Journal of the California Dental Association

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ucda20

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To cite this article: Gordon Lai, Craig Dunlap, Alan Gluskin, Walid B. Nehme & Adham A. Azim (2023) Artificial Intelligence in Endodontics, Journal of the California Dental Association, 51:1, 2199933, DOI: 10.1080/19424396.2023.2199933

To link to this article: https://doi.org/10.1080/19424396.2023.2199933

JOURNAL OF THE CALIFORNIA DENTAL ASSOCIATION
2023, VOL. 51, NO. 1, 2199933
https://doi.org/10.1080/19424396.2023.2199933

Artificial Intelligence in Endodontics

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ABSTRACT

Background: In recent years, with advancements in science and technology, artificial intelligence (AI) has been gaining more relevance in the field of dentistry in general, as well as endodontics. AI-guided algorithms have a great potential to better diagnose, treatment plan, and execute endodontic treatments, as well as outcome prediction of the various endodontic treatments. A review of literature was conducted to assess the application of AI in the field of endodontics.
Results: AI has been used in a variety of clinical applications including the assessment of root canal anatomy, working length, presence of root fractures, and outcome prediction.
Conclusion: Within the field of endodontics, AI has already been proven to be useful. The evolution of this technology and its continuous application can positively impact the field of endodontics and assist in preserving the natural dentition. Clinical implications: AI is currently being used for specific endodontic applications and possible potential applications in the future horizon.

ARTICLE HISTORY
Received 25 November 2022
Revised 24 March 2023
Accepted 3 April 2023

KEYWORDS
Artificial intelligence; endodontics; diagnosis; outcome prediction; root canal anatomy

Introduction

Since the term Artificial intelligence (AI) was first coined by John McCarthy in 1956, there has been a growing interest across many fields exploring the applications of AI. In its simplest form, AI can be described as the discipline that combines computer science and robust datasets to facilitate problem solving in different scenarios. In the early 1980's, expert systems were designed to replicate a human's decision-making process. This was considered the early successful applications of AI software back then, however, it was extremely time consuming.[1] With the improvement of computer technology over the years, as well as advancements in specialized algorithms, there has been increased incorporation of machine learning (ML) and deep learning (DL), which can be considered subdomains of AI. ML uses statistical learning algorithms to build smart systems, which can automatically learn and improve without explicitly being programmed.[1] DL, on the other hand, emulates the way a human brain filters information. It is associated with learning from examples by utilizing artificial neural networks (ANN). DL systems can help computer models to filter the input data through layers to predict and classify information. The advantage of DL as compared to ML algorithms is that they do not require manual input from domain experts, instead they learn from examples autonomously.[1]

Over the past decade, scientific publications related to AI in healthcare have quadrupled.[2] However, dental literature on the subject remains relatively sparse. In a recent systematic review, AI has been utilized in various applications including: dental imaging and diagnostics, caries detection, electronic records, and robotic interactions.[2] The aim of this article is to review the current endodontic applications of AI in diagnosis, treatment planning and execution, outcome prediction, as well as possible future applications to facilitate better treatment outcome for our patients.

AI in Endodontic Diagnosis

Detection of Periapical Lesions

The radiographic detection of periapical lesions can be challenging for even the most seasoned of clinicians. Studies have shown that in order for a periapical radiolucency to be visualized on a two-dimensional radiograph, there has to be on average 7.1% mineral bone loss or at least 12.5% cortical bone loss.[3] Further, there is a large degree of subjectivity in the interpretation of radiographs.[4]

Cone Beam Computed Tomography (CBCT) has been shown to be more accurate in the diagnosis of periapical lesions when compared to periapical radiographs. Patel and others showed that the overall sensitivity for the detection of periapical lesions was 28% for periapical radiographs and up to 100% for CBCT.[5] However, the interpretation of CBCT volumes can be tedious and time consuming. Additionally, there is the potential for the clinician, particularly if they are not trained oral radiologists, to overlook subtle density changes in CBCT volumes,[6] especially in larger fields of view. To overcome these issues, AI is currently being developed to aid the clinician in the localization of periapical pathosis.[6] Setzer et al used a deep learning system on twenty CBCT volumes containing 61 roots with and without periapical lesions. AI segmentation was used to label each voxel as "periapical lesion", "tooth structure", "bone", "restorative material", or

