Artificial Intelligence in dentistry: Advances and applications in modern clinical practice

https://doi.org/10.56238/sevened2024.006-021

Carlos Eduardo Oliveira Figueiredo Barroso[1], Eliseu Santana de Assis[2], Gabriel Olival de Sena Silva[3], Jéssica Delazari Ferreira[4], João Eduardo Santos Aguiar[5], Joelma Rosa Bueno[6], Lucas Baião Lopes Cançado[7] and Pedro dos Santos Neto[8]

ABSTRACT
The use of Artificial Intelligence (AI) has become relevant in several areas in recent times. The applicability of AI in healthcare points to promising results by helping with stages such as diagnosis, planning and treatment, increasing the possibility of success. With this in mind, this chapter discusses the latest advances in AI in the dental specialties of periodontics, dentistry, prosthetics, oral and maxillofacial surgery and legal dentistry, highlighting its benefits and future prospects.

Keywords: Artificial Intelligence, Dentistry, Machine Learning, Deep Learning, Neural Network.

[1] Graduated in Dentistry - Espírito Santo Integrated Colleges
Family Health Specialist - Capixaba Institute for Teaching, Research and Innovation in Health
E-mail: cadusfob@gmail.com
[2] Graduating in Dentistry - Federal University of Bahia
E-mail: eliseu2022@gmail.com
[3] Graduating in Dentistry - University Center of Maceió
E-mail: gsena6869@gmail.com
[4] Graduated in Dentistry - Federal University of Espírito Santo
Specialist in Collective Health - Capixaba Institute for Teaching, Research and Innovation in Health
E-mail: jessicadf.odonto@gmail.com
[5] Graduating in Dentistry - Society Educational Santo Antônio
E-mail: joao.eduardo.15@hotmail.com
[6] Graduated in Social Communication - Una University Center
Graduating in Dentistry - Belo Horizonte University Center
E-mail:buenojoelma2@gmail.com
[7] Graduating in Dentistry - Belo Horizonte University Center
E-mail: lucaslbaiao@gmail.com
[8] Graduating in Dentistry - Federal University of Sergipe
E-mail: pedronetoapenas@gmail.com

INTRODUCTION

In the last few years, there have been many technological advances, especially in the development of Artificial Intelligence (AI). AI comprises a field of science that seeks to enable machines to perform tasks that use human intelligence. Given its popularity, some AI models have attracted attention, such as ChatGTP, Siri, Alexa and Google Assistant, as they simplify everyday tasks and open up new forms of interaction and collaboration between humans and machines. The potential of AI goes beyond virtual assistance and is being used in various sectors, including medicine, finance, manufacturing and transport, helping to innovate and optimize processes.

The inspiration for the emergence of AI began in 1943 when some scientists began to question whether it was possible to replicate the structure of a neuron that makes up the human brain, at which point they created the first simplified concept of a brain cell in a mathematical model (McCulloch & Pitts, 1943).

In 1950, Alan Turing created a test called the "Turing Test", which assessed the machine's ability to simulate conversation with humans, in such a way that if the human could not distinguish whether they were talking to another person or to the machine, the machine was an intelligent machine (Turing & Haugeland, 1950).

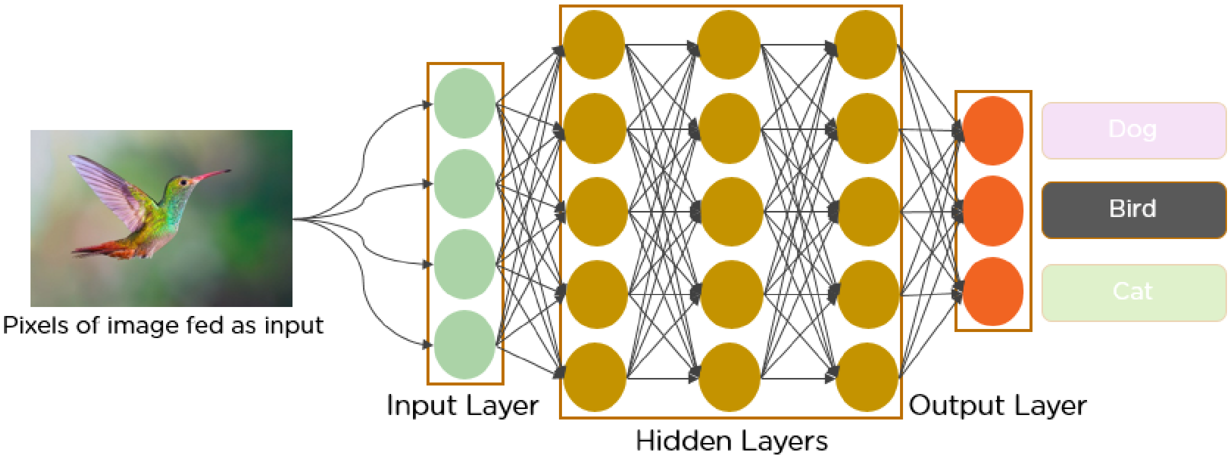
In 1955, at Dartmouth, the term "artificial intelligence" was presented by John McCarthy, Marvin Minsky, Nathaniel Rochester and Claude Shannon. The researchers sought to discover how to instruct machines to use language, forge abstractions and concepts, solve classes of problems exclusive to humans and improve themselves (McCarthy, Minsky, & Rochester, 2006).

