Review

# The use of artificial intelligence in dental and maxillofacial radiology

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## Abstract

The use of artificial intelligence in our everyday life is becoming more and more prevalent, from movie recommendations on Netflix to auto-correct features on our mobile phones. The field of medicine and dentistry can apply artificial intelligence to stay up to date with technological advancements and use them to increase the efficiency of practice. Although artificial intelligence is not widely used yet, it has great potential when used in combination with dental radiographs in the field of dentistry and maxillofacial surgery. Radiographs can act as a dataset for machine learning algorithms and enable artificial technology to carry out tasks such as diagnosing disease and treatment planning. Uses of artificial technology being investigated in dental research include dental charting, diagnosing caries, cysts and tumours, and treatment planning orthognathic and orthodontic cases.

## Abbreviations

*AI - Artificial intelligence*
*ANN - Artificial neural networks*
*CAD/CAM - Computer-Aided Design/ Computer-Aided Manufacturing*
*CBCT - Cone-beam computed tomography*
*CNN - Convolution neural network*

## Introduction

Artificial Intelligence (AI) is where technology learns to mimic aspects of cognitive behaviour, such as critical thinking, problem solving and learning. AI has already been utilised in the field of dentistry to detect and diagnose dentoalveolar pathologies, such as dental caries, periodontitis, periapical lesions and oral cysts. Research studies have also used AI to detect maxillary sinus perforations, oral cancers and lymph node metastasis.[1] Digital dental radiographs and intra oral scanning images collated by Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) technology can act as datasets for AI. Computers can learn to recognise anatomical landmarks and key features of pathological conditions using these datasets and complex algorithms.[2] Radiographs are an essential component of constructing risk assessments, diagnosis and treatment planning. Access, knowledge, and training surrounding cone- beam computed tomography (CBCT) has also improved in recent years.[3] The combination of using accurate 3D imaging with AI has the potential to offer high quality diagnostic value with increased ease. This review will explore the current and future use of AI in dental and maxillofacial radiology as well as clinical barriers to the application of AI technology.

## Artificial intelligence

AI can be defined using a hierarchy of intelligence as defined by Bostrom.[4] Artificial narrow intelligence is where technology is used to recognise patterns and solve classification based tasks. The next level up is defined as artificial general intelligence, which is comparable to total human cognitive ability. The final stage is artificial super intelligence, where cognitive ability would be beyond that of human capability.[4] The full potential of what AI can achieve is still being explored, with current research aiming to create AI that complements and co-operates with human intelligence.

Advancements in AI have been largely attributed to machine learning, which allows technology to use algorithms and datasets to learn and predict outcomes.[5] Deep learning is a sub-branch of machine learning that involves a process by which technology can learn a hierarchy of algorithms, as demonstrated by **Figure 1**.[6] This forms layers of algorithms stacked on top of each other to form a

complex deep network.[7] Deep learning improves on the principles of machine learning as it allows technology to solve more complex problems where the dataset is unstructured or interconnected. Artificial neural networks (ANN) are employed in deep learning. These networks have an input, an output, and several hidden layers that are not pre-defined. A convolution neural network (CNN) is a computer vision algorithm that performs image recognition and classification. CNN can automatically extract features and distinguish patterns from images.[8] CNN is the most widely used deep learning architecture utilised in dentistry due to its image detection abilities.[9] CNN consists of a hybrid neural network with an initial convolutional layer which identifies simple features such as edges, lines and textures. This information is then passed onto the subsequent layers within the neural network to detect more complex features and form an image.[7] CNN has reported high accuracy in detecting and diagnosing anatomical landmarks and dental pathology.[10]