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"background". This deep learning AI system was found to be 93% accurate in detecting lesions with a specificity of 88%.[7] Other research groups have shown that the AI detection of periapical lesions from both periapical radiographs and CBCT volumes are either equivalent to, or superior to, those of experienced specialists.[8,9] In the future, it may be possible for AI to "read" a CBCT scan, which could alert the clinician to areas of possible apical pathosis, as well as other odontogenic or non-odontgenic lesions that may be present on the scan. This can be of great value particularly in areas where access to oral radiologists and proper radiology training is limited.

Detection of Fractures

The radiographic detection of crown and/or root fractures is extremely challenging. A recent systematic review and meta-analysis revealed that CBCT imaging is only 78% accurate in diagnosing vertical root fractures (VRF).[10] Fukuda et al used AI to detect VRF on panoramic radiographs and reported a 75% sensitivity and a 93% positive predictive value in their detection.[11] Another study utilizing AI for the same purpose using both periapical radiographs and CBCT volumes on single rooted premolar teeth showed a 97% accuracy, 93% sensitivity, and 100% specificity in correctly diagnosing VRF.[12] Future research is ongoing to improve the overall diagnostic accuracy of AI and detecting fractures in multirooted teeth.[13] Optimizing AI in diagnosis of VRF can eliminate unnecessary treatment of non-restorable teeth as well as extraction of perfectly healthy teeth that were misdiagnosed.

AI in Treatment Planning & Execution

Determination of Root Canal Morphology

To perform successful root canal treatment, the clinician must know the root canal morphology of the tooth being treated.[6] Traditionally, periapical radiographs, bitewing radiographs, and CBCT imaging have been used for this purpose. However, evaluation of these imaging techniques can be subjective and requires training and experience. AI has been used to evaluate the root canal morphology and number of canals. Hiraiwa et al. utilized AI on panoramic radiographs and reported an 87% accuracy in the ability to diagnose single or multiple distal roots on mandibular first molars.[14] AI has also been used to accurately measure root canal curvatures and three-dimensional canal changes following root canal instrumentation.[15] Lahoud et al. studied three-dimensional tooth segmentation and found that AI was equally accurate and more efficient than human evaluators at determining the root canal morphology.[16] Already, there are commercial AI software companies such as Diagnocat (LLC Diagnocat, Moscow, Russia) that helps practitioners analyze their patients' CBCTs and determine the type of root canal morphology present. It also has the capability to automatically segment the teeth and create 3D Standard Tessellation Language (STL) models that dentists can print out for further analysis (Figure 1). Future directions in AI detection of root canal morphology include expanding AI datasets to include more variations of normal dentoalveolar anatomy.[13] Accordingly, AI can potentially assist clinicians in choosing the most appropriate endodontic files to clean the root canal system and automatically adjust the most appropriate speed and torque on their endodontic handpiece/motor that is required to complete the endodontic treatment with the least amount of procedural errors.

Determination of Working Length

Determining the apical limit of the root canal system is a critical step during root canal treatment. An accurate working length (WL) determination allows for thorough mechanical and chemical disinfection of the root canal system.[17] The correct WL also protects the periodontal tissues from instrumentation beyond the canal terminus and helps prevent the