Throughout this process, Artificial Intelligence has taken shape and is now subdivided into various segments, some of which are Machine Learning (ML) and Deep Learning (DL). In ML, systems are trained to carry out intelligent activities without the need for pre-established rules, adjusting themselves based on examples provided. This is especially relevant in healthcare, where ML can identify patterns in diagnostic data, improve treatments and even help in the discovery of new drugs, thus reducing human error and improving patient care (Alowais, Alghamdi, Alsuhebany et al., 2023).

DL is a part of ML in which systems learn not only isolated patterns, but also a combination of them, resulting in a complex system. The difference between DL and ML lies in the learning approach and the amount of data used. The pillars of DL are Artificial Neural Networks (ANNs), which mimic the neurons of the brain in a non-linear mathematical model. These networks consist of three layers: input (where information is entered), hidden (where processing takes place) and output (where decisions are made). The aim is to hierarchically organize the input information in order to calculate the correct values at the output, simulating human cognitive skills such as problem-solving and decision-making (Nguyen, Larrivée, Lee, Bilaniuk, & Durand, 2021).

There are different variations of ANNs, and another that is widely used in the field of dentistry is Convolutional Neural Works (CNNs), a specialized type of artificial neural network that is very useful for extracting image characteristics through convolutional operations. Using a special architecture for connecting neurons and mathematical operations to process digital signals, it is the most widely used algorithm for image recognition (Ding el al., 2023).

Figure 1. Example of a CNN's functionality.



Source: https://www.analyticsvidhya.com/blog/2021/05/convolutional-neural-networks-cnn/

AI is emerging as a promising tool in the field of dentistry. Its use is increasingly relevant in areas such as periodontics, dentistry, dental prosthetics, oral and maxillofacial surgery, and legal dentistry.

Its applications are mainly focused on diagnosis, clinical decision-making, therapeutic planning and prognosis, which highlights the many benefits of its incorporation into routine dental practice (Nguyen, Larrivée, Lee, Bilaniuk, & Durand, 2021; Ossowska, Kusiak, & Świetlik, 2022; Ding et al., 2023).

This technology, when applied effectively, has the potential to revolutionize care in various dental specialties. The journey towards an AI-assisted future in dentistry has already begun and its impact promises to be transformative.

APPLICATIONS OF ARTIFICIAL INTELLIGENCE IN DENTAL SPECIALTIES

PERIODONTICS

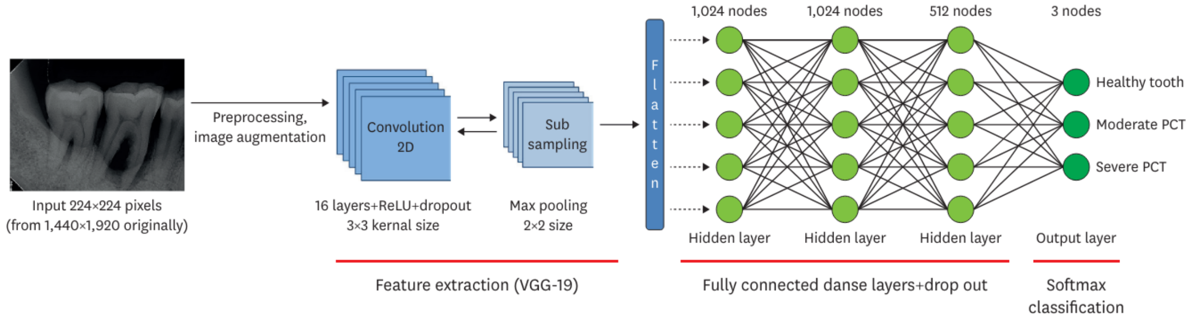
Periodontics is an area of dentistry whose function is to protect and treat the tissues of the periodontium affected by periodontal diseases, such as periodontitis, where bone resorption occurs and, consequently, tooth loss.

