

Revolutionizing Dental Diagnostics: A Comprehensive Review of Convolutional Neural Networks (CNN) in Dentistry

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Abstract

This article reviews the application of Convolutional Neural Networks (CNNs) in dentistry, highlighting how deep learning has transformed diagnostic and treatment processes. CNNs, a type of deep learning algorithm designed for image analysis, are used across various dental specializations including radiology, orthodontics, periodontics, prosthodontics, pedodontics, endodontics and oral surgery. The review explains CNNs data driven methods, particularly its ability to extract, classify and segment medical images such as dental radiographs, CT and MRI scans. Key benefits include improved diagnostic accuracy, faster and more reliable results, automated evaluations and enhanced planning for procedures such as implant placement and age estimation in forensic dentistry. The article concludes that CNNs

substantially advance dental diagnostics and treatment planning by increasing efficiency, reducing manual errors and providing early intervention for oral cancers. By reducing diagnostic time and minimizing human error, CNNs have the potential to revolutionize preventive dentistry and improve long term patient outcomes. However, CNNs face several challenges and limitations including data related issues such as absence of high-quality data, obstacles in advanced infrastructure, development and maintenance cost and several ethical and legal concerns. Ultimately AI, including CNNs, is expected to serve as crucial support system for dentists, assisting clinicians and researchers without replacing human critical thinking and oversight.

Keywords: Ameloblastoma, Convolutional Neural Networks, MRI Scans, X-rays

Introduction

Artificial Intelligence (AI) is the term which represents the big umbrella term to how it makes machines think, reason and solve problems by thinking as human brain ¹. This leads to the subset of AI which focuses on machines learning from data ². Then the deep learning which is the subset of Machine Learning. This used Artificial Neural Networks which have many programmed layers within it. Hence the layers are called “deep” ³. Convolutional Neural Network (CNN) is a type of deep learning algorithm ⁴. The foundational difference comes where deep learning is highly based on analyzing the data or information provided to learn and making predictions from the data. Whereas CNN is based majorly on learning and analyzing images, videos and their objects, edges and shapes ⁵. CNNs are extensively applied in different branches of dentistry, due to their ability to assist in diagnosis, treatment planning and research. To highlight their applications based on the branches of dentistry: CNN analyzes the dental radiographs, detection of caries and periodontal diseases ⁶. While coming to orthodontics CNN can help with cephalometric analysis. The indirect use of CNN in implants would be when it analyses the bone segmentation images for implant planning. Early cancer detection, age estimation in forensic dentistry and early detection of dental anomalies. CNN, along with deep learning, considering all the data provided and the analysis is helping dentists on a broad scale. CNN is being used in the field of medicine for medical image analysis ⁷, assisting doctors in procedures like dermatology, ophthalmology, radiology and oncology ^{2,3}. It extracts images from CT and MRI and helps in diagnosis of various health care problems using different types of medical imaging ⁸. CNNs perform primary tasks such as categorizing an image into specific class, identification of location of

lesions, organs or other objects of interest. Segmentation is a function where the opacity or radiolucency of pathology or an organ can be precisely identified ².

To understand the working of CNN, let's understand where deep learning helps. Deep learning works on the non-image data like medical records, definitions, and all the other forms in which there is information available about the teeth and their structures. Then all this information is loaded into the system ⁹. On coming to CNN, we need to provide high quality images or X-rays just like how a dentist would look at an X-ray. The CNN then filters these images into detailed bits such as all the edges, shapes and textures ¹⁰. It then detects different basic and complex features, and further by activation function decides which patterns are important and what needs to be further looked up on ¹⁰. It then decides to provide and gather the detected features and make a final decision. The information is then looked up and just like a dentist's experience, CNN learns from feedback and more information from other uploaded images and improves to accurately recognize dental problems ⁶. CNNs enhance diagnostic efficiency and accuracy in dental field, and it is expected that it can come close to human competence levels ⁶.

Methodology

To review the literature, studies were selected from PubMed and Google Scholar, without restrictions on publication year, to provide a comprehensive overview of current knowledge regarding the application of Convolutional Neural Networks (CNN) in dentistry. The review focuses on evaluating the effectiveness and diagnostic performance of CNNs in various dental specialties. Search terms included: “Convolutional Neural Networks”, “Deep Learning”, “Artificial Intelligence”, “Dentistry”, “Dental imaging”, “Oral Radiology”, “Orthodontics”, and “Periodontics”. The

research encompassed case reports, clinical studies and systematic reviews.