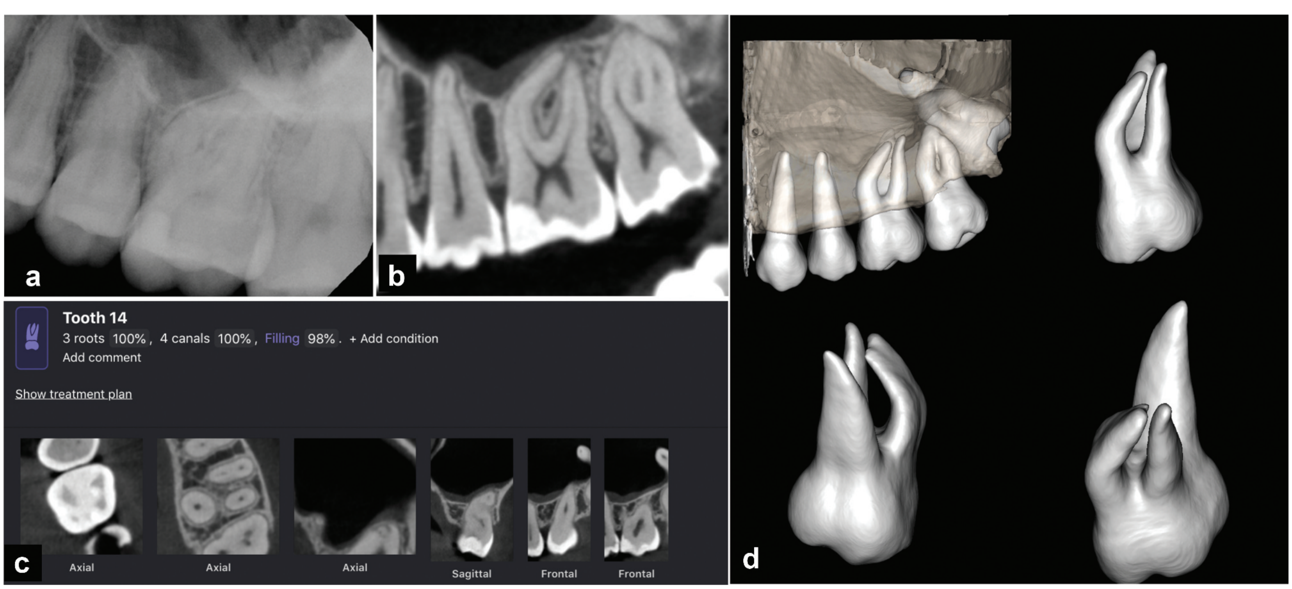

Figure 1. Illustration of Diagnocat AI software interpretation of a radiographic image, generation of a radiology report, and 3D STL files for 3D printing. (a) A digital periapical radiograph showing tooth #14. (b) A CBCT sagittal view of tooth #14. (c) AI software showing the number of roots/canals, the existing restorations, as well as the level of certainty regarding the interpretation. (d) Teeth segmentation automatically generated by the software allowing the clinician to visualize the severe dilaceration on the MB root.

extrusion of debris and reduces post-operative pain.[18] It has been shown that a millimeter loss in WL can reduce the success rate by 12–14% when dealing with infected root canal systems.[19,20] Also, the treatment outcome can be negatively affected if the canals are obturated beyond the radiographic apex.[20]

Current methods of canal length determination are primarily performed using a combination of electronic apex locators and periapical radiographs. The accurate interpretation of digital radiographs is highly dependent on the image quality and the subjectivity of the clinician.[21] In addition, the cemento-dentin junction, where instrumentation should terminate, can be located between 0.5 to 2 mm away from the radiographic apex.[22] While apex locators can provide a high degree of accuracy,[22] apex locator readings can be associated with errors in wet canals, presence of metallic restoration or defective cables.[23] All these variables can contribute to inaccurate measurements that can negatively impact the treatment outcome.

AI algorithms are currently being developed to aid the clinician in the location of the apical terminus on radiographs. Using a cadaver model to mimic the clinical situation, Saghiri et al used AI to determine working length measurements and found that AI was 100% accurate in determining the root length when compared to the actual measurement following tooth extraction. They also concluded that AI was able to locate the minor apical constriction 96% of the time.[24] Further advancement of this technology can allow AI to gather information from imaging techniques and translate this information to the endodontic handpiece/motor operated by the clinician and drive the endodontic files to the cemento-dentin junction with minimum operator interference to preserve the apical constriction and prevent over instrumentation.