AI has shown promise in this area, with several studies demonstrating the effectiveness of using CNNs to diagnose periodontal problems. Krois et al. (2019) and Chang et al. (2020) used

CNNs to analyze radiographs in order to provide efficient diagnoses and predictions about periodontal disease, comparing the results with the opinion of experienced professionals in the field. The data obtained was similar when compared to the professionals, indicating that the use of CNNs can help in the imaging diagnosis of periodontal disease.

It is important to note that these studies have some limitations, such as the limited availability of databases and the variable quality of the radiographs. For the system to work properly, high quality radiographs are required, but this is not always the case.

Figure 2. Demonstration of the functionality of CNNs in the evaluation of radiographs for the assessment of healthy teeth, moderately periodontally compromised teeth and severely periodontally compromised teeth.



Source: Copyright by Chang et al., 2020.

Therefore, the use of neural networks can help dentists diagnose periodontal disease. However, in order to achieve a more accurate diagnosis, it is essential to carry out a clinical examination, including the use of a periodontal probe to assess bleeding and probing depth, as well as pulp tests, which are fundamental to the final diagnosis (Lee, Kim, Jeong, & Choi, 2018).

Thanathornwong and Suebnukarn (2020) highlight the importance of prospective studies aimed at improving the techniques used in AI systems. In addition, the search for more up-to-date neural network systems could make a significant contribution to advances in the diagnosis of periodontal disease.

RESTORATIVE DENTISTRY AND PROSTHODONTICS

Restorative Dentistry is the branch of dentistry that works to repair teeth through restorative treatments, while prosthodontics covers the manufacture of parts that are capable of restoring the crown of teeth or replacing teeth in spaces where they are missing, with the aim of re-establishing oral function.

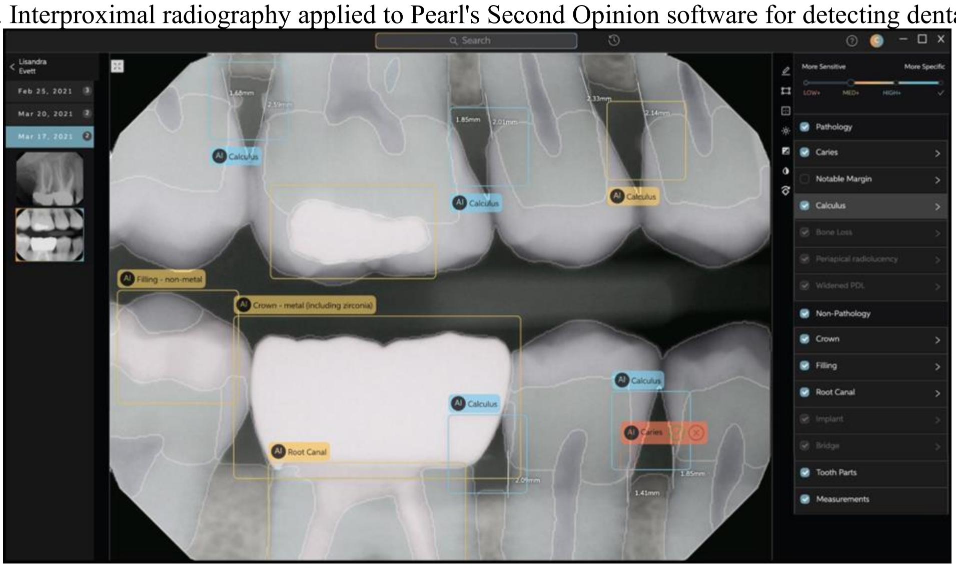
With technological development, workflows in these areas have increasingly used digital resources and, as a result, AI applications have been increasing progressively. Currently, there are reports of AI models as a tool with the potential to assist in various stages of restorative treatments, with applications ranging from the diagnosis of the oral condition and initial planning to the manufacture of prosthetic parts, which enables more efficient work processes and treatments than the methods usually used (Ahmed et al., 2021; Ding et al., 2023; Revilla-León et al., 2023).