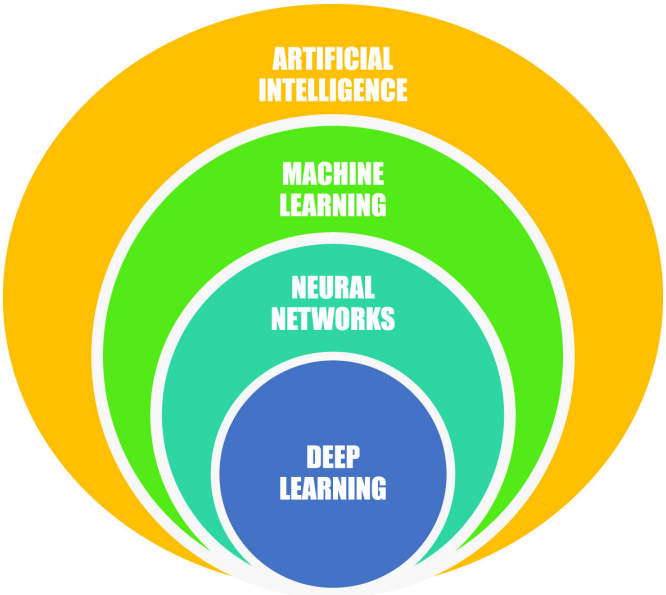


**Figure 1. The various aspects of artificial intelligence. Reprinted from Khanagar et al (2021)[6], by Elsevier.**

## Application of artificial intelligence in dental and maxillofacial radiology

### Dental charting

Studies have shown that AI in combination with dental radiographs can used to complete digital tooth charting. Tooth detection can be carried out using pixel-level segmentation methods, whilst tooth charting is based on the extraction of features such as width/height teeth ratio or crown size.[11] Tuzoff et al[11] investigated the use of CNNs in detecting and numbering teeth using panoramic radiographs, as shown by **Figure 2**. A dataset containing 1352 panoramic radiographs of the adult dentition was used to train the AI system. A separate group of 222 panoramic radiographs were assessed using the AI system to evaluate its performance, the outcome was then compared to tooth classification carried out by clinical radiology experts. They found that a CNN system achieved a similar sensitivity and specificity for tooth detection and classification as radiology experts. Lin et al[12] utilised an AI support-vector machine and dental bitewing radiographs for tooth classification. For tooth numbering, they combined an algorithm that detects missing teeth and a simplified alignment sequence to allow them to assign a number to each tooth. They reported that their AI system had an overall accuracy of 95% for classification, and 98% for numbering.[12] This demonstrates that AI systems can have high accuracy when it comes to dental charting, comparable to that carried out by clinicians. This could be used to aid dental practitioners during examinations with minor amendments if necessary. The advent of automatic dental charting would help to streamline dental appointments thereby increasing efficiency.

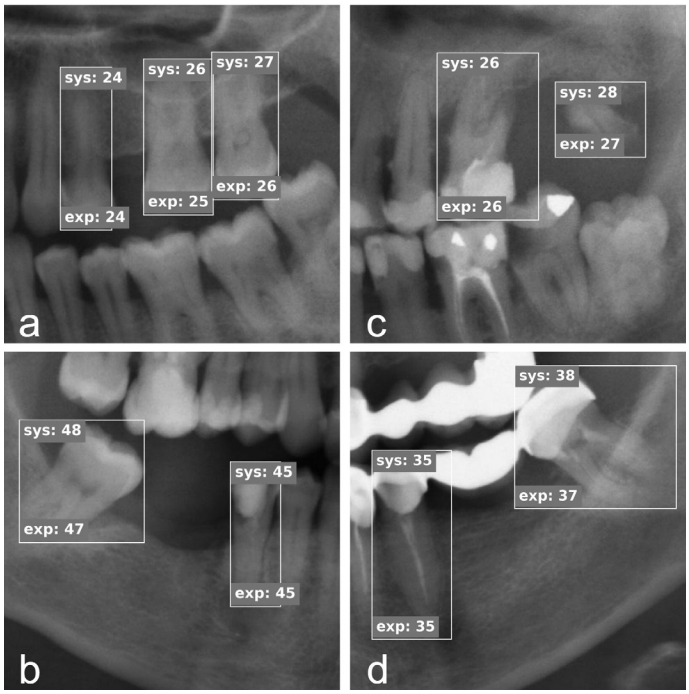


**Figure 2. Tooth numbering errors produced by experts, the AI system classification result is at the top (sys) and the expert classification is given at the bottom (exp). Reprinted from Tuzoff et al (2019)[11], by BIR Publications.**

### Dental caries

Dental caries affects around 35% of the global population and evidence shows that over 20% of non-carious lesions are incorrectly diagnosed as caries.[13,14] Normally, a clinical examination, bitewing radiographs and a caries risk assessment are used to form a caries diagnosis. The presence of dark shadowing can indicate caries on an intra-oral radiograph. However, shadows can also be due to artefacts such as radiographic burnout, overlapping structures, or differences in contrast between restorative materials and tooth tissue. AI has shown to have the ability to diagnose caries with a high degree of accuracy, which may help to combat the irregularities in caries diagnosis between clinicians. Lee et al[13] used a pretrained CNN network to analyse 3000 periapical radiographs for dental caries. The diagnostic accuracy for carious premolar and molar models was 89% and 88%, respectively. Similarly, Ali et al[15] found that AI systems were able to distinguish between carious and non-carious teeth with a high degree of accuracy. An ANN system was used to detect and classify dental caries in dental radiographs. They reported that the diagnostic accuracy for carious teeth was 96%, comparatively the diagnostic accuracy for non-carious teeth was 98%.[15] If caries is diagnosed, the tooth often enters the restorative cycle to arrest the disease progression. This can affect the overall prognosis of the tooth as it can risk pulpal vitality.[16] Therefore, if AI can be used to supplement caries diagnosis, it may help to prevent unnecessary treatment.