AI in Outcome Prediction

AI has been used to predict certain outcomes with regards to endodontic treatment. In a study by Lee et al., the authors looked to create an effective AI based module that would allow for accurate clinical decisions on tooth prognosis, in consideration of an ideal treatment plan.[25] This study utilized data from a multidisciplinary study team at Harvard which consisted of leading specialists from prosthodontics, periodontics, endodontics, and experienced clinician educators. Their results showed that an effective AI-based module allows for accurate clinical decisions on tooth prognosis with comparable results to clinicians from multiple disciplines.

For endodontic retreatment cases, a study by Campo et al. utilized a case-based reasoning paradigm to predict the outcome of nonsurgical root canal retreatment with benefits and risks.[26] The system reported whether one should perform retreatment or not. Case based reasoning refers to the process of creating solutions to problems modeled on previous encounters with similar past problems. In that process information is gathered from similar cases, and different clinical approaches. The system includes data from different areas such as performance, recall and statistical probabilities. The strength of the system is that it might be able to predict the outcome of the treatment. However, the limitation is that the system would be only as good as the information in the data. The more data collected, the better sensitivity, specificity, and accuracy of such approaches.

With regards to endodontic microsurgery, Qu et al. examined different machine learning models for prognosis prediction by analyzing 8 common predictors: including tooth type, lesion size, type of bone defect, root filling density, root filling length, apical extension of post, age, and sex. The study showed that there is potential in being able to predict the prognosis of endodontic microsurgery with 80% accuracy.[27] Further application of this technology can assist clinician in predicting the long-term prognosis of the various treatment options before and after intervention by factoring elements related to diagnosis, and prognostic risk determination.[6]

Future Trends

Photorealistic 3D Reconstructions

An exciting area that has been gaining more interest is the use of AI enhanced algorithms is to create photorealistic 3D reconstructions of the root canal space and the tooth anatomy as well as common orofacial lesions. This novel reconstruction method is referred to as cinematic rendering (CR). CR can create these photorealistic 3D images based on CBCT data sets by using high dynamic range rendering lightmaps to create a natural lighting environment.[28] This can potentially improve the diagnostic accuracy by better displaying the anatomical details (Figure 2).[28] In the medical field, cinematic rendering has been combined with the use of augmented reality headsets to allow users to view and manipulate the images in actual physical space[28] which is something that can be implemented into the dental field as well. Such technology may have a great potential in clinical training and teaching.

Robotics & Microbots

Another future application is the development of AI-guided robots to aid in rendering actual treatment on the patients. Image-guided robotic surgery has been used frequently in neurosurgery and orthopedics. This involves the use of preoperative or intraoperative images along with a tracked device to create an interactive map of deep anatomy, vasculature, and pathology.[29] Currently in the field of implant dentistry, there has been development of robots to aid in implant placement and some studies have shown that the mean deviations of the implant robotic placement were as accurate as both static and dynamic navigations.[30] It would be expected that a similar system can be developed to aid in endodontic microsurgery or even with routine root canal treatment. One major limitation to robotic surgery is the lack of tactile feedback.[31] Dental practitioners are dependent on sensory feedback, but robotic systems do not allow for the feeling of pressure or tension that are common to endodontic tactile sensations. The newest robotic models that are currently in development are trying to address this problem by providing surgeons with continuous, real time sensory feedback.[31] In order to avoid the difficulties encountered in relaying force and tactile information directly to the operators' hands, many studies have focused on 'sensory substitution' providing haptic or sensory information though auditory or graphical cues.[31]