The application of CNNs to aid in the diagnosis of dental condition has been evaluated by some studies and has been successful in detecting proximal lesions on interproximal radiographs when compared to professionals in the field (Chen, Guo, Ye, Zhang, & Liang, 2022).

This technology was also able to correctly identify caries on occlusal and smooth surfaces, as well as classify them into non-cavitated or cavitated caries lesion categories using photographs of permanent teeth as a basis. The findings reinforce the high viability of applying AI methods to diagnose dental caries by being able to do so with greater precision (Kühnisch et al., 2022).

One of the most recent advances in AI for diagnostic purposes was the creation of Pearl's Second Opinion software, which surpassed human accuracy in detecting signs of common dental pathologies and conditions on radiographs, such as incipient caries or early signs of periapical radiolucency (Kukucka, 2024).

Figure 3. Interproximal radiography applied to Pearl's Second Opinion software for detecting dental caries.



Source: https://www.hellopearl.com/products/second-opinion

Some researchers have developed an AI-based computer vision algorithm programmed to analyze panoramic radiographs in order to automatically detect and classify dental restorations, achieving a success rate of over 90% for both purposes (Abdalla-Aslan et al., 2020).

In addition, AI technology has performed well in predicting the likelihood of composite resin crowns detaching. This was proven in a study that evaluated crowns manufactured using computer-aided design/computer-aided manufacturing (CAD/CAM) by analyzing images of dental preparations in 3D models obtained by scanning selected patients. In this way, by being able to predict possible failures, the use of AI directs the production of restorations with greater precision and safety (Yamaguchi et al., 2019).

Technological advances are also present in CAD/CAM, with the implementation of AI Scan 2.0 in the 3Shape TRIOS intraoral scanner, which facilitates the digitization of mandibular and maxillary components. AI Scan 2.0 displays intelligent discernment by identifying soft tissue along with other crucial intraoral details. The result is a flawless final digital document that accurately encapsulates the patient's intraoral situation free of unnecessary soft tissue information and therefore more useful in clinical applications (Ding et al., 2023).

Figure 4. Scanner 3Shape TRIOS.

Source: https://www.3shape.com/en

Other applications of AI are also present in the automatic design of crowns and removable partial dentures, which is becoming increasingly relevant in helping with procedures such as selecting tooth color, mapping the finishing line of preparations and predicting facial changes in patients with removable dentures (Revilla-León et al., 2023).

Crowns produced by 3D printing in composite resin using AI obtained better marginal adaptation to the preparation, as well as considerably reducing the time spent when compared to other methods involving human labor, such as waxing and digital drawings (Liu et al., 2024).

An AI method called 3D-Deep Convolutional Generative Adversarial Network (3D-DCGAN) was used to automatically produce dental crowns using lithium disilicate material. As a result, the designed pieces showed greater similarity to natural teeth in terms of both morphology and biomechanics, indicating that this technology is capable of offering high precision in the reproduction of customized dental crowns (Ding et al., 2023).

AI also contributes to analyzing and improving the composition of prosthetic parts. AI has been able to identify the components that are effective in providing high flexural strength of composite resin and thus predict greater success of the materials' performance in masticatory function (Li et al., 2022).

Optimization in the casting process of metal prosthetic parts was also possible in another study, due to the minimization of porosity in the cast metal and a reduction in overall manufacturing time. In view of the above, there is a greater chance of achieving the desired results in rehabilitation with prostheses produced using AI (Revilla-León et al., 2023).

It should be noted that, given the benefits of technologies that apply AI, both dental professionals and patients benefit from the possibility of more accurate diagnoses, more efficient planning and execution of procedures, automatic and agile production of prosthetic parts, as well as greater comfort, safety and speed in restorative and prosthetic treatments. It is considered that improvements still need to be made to overcome some limitations, such as providing improved information, and more studies are needed to broaden the scope of clinical applications.