### Oral diseases

AI has also been used in dental research to detect and classify oral tumours and cysts, as shown by **Figure 3**. Poedjiastoeti et al[17] investigated the use of CNN to detect ameloblastomas and odontogenic keratocysts from dental panoramic radiographs. Differentiation between oral cysts and tumours using 2D radiographic imaging is complex, as they have similar characteristics. A 16-layer CNN model was trained by the researchers and 100 radiographic images were analysed to assess its diagnostic accuracy. They found that the CNN system had a similar sensitivity, specificity, and diagnostic accuracy compared to oral and maxillofacial specialists. The most significant difference was the diagnostic time; the CNN system took 38 seconds whereas the oral and maxillofacial specialists

took 23 minutes. The increased efficiency of CNNs could have a dramatic impact on healthcare and may help to reduce the stress and work load that healthcare professionals face. Mikulka et al[18] compared six different AI systems used to classify jawbone cysts. Dental panoramic radiographs were assessed using the various AI classification systems, the diagnostic accuracy was compared against diagnoses made by medical experts. They found that the Naive Bayes system produced the highest diagnostic accuracy of 88.9% for follicular cysts, whereas Decision Tree and neural network systems produced the highest diagnostic accuracy of 88.9% for radicular cysts. This demonstrates that a range of AI systems can be used to distinguish between oral tumours and cysts to a relatively high degree of accuracy.[18] These studies demonstrate the potential of AI in detecting oral tumours and cysts. This technology can act as an aid for general dental practitioners who may have limited experience or confidence in diagnosing oral tumours and cysts. This could reduce the number of referrals and provide patients with a quicker diagnosis. Early detection and treatment are especially valuable where you have potentially malignant tumours.[19]

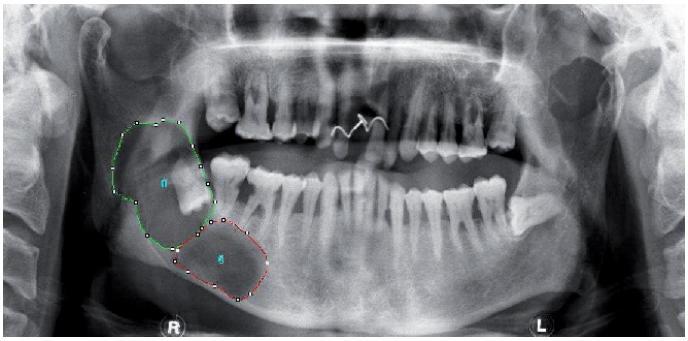


**Figure 3. Semi-automatic segmentation by an AI system allowing two areas in the posterior mandible to be marked simultaneously. Reprinted from Mikulka et al (2013)[18], by Radioengineering Journal**.

## Orthodontics

Within orthodontics, AI has been used to aid decision making and treatment planning by determining the need for orthodontics, extractions and orthognathic surgery. Cephalometric radiographs are important for diagnosing and treatment planning in orthodontics. A systematic review found that several studies that investigated the ability of CNN systems to identify cephalometric landmarks produced similar results to analysis by specialists.[20] Decision making regarding orthodontic extractions is complex and specialist opinion may vary based on a clinician's experience. Teeth can be extracted to alleviate crowding, correct anterior posterior inter-arch discrepancies, and correct crossbites. Xie et al[21] evaluated the ability of AI systems to predict whether orthodontic extractions were required. A variety of indices were used to screen cephalometric radiographs of 180 patient cases. This information was used to train an ANN system to predict whether patients with a malocclusion between 11 and 15 years old required extractions. They found the ANN system predicted whether extraction or non-extraction was required with 80% accuracy.