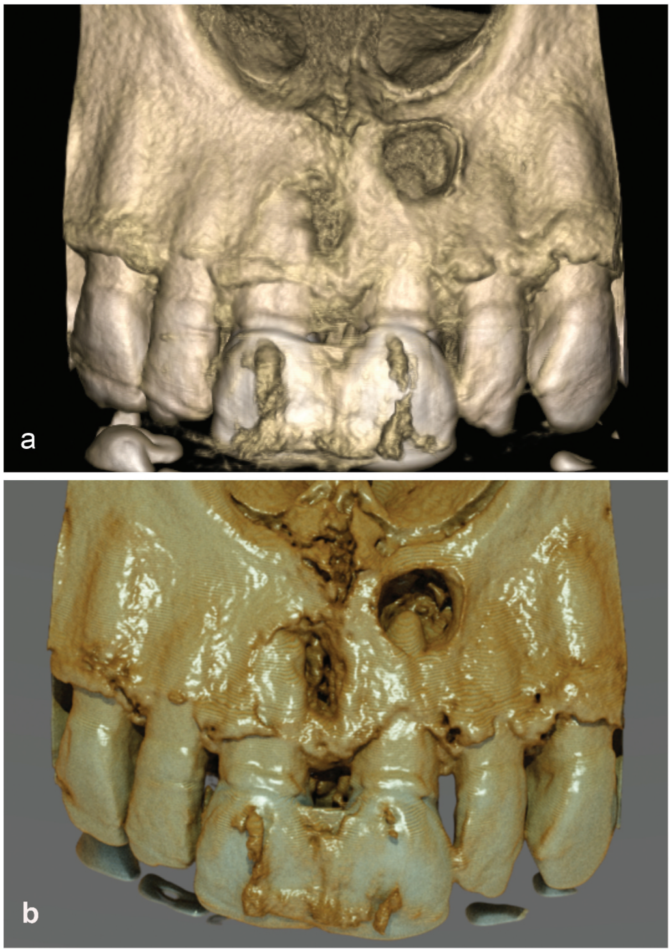

Figure 2. This is a case highlighting periapical lesions on both teeth #8, and #9. (a) A depiction of what a traditional 3D volume rendering from CBCT dataset looks like vs those produced using cinematic rendering using e-Vol DXS CDT software (Bauru, Brazil) (b).

Besides AI guided robots, AI guided microrobots is another field of endodontics that holds a lot of potential. In endodontics there is a push to continually enhance the ultimate therapeutic strategy of defeating the biofilm colonies of bacteria which adhere to the dentin, within the most complex areas of the root canal wall.[32] With known irregularities and anatomical complexities, the root canal system is one of the most clinically challenging spaces in the oral cavity.[17] As a result, biofilm not fully eliminated from the intricacies of the canal space remains a leading cause of treatment failure and persistent endodontic infections.[17]

Because there are limited means to diagnose or assess the efficacy of disinfection, differing approaches dealing with bacterial biofilm disruption and removal have been developed over the last two decades. These include the use of lasers, light energy and ultrasound applications along with enhanced irrigation technologies to disrupt and remove the biofilm.[32,33] Recently, these strategies have been considered in conjunction with self-propelled micro-robots (microbots) that convert energy from the environment into mechanical energy.[32,33] Because of their active motion, these microscopic entities (often smaller than a pin-head) can increase penetrability into the biofilm, and can be manipulated through "augmented reality" to deliver disinfectants, drugs, and/or contribute to mechanical capabilities that allow the opening and shaping of infected spaces.[34] In current research, Babeer et al. showed that magnetically actuated 3D molded microbots are controlled precisely to target the apical region of the root canal uninterrupted by the surrounding periodontium as visualized and tracked by CBCT through an "augmented reality" protocol.[32] The ability to conform to the narrow and difficult-to-reach spaces within the root canal system allows for a more effective disinfection in comparison to the files and instrumentation techniques presently used. The development of tiny self-propelling robots capable of harvesting energy from their surroundings or from external energy sources, has given the scientific community a glimpse of a myriad of future therapeutic opportunities.[34,35]

Conclusion

The current AI models being researched have several promising applications within the field of endodontics including the detection of periapical pathosis, root fractures, determination of working length, and prediction of treatment outcomes. It is critical, however, to build these AI models from data obtained from experienced clinicians to ensure accuracy and consistency. When compared to other fields of dentistry, AI usage in endodontics is still relatively sparse but there are exciting areas that hold further promise for usage growth. Endodontics is not an outlier as we look at future change within our profession of dentistry. Opportunities are ever increasing within our discipline. The future of endodontics as a treatment modality within dentistry possesses a myriad of possibility in rendering teeth salvageable for a lifetime. The expectations are only limited by our imagination and our scientific curiosity!