BUCOMAXILLOFACIAL

In the area of oral and maxillofacial surgery, the responsible professional is characterized as an bucomaxillofacial, who will work in the diagnosis and treatment of conditions related to the face, mouth, jaw and associated structures, trained to deal with a variety of conditions, including congenital craniofacial deformities, facial trauma, jaw diseases, orofacial tumors, temporomandibular dysfunction and orthognathic surgery.

Mouth cancer

Lately, there has been growing interest in the application of AI techniques for the prognosis and diagnosis of oral cancer. These techniques encompass ANNs, genetic algorithms, fuzzy logic, among others, and are emerging with a substantial impact, refining diagnostic accuracy in various medical disciplines (Al-Rawi et al., 2022).

Some research that employs ANNs for the early detection of oral cancer, using technology that includes the digitization of cytological slides, has already shown the effectiveness of AI to be comparable to that of conventional cytology and histology (Al-Rawi et al., 2022).

Another study using CNNs to classify tongue cancer patients based on oral endoscopic images showed acceptable performance in diagnosing tongue cancer, revealing that CNNs are more effective at discriminating between mild and severe malignant lesions. CNN algorithms are proving to be a suitable tool for cancer detection. In another study, it was possible to identify and distinguish between several different types of tumors using intraoral optical images (Heo et al., 2022).

Figure 5. Endoscopic Device.

Source: The Autors 2024.

AI shows greater accuracy in analyzing and predicting oral cancer compared to traditional diagnostic methods. In addition, most AI algorithms show accurate results in predicting the occurrence of oral cancer (Rosma et al., 2010).

It can be concluded that artificial intelligence is more accurate at analyzing and predicting oral cancer than traditional diagnostic methods. In addition, most AI algorithms show accurate results in predicting the occurrence of oral cancer (Chauveron et al., 2024).

Facial prostheses

In a field where science, technology and aesthetics converge synergistically, bucomaxillofacial specialization stands out for its unique ability to restore not only functionality, but also aesthetics in subjects affected by facial deformities, mostly caused by cancer treatments and severe mutilations resulting mainly from car accidents. When patients undergo cancer removal, they will have facial deformities, and a multidisciplinary medical team has developed significant projects in which patients' facial appearance and functionality are restored through facial prostheses.

This specialty can be seen as the only viable method for social integration, directly contributing to their quality of life (Carvalho et al., 2013).

These professionals need extensive anatomical knowledge, especially when deformities affect reference points of unique facial elements, such as the nose, so canonical measurements are crucial for harmonious integration of the face (Cardoso et al., 2006).

Conventionally, facial prostheses are made by replicating the patient's individual features using a plaster and alginate matrix. From these molds, plaster or wax models are replicated, which are subsequently filled with the elastomer (Carvalho et al., 2013).

Figure 6. Ear prostheses.

Source: https://br.pinterest.com

Despite morphological and symmetrical understanding, professionals face significant restrictions in the production of materials, due to the propensity for inadequate results, including the formation of bubbles or failures in anatomical transfer (Brophy, 2005).

The integration of technology in identity reconstruction is emerging as a promising alternative in the manufacture of 3D facial prostheses, offering speed and a high aesthetic standard. 3D printers initially use images from the Eigenfaces library, the Eigenfaces method extracts and encodes relevant information from the facial image for analysis (Agarwal et al. 2010).

Some authors propose an approach for restoring gaps in images using RNCs, demonstrated using the example in the following figure (Liu et al. 2018).

Figure 7. Facial reconstruction representation using CNNs.

Source: The Autors 2024.

The first tests were not very effective. Analyzing the images using neural networks proved costly, especially as the resolution increased from 64x64 to 1000x1000 pixels (Albawi et al., 2017).

Like researchers in the past, the search for improved rehabilitation methods for mutilated patients continues, and in this context, AI has emerged to address the challenges faced in creating facial prostheses (Albawi et al., 2017).

Important references to large, labeled data sets:

1. **Labeled Faces in the Wild (LFW)**: Database with more than 13,000 images of faces collected from the web, with each face labeled. Last updated in May 2017.
2. **Bosphorus Database:** Aimed at 3D and 2D human face processing research, with 4666 images of faces from 105 subjects.
3. **ImageNet**: Data set with more than 15 million high-resolution images, labeled in 22,000 categories, collected and labeled using Mechanical Turk.