Working of CNN

CNN is the type of deep learning algorithm specifically created for processing data arranged in a grid pattern⁵. CNN uses a deep learning approach to automatically identify the most effective features for representing images. CNN typically involves several layers, each designed to serve a particular function.

1. **Convolutional Layer-** These layers filter the data which is fed to the system, capturing unique features or patterns⁴. The convolutional layer applies filters to the input data and extract features which help in reducing the number of parameters⁷.
2. **Activation Functions-** The Rectified Linear Unit (ReLU) is a type of activation function commonly used in CNN⁵. ReLU introduces non-linearity, allowing the network to perform complex functions and improve performance⁷.
3. **Pooling Layers-** Pooling layer usually follows convolutional layer, with its main purpose of reducing the size or dimensionality of the convolutional layers output⁴. The pooling layer also retains the essential information while discarding unnecessary ones⁵.
4. **Fully Connected Layers-** These are the end layers of the CNN architecture. They process the data for final prediction and classification by mapping the image features by categorizing for classification⁶.

Applications of CNN in Dental Practice

1. **Diagnosis and detection-** CNNs are widely used for detection and diagnosis, effectively and quickly in

radiological images with increased accuracy⁴. CNN can be applied to panoramic radiographs, periapical and bitewing radiographs¹. Research indicates that CNN can detect approximal caries in pediatric patients with high precision. CNN has been seen surpassing the average performance of human dentists by providing high accuracy in diagnosing approximal caries and categorizing the caries according to severity⁴.

2. **Forensics and age estimation-** Forensic dentistry plays a crucial role in identifying individuals in legal and criminal investigations by determining gender and age¹¹. CNN developed gender estimation based on dental X-ray images such as orthopantomograms (OPG) by identifying features within the images which differentiate between male and female patients. The ability to determine gender from X-ray with high accuracy is highlighted as an important step in investigating process in forensic dentistry. Dental age estimation by CNN in forensics is more successful and faster than traditional radiographic methods¹¹. The age estimation is developed by OPGs across different age ranges and differentiating them among specific age-related features¹².
3. **Oral Medicine and Radiology-** CNN has transformed the method of analysis of dental images and their implementation of artificial intelligence into dental care⁵. Radiology is the first field where AI appeared, as it uses the maximum number of images to generate radiographic data¹³. This can provide increased accuracy and speed of diagnostic assessments, largely applied in computer-aided diagnosis (CAD) for various medical purposes including analysis of dental images³. CNN are effective tools for detecting dental pathologies by analyzing images¹⁴. The three primary tasks

performed by CNN are Classification, Detection and Segmentation ¹⁵.

4. **Periodontology-** CNN in periodontics primarily is used in detection, measurement and assessment of periodontal bone loss and peri-implant bone loss ¹. Neural networks including CNN are being used to minimize errors in diagnosis and provide more precise assessments ². Along with the diagnosis of periodontitis CNN can also classify or put the diagnosis into stages of disease. A modified R-CNN model has been detecting dental implants and finding key points around them, such as marginal bone loss and peri-implantitis severity ¹⁶. Such AI systems detect periapical lesions which are also associated with periapical periodontitis ¹³.
5. **Orthodontics-** In the field of Orthodontics, CNN works by landmark detection and cephalometric tracing, which by human force is a time taking process and might cause errors when performed manually. They are more accurate in detecting cephalometric landmarks in both 2D and 3D imaging ¹⁷. CNN can automatically identify and number teeth, along with evaluation of parameters like angulation, class and position of impacted teeth such as third molars on panoramic radiographs ³. CNN and similar AI systems can assist orthodontists in making treatment decisions such as the need for extraction or success of different treatment methods ¹. The relevant orthodontic surgical cases including Temporomandibular Joint (TMJ) disorder, osteoarthritis and disc displacement can also get diagnosed.
6. **Prosthodontics-** CNN are used for classifying radiographs into categories such as Cavity, filling and implant. It also detects missing teeth which are relevant for prosthetic planning ¹⁴. CNN can also

identify the stage of implant treatment on panoramic radiographs. It also measures peri implant bone loss on radiographs ². A 3D-CNN has been developed to generate partial dental crowns in computer-aided design (CAD) for restorative dentistry ¹⁸. CNN are well suited for these tasks because their convolutional layers are effective at extracting such specific features from images.