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References

1. Education IC Artificial Intelligence (AI). https://www.ibm.com/cloud/learn/what-is-artificial-intelligence. 2020. Accessed November 10, 2022.
2. Umer F, Habib S. Critical analysis of artificial intelligence in endodontics: a scoping review. *J Endod*. 2021;48(2):152–160. doi:10.1016/j.joen.2021.11.007.

3. Bender I. Factors influencing radiographic appearance of bony lesions. *J Endod*. 1997;23(1):5–14. doi:10.1016/S0099-2399(97)80199-9.
4. Goldman M, Pearson A, Darzenta N. Endodontic success—who's reading the radiograph? *Oral Surg*. 1972;32(3):432–437. doi:10.1016/0030-4220(72)90473-2.
5. Patel S, Dawood A, Mannocci F, Wilson R, Ford T. Detection of periapical bone defects in human jaws using cone beam computed tomography and intraoral radiography. *Int Endod J*. 2009;42(6):507–515. doi:10.1111/j.1365-2591.2008.01538.x.
6. Aminoshariae A, Kulild J, Nagendrababu V. Artificial intelligence in endodontics: current applications and future directions. *J Endod*. 2021;47(9):1352–1357. doi:10.1016/j.joen.2021.06.003.
7. Setzer F, Shi K, Zhang Z, et al. Artificial intelligence for the computer-aided detection of periapical lesions in cone-beam computed tomographic images. *J Endod*. 2020;46(7):987–993. doi:10.1016/j.joen.2020.03.025.
8. Ekert T, Krois J, Meinhold L, et al. Deep learning for the radiographic detection of apical lesions. *J Endod*. 2019;45(7):917–922. e5. doi:10.1016/j.joen.2019.03.016.
9. Orhan K, Bayrakdar I, Ezhov M, Kravtsov A, Özyürek T. Evaluation of artificial intelligence for detecting periapical pathosis on cone-beam computed tomography scans. *Int Endod J*. 2020;53(5):680–689. doi:10.1111/iej.13265.
10. Malli Suresh Babu N. Diagnosis of vertical root fractures by cone-beam computed tomography in root-filled teeth with confirmation by direct visualization: a systematic review and meta-analysis. *J Endod*. 2022;47:1198–1214.
11. Fukuda M, Inamoto K, Shibata N, et al. Evaluation of an artificial intelligence system for detecting vertical root fracture on panoramic radiography. *Oral Radiol*. 2019;36(4):337–343. doi:10.1007/s11282-019-00409-x.
12. Johari M, Esmaeili Gavgani F, Andalib A, Garjani S, Saberkari H. Detection of vertical root fractures in intact and endodontically treated premolar teeth by designing a probabilistic neural network: an ex vivo study. *Dentomaxillofac Radiol*. 2017;46(2):20160107. doi:10.1259/dmfr.20160107.
13. Asiri AF, Altuwalah AS. The role of neural artificial intelligence for diagnosis and treatment planning in endodontics: a qualitative review. *Saudi Dent J*. 2022;34(4):270–281. doi:10.1016/j.sdentj.2022.04.004.
14. Hiraiwa T, Ariji Y, Fukuda M, et al. A deep-learning artificial intelligence system for assessment of root morphology of the mandibular first molar on panoramic radiography. *Dentomaxillofac Radiol*. 2018;48(3):20180218. doi:10.1259/dmfr.20180218.
15. Christodoulou A, Mikrogeorgis G, Vouzara T, et al. A new methodology for the measurement of the root canal curvature and its 3D modification after instrumentation. *Acta Odontol Scand*. 2018;76(7):1–5. doi:10.1080/00016357.2018.1440321.
16. Lahoud P, EzEldeen M, Beznik T, et al. Artificial intelligence for fast and accurate 3D tooth segmentation on CBCT. *J Endod*. 2021;47(5):827–835. doi:10.1016/j.joen.2020.12.020.