Figure 8. Image Bank.

Source: https://vis-www.cs.umass.edu/lfw/

The effectiveness of an image processing algorithm is intrinsically linked to the quality of the image on which it is used (Agarwal et al. 2010).

The production of 3D facial prostheses begins with capturing images of the patient's affected region, using artificial intelligence to analyze proportions and facial features. Once the model has been approved, artificial intelligence coordinates the manufacture of the prosthesis, considering both aesthetic and functional aspects, using the 3D printing technique (Agarwal et al. 2010).

Figure 9. Facial prostheses.

Source: https://br.pinterest.com

Therefore, in the field of prosthesis manufacturing, the technology employed allows for the integral production of these devices through the combination of 3D printers and AI. This approach, based on the plasticity of these technologies, makes it possible to precisely shape the different constituent parts of the prosthesis, ensuring meticulous customization to meet the patient's functional and aesthetic needs (Becker et al 2016).

Temporomandibular disorder

Still in the field of bucomaxillofacial, we are faced with other challenges such as TMD (temporomandibular disorder), where we are seeing success with the inclusion of AI.

Generally, TMJ (temporomandibular joint) disorders include medical conditions that affect the joint and its associated structures, resulting in pain in the jaw joint, dysfunction and discomfort in surrounding areas (Ozsari, Güzel, Yılmaz, & Kamburoğlu, 2023).

Data acquisition for the automated diagnosis of TMJ-related diseases plays a crucial role in ensuring the accuracy and reliability of the diagnostic process. The types and quality of data used to train and test ML and DL algorithms significantly influence the system's performance in identifying and categorizing TMJ-related conditions (Fang, Xiong, Lin, Wu, Xiang & Wang, 2023; Ozsari, Güzel, Yılmaz, & Kamburoğlu, 2023).

Figure 10. TMJ pain.

Source: The Autors 2024.

Using clean and reliable data minimizes the risk of false positives or false negatives and improves the overall performance of the system. The size of the data set used to train the algorithm is extremely important. Ensuring diversity in the dataset, covering a wide range of TMD-related cases, is crucial to allow the algorithm to deal with various conditions and manifestations. A diverse dataset avoids bias towards specific types of TMD and improves the system's ability to recognize less common disorders (Diniz de Lima, E. et al., 2021; Farook, Jamayet, Abdullah, & Alam, 2021; Ito, S. et al., 2022; Ozsari, S. et al., 2023).

LEGAL DENTISTRY

Legal dentistry is a field of work that was regulated in Brazil in the last century and its function is to apply dental knowledge to the interests of justice in order to analyze, expertize and evaluate phenomena of various kinds that may affect humans, provided that such an event is supported by the competence of the dental surgeon (Gobbo et al., 2021; Trevisol et al., 2021; Vaswani, Caenazzo & Congram, 2023).

The development and advancement of technologies has frequently revolutionized the most diverse areas, and forensic dentistry is no different. The use of AI as a means of aiding forensic examinations has been increasingly studied with the aim of providing a support system for forensic examiners (Neto et al., 2019; Mohammad, Ahmad, Kurniawan & Yusof, 2022).