7. **Pedodontics-** Pediatric dentistry has the highest proportion of AI applications in making predictable decisions, primarily for dental age estimation which is crucial for timing appropriate treatment ¹. As we know it is challenging as well as crucial to detect caries early in primary teeth, which are vulnerable to rapid progression ⁴. Proximal caries could be difficult to diagnose in children, and this is where CNN uses panoramic radiographs of children to identify dental caries. CNN also detects anomalies such as hypodontia, premolar agenesis, detection of supernumerary teeth and detection of mesiodens on panoramic radiographs of children ¹⁴. It also automatically identifies and number teeth on radiographs when it is challenging to identify during the presence of primary and permanent teeth, tooth germs and mixed dentition.
8. **Conservative and Endodontics-** CNN can be used to evaluate the anatomy of root canal ². Predicting the presence of C-shaped canals in mandibular molars and detecting separated root canal instruments on panoramic radiographs ¹. These are also useful in detecting vertical root fractures. CNN may analyze gene expressions for radicular cysts and periapical granulomas ².
9. **Oral and maxillofacial surgery-** CNN are used for detection of anatomical structures such as identifying impacted third molars and their proximity to inferior

alveolar nerves ¹. It is used for automatic detection and segmentation of mandibular canals, and differential diagnosis of odontogenic cystic lesions such as ameloblastoma and odontogenic keratocyst. They have shown increased accuracy in diagnosis of cysts and tumors of jaws ¹. AI systems are also diagnosing, detecting, and predicting the prognosis of oral cancer and differentiating between benign and malignant ones ¹⁹. CNN is also used to predict postoperative results for orthognathic surgery and for

segmenting dental images, including teeth, bone and pathological features which are crucial for surgical treatment plans ².

10. **Oral pathology-** CNN are applied to histopathological images for rapid diagnosis of Oral Squamous Cell Carcinoma ¹⁹. They have also been applied for detection and differential diagnosis of odontogenic cystic lesions such as ameloblastoma and odontogenic keratocyst ¹.

Field	Application	Benefits
Diagnosis	Caries detection, radiograph interpretation	High accuracy, faster and reliable diagnostics
Forensics	Age and gender estimation from dental X-rays	Quick and accurate identification
Radiology	Image classification, detection, segmentation	Enhanced diagnostic efficiency and precision
Periodontology	Bone loss assessment, disease staging	Precise diagnosis, automated evaluations
Orthodontics	Landmark detection, tooth positioning	Saves time, reduces manual errors
Prosthodontics	Implant stage analysis, crown design (CAD)	Supports planning and restoration workflows
Pedodontics	Age estimation, caries and anomaly detection	Early intervention and better treatment timing
Endodontics	Root canal anatomy, fracture and lesion detection	Improved root complexity visualization
Oral Surgery	Surgical planning, tumor and cyst diagnosis	Safer procedures, better outcome predictions
Oral Pathology	OSCC and cyst detection from histological images	Faster, more accurate pathology interpretation

Challenges and Limitations

While CNN shows significant effectiveness in various applications within dentistry and oral and maxillofacial surgery, several challenges are highlighted across the field. Data-Related Challenges of how a smaller dataset can impact the model accuracy, and this limits the diversity in data ¹⁹. Gathering, processing and labelling data is a laborious and time-consuming process ⁵. Standardization and quality of data is required where the absence of a standard dataset which can be relied upon is a major hurdle ¹⁹. There is a need for standardization of data per algorithm. Quality of data such as image contrast or uneven exposure and blurred model performance need to be monitored ⁴. While CNN can match or even exceed

human performance on many tasks, they may have lower accuracy than experienced clinicians in certain situations with limited data or specific conditions ²⁰. AI systems often require advanced infrastructure, and implementing AI technology may require adjustments to existing hardware/software systems and training personnel ¹⁹. Deploying AI technology may involve additional hardware and software development costs, as well as maintenance and update costs ⁷. Need for external validation where models trained on specific datasets and populations from one geographic region may have limited usage on data from other geographic regions or populations ¹³. Ethical and legal challenges- The use of AI training data raises concerns about privacy and data

security, requiring regulations and informed consent. It also raises questions regarding who is liable if AI provides incorrect diagnosis¹. There could also be a sample distribution bias in datasets, which may affect the model's fairness and applicability⁷. Absence of Evaluation Standards where lack of Evaluation standard makes it difficult to compare models effectively across studies¹³.