17. Sjögren U, Hagglund B, Sundqvist G, Wing K. Factors affecting the long-term results of endodontic treatment. *J Endod*. 1990;16(10):498–504. doi:10.1016/S0099-2399(07)80180-4.
18. Ricucci D, Langeland K. Apical limit of root canal instrumentation and obturation, part II. A histological study. *Int Endod J*. 1998;31(6):394–409. doi:10.1046/j.1365-2591.1998.00183.x.
19. Chugal N, Clive J, Spångberg LSW. Endodontic infection: some biologic and treatment factors associated with outcome. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2003;96(1):81–90. doi:10.1016/S1079-2104(02)91703-8.
20. Ng YL, Mann V, Rahbaran S, Lewsey J, Gulabivala K. Outcome of primary root canal treatment: systematic review of the literature - part 2. Influence of clinical factors. *Int Endod J*. 2008;41(12):6–31. doi:10.1111/j.1365-2591.2008.01484.x.
21. Tewary S, Luzzo J, Hartwell G. Endodontic radiography: who is reading the digital radiograph? *J Endod*. 2011;37(7):919–921. doi:10.1016/j.joen.2011.02.027.
22. Piasecki L, Carneiro E, da Silva Neto UX, et al. The use of micro–computed tomography to determine the accuracy of 2 electronic apex locators and anatomic variations affecting their precision. *J Endod*. 2016;42(8):1263–1267. doi:10.1016/j.joen.2016.04.024.
23. Martins J, Marques D, Mata A, Caramês J. Clinical efficacy of electronic apex locators: systematic review. *J Endod*. 2014;40(6):759–777. doi:10.1016/j.joen.2014.03.011.
24. Saghiri MA, Garcia-Godoy F, Gutmann J, Lotfi M, Asgar K. The reliability of artificial neural network in locating minor apical foramen: a cadaver study. *J Endod*. 2012;38(8):1130–1134. doi:10.1016/j.joen.2012.05.004.
25. Lee S, Chung D, Asano A, et al. Diagnosis of tooth prognosis using artificial intelligence. *Diagnostics*. 2022;12(6):1422. doi:10.3390/diagnostics12061422.
26. Campo L, Aliaga I, De Paz J, et al. Retreatment predictions in odontology by means of CBR systems. *Comput Intell Neurosci*. 2016;2016:1–11. doi:10.1155/2016/7485250.
27. Qu Y, Lin Z, Yang Z, Lin H, Huang X, Gu L. Machine learning models for prognosis prediction in endodontic microsurgery. *J Dent*. 2022;118:103947. doi:10.1016/j.jdent.2022.103947.
28. Bueno M-O, Estrela C-O, Granjeiro J-O, et al. Cone-beam computed tomography cinematic rendering: clinical, teaching and research applications. (1807-3107 (Electronic)).
29. Leung T, Vyas D. Robotic surgery: applications. *Am J Rob Surg*. 2014;1(1):38–41. doi:10.1166/ajrs.2014.1004.
30. Bolding S, Reebye U. Accuracy of haptic robotic guidance of dental implant surgery for completely edentulous arches. *J Prosthet Dent*. 2021;128(4):639–647. doi:10.1016/j.prosdent.2020.12.048.
31. Shah J, Vyas A, Vyas D. The history of robotics in surgical specialties. *Am J Rob Surg*. 2014;1(1):12–20. doi:10.1166/ajrs.2014.1006.
32. Babeer A, Oh MJ, Ren Z, et al. Microrobotics for precision biofilm diagnostics and treatment. *J Dent Res*. 2022;101(9):220345221087149. doi:10.1177/00220345221087149.
33. Hwang G, Paula A, Hunter E, et al. Catalytic antimicrobial robots for biofilm eradication. *Sci Rob*. 2019;4(29):eaaw2388. doi:10.1126/scirobotics.aaw2388.
34. Brodie A, Vasdev P. The future of robotic surgery. *Ann R Coll Surg Engl*. 2018;100(Supplement 7):4–13. doi:10.1308/rcsann.supp2.4.
35. Chautems C, Zeydan B, Charreyron S, Chatzipirpiridis G, Pané S, Nelson BJ. Magnetically powered microrobots: a medical revolution underway? *Eur J Cardiothorac Surg*. 2017;51:ezw432. doi:10.1093/ejcts/ezw432.