, the categorization system could assist non-dental health practitioners with an acceptable treatment approach..[9]

4.4 DETECTION OF IMPLANT DESIGN SYSTEM USING CNN

Dental implants are a form of tooth replacement that can be utilized to replace or repair missing teeth. Hundreds of manufacturers developed nearly 4000 distinct types of dental implant systems all over the world. Straight, tapered shaped, conical shaped, ovoid shaped, trapezoidal shaped, internal shaped, and external fixture structures, as well as diverse surface treatment procedures,

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are continually being created and clinically implemented which are either machined, blasted, acid-etched, hydroxyapatite-coated, titanium plasma-sprayed, or oxidised

As a result, if clinical dental practitioners are unable to recognise and distinguish the dental implant systems when any mechanical or biological problems arise, intrusive treatment modalities for repair and for replantation are more likely. While panoramic radiographs and periapical radiographs are the most common methods for detecting dental implant systems, radiographs make it difficult to differentiate between systems with common and same shapes or features. Owing to major intrinsic shortcomings such as noise or haziness, and distortion, this is the reality. As a result, employing an automated system can be more beneficial, time-saving, and effective.

Key studies that used CNN to identify implant system

2020, Jae-Hong Lee et al [21] Using panoramic and periapical radiographs, the effectiveness of convolutional neural network for the classification and detecting the dental implant system. Stated that:

- The Straumann BLT implant system used to have the highest accuracy in panoramic and periapical radiographic images.
- Deep CNN architecture (AUC = 0.971, 95 percent confidence interval 0.963–0.978) and board-certified periodontist (AUC = 0.925, 95 percent confidence interval 0.913–0.935) were found to have accurate classification accuracy.
- Using panoramic images and periapical radiographic images, researchers discovered that CNN structure was important for identifying and classifying dental implant systems.

4.5 MISCELLANEOUS

1. **DIAGNOCAT**:

Diagnocat is a computer programme that uses artificial intelligence to view dental computed tomography images. Radiological Research, Implantology Report, Endodontic Study, Third Molar Study, and Stereo Lithography are among the AI-based applications for various dental practises.

Diagnocat's front-end is streamlined to make diagnosis easier for clinicians who aren't qualified in programming or machine learning, despite the fact that it uses sophisticated CNN algorithms. The following is its diagnostic procedure:

• Images from CBCT (cone beam computed tomography) are saved in DICOM format.
• In just a few minutes, the tool's CNN analyses the patient's maxillofacial structure and periodontal disorders.
• The tool shows panoramic and cross-sectional views together with pertinent information.
• A report with visual and textual descriptions of the teeth of interest is produced.[22]

Diagnocat overcomes the shortcomings of clinical diagnosis for tangible reasons as a diagnostic method that achieves clinical standards of accuracy with pace, accuracy, and valuable insight. It consists of a massive pre-trained dataset that compares the features of unseen data to 20,000 dental computed tomography images. The tool is focused on 3D convolutional neural network models, unlike previous attempts in the field of AI-assisted diagnostics. Most significantly, it was

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created in partnership with experts in maxillofacial radiology and dentistry, based on well-established concepts and with a thorough understanding of the topic.

2. **ORALCAM**:

OralCam is a smartphone app that helps users self-examine common oral conditions. Other than a smartphone to upload images of their teeth, no other equipment is needed. Mobile applications provide the possibility of encouraging oral health with the rapid growth of smartphones. These apps that enable users to self-examine common oral conditions by photographing their teeth. However, it has a small examination area, which is mainly confined to the labial surface of teeth, and it lacks its ability to display the dental plaque areas .

5. COMMON LIMITATIONS OF KEY STUDIES

The few applications of CNN in recognising Periodontally compromised teeth tend to have a number of common flaws that prevented them from achieving a degree of diagnosis accuracy that was substantially higher than that of qualified examiners clinical attempts.

1. The input data is the source of these limitations. The data sets fed into CNNs are often inadequate for learning critical features that differentiate damaged teeth from healthy teeth.
2. In order to save processing time, power, and storage space, these images are often cropped into segments or reduced in resolution, which erases important composite information and reduces accuracy.
3. Additional data or the use of data augmentation and regularisation techniques are required to solve the overfitting problem.
4. Another drawback is that only 2-dimensional periapical radiographs can be used to make a complete diagnosis of periodontally compromised teeth. Above and beyond the binary production from the CNN, a thorough analysis of radiographic and clinical data, is needed for accurate diagnosis and prediction of Periodontal disease.
5. 2-dimensional images are more blurred than 3-dimensional images. As a result, using 3-dimensional CNN algorithms with Computer Tomography and Magnetic Resonance Imaging data could increase accuracy even more, which was outside the reach of the previous studies.[17,18]

6. CONCLUSION

Computer-aided diagnostic systems have shown excellent efficiency and better outcomes in a number of medical and dentistry sectors. In recent decades, convolutional neural networks (CNNs) have become a popular deep learning research method, displaying exceptional performance in image processing tasks such as identification, classification, and fragmentation. CNNs may be used in diagnostic-assistance systems to help dentists evaluate and record dental images in a more detailed, systematic, and timely manner. It also eliminates the need for clinical tests and prevents infections, in addition to being a cost-effective solution.

Despite deep CNN algorithms' excellent performance and reliability, basic research and clinical application in the dental field are confined to small area. Deep learning algorithms are currently being developed and improved. Through the continuous compilation of high-quality image datasets and hence the use of improved algorithms, CAD is predicted to become an effective and efficient way of assessing and anticipating periodontally damaged teeth. With the advancement of

3D algorithms and computational resources, the role of CNN in the detection and treatment of periodontally compromised teeth is also likely to improve significantly.[23]
While algorithms can be rewritten and improved multiple times to improve diagnosis accuracy, technical advances in radiography resolutions, 3D capturing, and minimising size while optimising image quality all need to improve at a comparable rate, and further research is needed. In calibrating and developing algorithms, as well as extracting useful insights from AI-generated reports, there is still — and maybe always will be — a need for human judgement and expertise. Subject experts analysing the diagnostic results of ever-improving AI tools to determine the best treatment options appears to be the best path forward in the never-ending search of fast, reliable, and successful diagnosis.

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