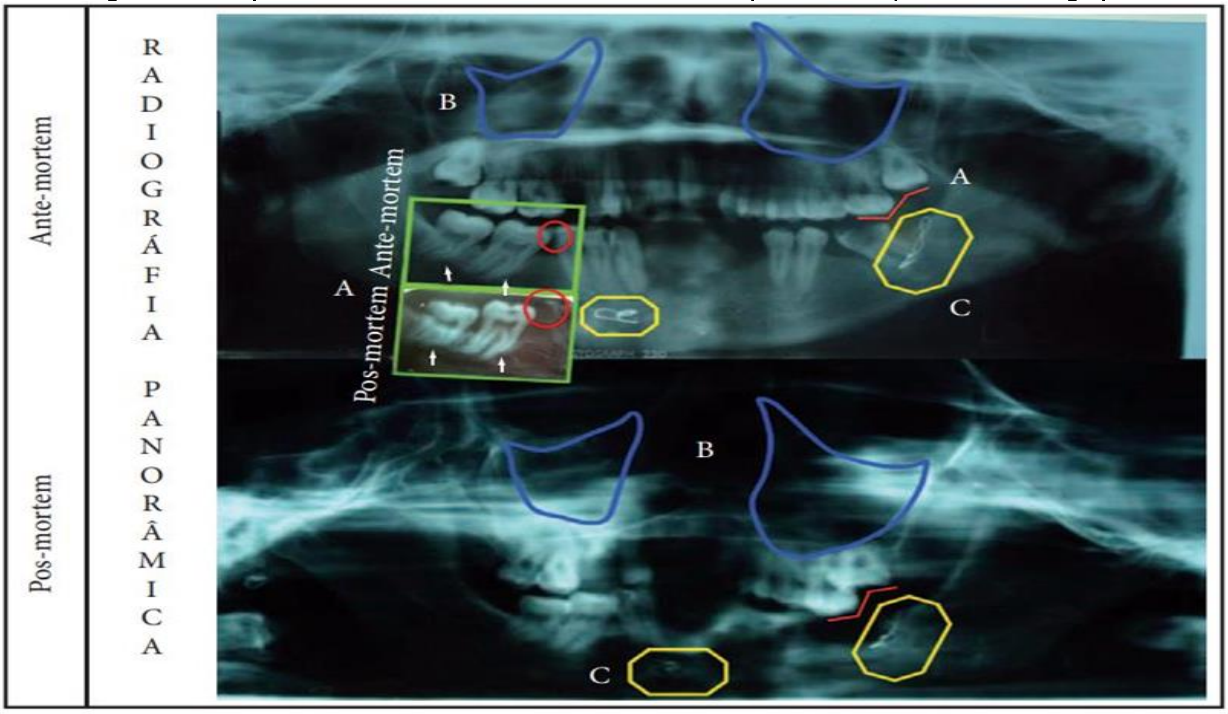
The human identification process is of paramount importance to guarantee human dignity in a number of contexts. In view of this, there are 3 basic methods:

1. Dactyloscopy, a strategy that may not be applicable depending on the individual's condition;
2. Through forensic dentistry, a method that can be applied both in simple situations and in extreme occasions, such as natural disasters with many deaths, due to the great resistance of teeth and adjacent structures;

3. DNA identification, which is a more precise technique, but is time-consuming and exorbitantly expensive (Blau, Graham, Smythe & Rowbotham, 2020; Trevisol et al., 2021).

In this context, AI, with the application of its subfields, has the potential to provide a structured decision support system for dental examiners. By training AI with pre-processed X-ray data, where they are trained to identify relevant characteristics in the images, such as structures, restorations, tooth loss and other properties, they would be able to recognize and evaluate the similarities and differences between the information collected before and after death, being able to support the expert in the decision of whether the information agrees or not (Neto et al., 2019; Fan et al., 2020; Kim, Ha, Jeon, Lee & Han, 2021; Mohammad et al., 2022).

Figure 11. Comparison between elements in ante-mortem and post-mortem panoramic radiographs.



Source: Copyright by Musse et al., 2011.

Artificial intelligence can also be used to determine age through radiographic analysis. When knowledge of the chronological age of a living or dead individual is relevant, such as in the case of victims with no proven age, the identification of juvenile offenders or the adoption of minors (Heinrich, 2024; Shen et al., 2024).

In this context, the use of AI with image processing and ML techniques, together with training with large volumes of data, can, through analysis of the panoramic radiographs of the target individuals, classify the stages of mineralization of the teeth and produce an age assumption. As a result, by using these results in conjunction with the examination carried out by the dental expert, a greater accuracy of chronological age estimation can be achieved (Miranda, Neves, Gomes, & Corte-Real, 2016; Gobbo et al., 2021; Shen et al., 2024).

CONCLUSION

In view of the above, dentistry has always advanced very quickly, but it has never been so closely associated with the development and application of technologies. Among recent technological tools, artificial intelligence has become an object of great investment as it is capable of revolutionizing the work of dental surgeons in a wide range of specialties, making it possible to deliver better quality treatments by increasing the accuracy of diagnoses, aiding in the planning and prediction of treatment results, as well as reducing the working time of dentists. Finally, it is hoped that with the constant and progressive development of AIs, in the future they will be able to surpass the performance of specialists, enabling a real revolution in oral health care, significantly impacting patients' quality of life.

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