Conclusion

In conclusion, CNNs have emerged as a transformative technology in dental imaging analysis, offering significant advantages in objectivity, efficiency, and accuracy across numerous diagnostic tasks in almost all dental branches. They effectively address challenges related to subjective interpretation, early disease detection, variable image quality, time constraints, human error, and complex pattern recognition¹. However, their widespread clinical integration is still hampered by critical limitations, primarily centered around the availability and quality of large, diverse annotated datasets, technical issues like robustness and optimization, and practical barriers related to cost, infrastructure, training, and ethical considerations²¹. Future research needs to focus on overcoming these obstacles to fully realize the potential of CNNs in enhancing dental care.

Future Perspective

A crucial future direction is the creation of large and more diverse datasets²². This includes collecting images from different populations and geographical regions to improve the generalizability of models. Conducting longitudinal studies is necessary to examine the long-term impact, effectiveness and sustainability of AI applications²⁰. AI has potential for further application in dental identification, forensic dentistry and treatment planning³. AI is expected to primarily serve as a decision

support mechanism for dentists, helping to alleviate workload and reduce the possibility of errors, particularly for less experienced practitioners¹. Future research aims to prioritize cross-hospital collaborations to significantly expand sample sizes and enhance predictive capabilities²³. Encouraging partnerships and collaborations across various stakeholders, including dental professionals, technology developers, organizations, and academic institutions, is considered crucial to streamline the integration of AI in dentistry²⁰. AI can assist clinicians but not replace them. Human critical thinking and oversight are necessary.

References

1. Chen W, Dhawan M, Liu J, Ing D, Mehta K, Tran D, et al. Mapping the Use of Artificial Intelligence–Based Image Analysis for Clinical Decision-Making in Dentistry: A Scoping Review. *Clin Exp Dent Res*. 2024 Dec;10(6):e70035.
2. Ossowska A, Kusiak A, Świetlik D. Artificial Intelligence in Dentistry—Narrative Review. *Int J Environ Res Public Health*. 2022 Mar 15;19(6):3449.
3. Rubiu G, Bologna M, Cellina M, Cè M, Sala D, Pagani R, et al. Teeth Segmentation in Panoramic Dental X-ray Using Mask Regional Convolutional Neural Network. *Appl Sci*. 2023 July 6;13(13):7947.
4. Yavsan ZS, Orhan H, Efe E, Yavsan E. Diagnosis of approximal caries in children with convolutional neural networks based detection algorithms on radiographs: A pilot study. *Acta Odontol Scand*. 2025 Jan 6;84:18–25.
5. Brahmi W, Jdey I, Drira F. Exploring the role of Convolutional Neural Networks (CNN) in dental radiography segmentation: A comprehensive Systematic Literature Review. *Eng Appl Artif Intell*. 2024 July;133:108510.