> *These studies show great potential for AI in carrying out more complex decision-making tasks, previously only possible with human cognition. However, AI should not take precedence over orthodontic opinion and decisions made by AI need to be reviewed by orthodontic specialists.*

The introduction of orthodontic therapists in 2007 in the UK has led to changes to the structure of the orthodontic team.[22] Looking ahead AI systems may be useful in providing a second opinion for less experienced orthodontists and orthodontic therapists.[20]

## Challenges and limitations

AI technology may have the potential to increase efficiency, improve diagnostic accuracy and reduce workload for dental professionals. However, there are barriers and limitations facing AI research and AI application in dentistry. AI employs machine learning algorithms used to train computers and digital software to detect, diagnose and treatment plan in dentistry. Machine learning requires a large sample of data so that the computer can be trained. These can be provided in the form of digital radiographs.[23] Digital radiographs need to be readily accessible as digitalising film radiographs is too time consuming.[1] Additionally, It may be difficult to obtain large samples of patient data due to issues regarding consent and confidentiality. There is also the challenge of storing large amounts of data. AI utilising cloud-based storage systems is one option being explored to accommodate extensive collections of data.[24] There tends to be smaller datasets in dentistry compared to medicine when programming AI systems. Transfer learning is a model that is being used to overcome this issue, this is where AI systems can be trained using similar images to perform a different task. For instance, to detect caries on a dental radiograph, the AI system can be initially trained to detect disease from chest radiographs; the knowledge gained from analysing the chest x-rays can then be applied to a different but related scenario such as detecting caries from a dental radiograph.[25] The amount of data is shown to be positively corelated with the performance of machine learning algorithms, therefore datasets are vital to the optimum functioning of AI systems.[23]

Whilst the use of AI is becoming more common in day-to-day life, the use of AI in a medical or dental setting may make clinicians and patients feel uneasy. A qualitative study discussing the implementation of AI in dental practices in Germany found that dentists were worried that they could become too reliant on AI systems over time and that AI systems may influence their own clinical judgement. Both patients and dentists also had fears that AI systems may make incorrect therapeutic decisions.[1] Whilst clinicians also make mistakes, due to machine learning, an incorrectly functioning algorithm can potentially cause harm to many patients.[23] Dentists should be mindful that reports produced by AI systems will not protect them from liability and failure to diagnose or treatment plan appropriately. Therefore, dentists still need to take responsibility when interpreting and analysing radiographs.[26] Patients have also expressed positive attitudes towards practices using AI technology, describing it as "innovative" and that it also demonstrates that the practice is up-to-date with current developments.[1] This highlights the needs for increased education regarding how AI systems operate with extensive training on managing AI systems and identifying when they malfunction.

Randomised blinded clinical trials are required to prove the efficacy and accuracy of AI systems.[26] Currently there are largely in-vitro studies investigating the use of AI in dentistry, therefore the clinical application of the results from these studies needs to be evaluated. The expense of purchasing, installing, and maintaining AI technology also needs to be assessed against the benefits of AI. Studies regarding AI use in dentistry often vary due to the use of different AI systems, datasets, and performance indicators. This makes comparison between different studies difficult or inappropriate in certain instances. There is a need for more standardisation so that definitive conclusions can be drawn surrounding the use of AI systems in dentistry.[23]

## Conclusion

The transition of AI from a concept dramatised in science-fiction films to realistic everyday technology that is changing the way we live our lives has been pivotal. The field of dental and maxillofacial radiology

has been significant in enabling the application of AI in dentistry. Developments in AI technology such as machine learning, transfer learning and CNNs have expanded the capabilities of technology. AI can be used to diagnose disease, make complex management decisions and treatment plan. However, there are limitations to what AI technology can achieve. The advent of AI does not negate dental professionals from their professional responsibilities to ensure optimum standards of patient communication and care are delivered. AI may be used to detect, diagnose and treatment plan but dental care professionals are influential in encouraging behavioural change in patients, and providing holistic individualised care which cannot be provided by standardised machines. Advancements in technology that have the potential to improve patient and staff satisfaction by improving efficiency should be encouraged, in addition to further high-quality research assessing the full benefit that AI technology can provide within dentistry.

**Contribution statement** The author has made substantial contributions to the conception or design of the work, drafted the work, and gave final approval of the version to be included in Inspire.



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## Yasmin Aziz

I am a final year dental student at Cardiff University and will be completing my dental foundation training in Sussex. My special interests include restorative dentistry and oral surgery. Dentistry has progressed from a profession solely responsible for treating disease to one that is increasing concerned about aesthetics. As a result of this shift, I have become interested in the range of tooth whitening technologies available and the mechanism by which they whiten teeth. I am also interested in the influence of artificial intelligence on the field of oral maxillofacial radiology and its potential future uses in healthcare.