6. Zang X, Luo C, Qiao B, Jin N, Zhao Y, Zhang H. A deep learning model using convolutional neural networks for caries detection and recognition with endoscopes. *Ann Transl Med.* 2022 Dec;10(24):1369–1369.
7. Abu PAR, Mao YC, Lin YJ, Chao CK, Lin YH, Wang BS, et al. Precision Medicine Assessment of the Radiographic Defect Angle of the Intrabony Defect in Periodontal Lesions by Deep Learning of Bitewing Radiographs. *Bioengineering.* 2025 Jan 8;12(1):43.
8. Bayraktar Y, Ayan E. Diagnosis of interproximal caries lesions with deep convolutional neural network in digital bitewing radiographs. *Clin Oral Investig.* 2022 Jan;26(1):623–32.
9. AL-Ghamdi ASAM, Ragab M, AlGhamdi SA, Asseri AH, Mansour RF, Koundal D. Detection of Dental Diseases through X-Ray Images Using Neural Search Architecture Network. Chaudhary G, editor. *Comput Intell Neurosci.* 2022 Apr 30;2022:1–7.
10. Alotaibi G, Awawdeh M, Farook FF, Aljohani M, Aldhafiri RM, Aldhoayan M. Artificial intelligence (AI) diagnostic tools: utilizing a convolutional neural network (CNN) to assess periodontal bone level radiographically—a retrospective study. *BMC Oral Health.* 2022 Sept 13;22(1):399.
11. Hundur Hiyari M, Pasic M, Zukic S. Application of Convolutional Neural Networks for Determining Gender and Age in Forensic Dentistry. *Cureus* [Internet]. 2024 Nov 5 [cited 2025 Sept 12]; Available from: <https://www.cureus.com/articles/294357-application-of-convolutional-neural-networks-for-determining-gender-and-age-in-forensic-dentistry>
12. Yavuz BS, Ekmekcioglu O, Ankarali H. Comparison of different dental age estimation methods with deep learning: Willems, Cameriere-European, London Atlas. *Int J Legal Med.* 2025 July;139(4):1661–72.
13. Szabó V, Orhan K, Dobó-Nagy C, Veres DS, Manulis D, Ezhov M, et al. Deep Learning-Based Periapical Lesion Detection on Panoramic Radiographs. *Diagnostics.* 2025 Feb 19;15(4):510.
14. Uyar T, Uyar DS. Assessment of using transfer learning with different classifiers in hypodontia diagnosis. *BMC Oral Health.* 2025 Jan 15;25(1):68.
15. Putra RH, Astuti ER, Nurrachman AS, Putri DK, Ghazali AB, Pradini TA, et al. Convolutional neural networks for automated tooth numbering on panoramic radiographs: A scoping review. *Imaging Sci Dent.* 2023;53(4):271.
16. Cha JY, Yoon HI, Yeo IS, Huh KH, Han JS. Peri-Implant Bone Loss Measurement Using a Region-Based Convolutional Neural Network on Dental Periapical Radiographs. *J Clin Med.* 2021 Mar 2;10(5):1009.
17. Wong KF, Lam XY, Jiang Y, Yeung AWK, Lin Y. Artificial intelligence in orthodontics and orthognathic surgery: a bibliometric analysis of the 100 most-cited articles. *Head Face Med.* 2023 Aug 23;19(1):38.
18. Farook TH, Ahmed S, Jamayet NB, Rashid F, Barman A, Sidhu P, et al. Computer-aided design and 3-dimensional artificial/convolutional neural network for digital partial dental crown synthesis and validation. *Sci Rep.* 2023 Jan 28;13(1):1561.
19. Vinay V, Jodalli P, Chavan MS, Buddhikot ChaitanyaS, Luke AM, Ingafou MSH, et al. Artificial Intelligence in Oral Cancer: A Comprehensive Scoping Review of Diagnostic and Prognostic Applications. *Diagnostics.* 2025 Jan 24;15(3):280.
20. Jha Kukreja B, Kukreja P. Integration of Artificial Intelligence in Dentistry: A Systematic Review of

Educational and Clinical Implications. Cureus [Internet]. 2025 Feb 20 [cited 2025 Sept 12]; Available from: <https://www.cureus.com/articles/331932-integration-of-artificial-intelligence-in-dentistry-a-systematic-review-of-educational-and-clinical-implications>

21. Musri N, Christie B, Ichwan SJA, Cahyanto A. Deep learning convolutional neural network algorithms for the early detection and diagnosis of dental caries on periapical radiographs: A systematic review. *Imaging Sci Dent.* 2021;51(3):237.
22. Su AY, Wu ML, Wu YH. Deep learning system for the differential diagnosis of oral mucosal lesions through clinical photographic imaging. *J Dent Sci.* 2025 Jan;20(1):54–60.
23. Su TY, Wu JCH, Chiu WC, Chen TJ, Lo WL, Lu HHS. Automatic classification of temporomandibular joint disorders by magnetic resonance imaging and convolutional neural networks. *J Dent Sci.* 2025 Jan;20(1):393–401.