CHAPTER 8

Deep Learning and Artificial Intelligence Applications in Dentomaxillofacial Radiology

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Abstract: Artificial intelligence (AI) and Deep Learning (DL) started to play an active role in real-life problem solutions, and they have a rising trend across all medical fields, including dentistry. Since there are advanced improvements in image recognition techniques, a better radiological diagnose, prediction of the prognosis, and clinical decision making with a reduced workload are becoming possible for dentomaxillofacial radiologists. Promising results were obtained regarding dental caries detection, periapical/periodontal lesion detection, anatomical landmark localization, osteoporosis diagnosis, and implant dentistry; nonetheless, AI models do not substitute for most of the conventional processes yet. Further studies should be done to verify the feasibility and reliability of AI and DL applications in clinical practice.

This chapter focuses on artificial intelligence and machine learning applications in dentomaxillofacial radiology.

Keywords: Artificial Intelligence, Dentomaxillofacial Radiology, Dental Radiology, Dentistry, Decision-Making, Digital Dentistry, Diagnostic Systems, Machine Learning.

Artificial intelligence applications, which date back to 1956, come to the agenda with serial developments, especially in diagnosis and radiology in health. In addition, it is considered an application that will serve humanity for a long time to cover the whole diagnosis-treatment with clinical trials to make the right decisions in the treatment stage [1, 2].

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Considering that machines can do calculations faster than people without interruption, it can be said that the use of artificial intelligence developments in the health sector will be extremely beneficial. Unlike a clinician, machine learning systems can observe and process almost unlimited numbers of data simultaneously. In addition, since these systems can learn from the data of each case, they can learn to evaluate more cases in minutes than a clinician can see over the life of a clinician [3 - 13].

Artificial intelligence is being used in health, such as disease diagnosis, drug development, personalized therapies, and gene regulation. Diagnosing a disease accurately is a challenging process, as every clinician knows, which requires years of medical training and, in some cases requiring very long periods. Machine Learning, especially Deep Learning algorithms, has recently made great progress in automatically diagnosing diseases, making diagnosis cheaper and more accessible [3 - 12, 14].

Since there are many data related to issues like [14, 15]:

Detection of lung cancer by CT
Sudden cardiac death due to ECG and cardiac MRI images
Assessment of the risk of other heart diseases
Classification of skin lesions in skin images,
Diagnosis of diabetic retinopathy in orbit images

Artificial intelligence algorithms can be as successful as the experts in diagnosing these situations.

In addition, the algorithms can give fast and accurate results in a few seconds on this type of procedure and will provide the same quality radiological diagnosis all over the world at a much cheaper price [3, 4, 6, 7, 9, 10].

AI can be used to diagnose many diseases in many countries with poor socio-economic status. For example, in countries with a high prevalence of tuberculosis, it is sometimes impossible for patients to be diagnosed due to the small number of radiologists who will evaluate the images of patients. Because artificial intelligence can accurately diagnose pulmonary tuberculosis with 95% sensitivity and 100% specificity, it can be easily diagnosed even in countries where radiologists are available with artificial intelligence by evaluating radiographs to be loaded from health centers [16].

Consider consultation with a physician for a patient with type 2 diabetes. Today, doctors spend a significant amount of time on all procedures, such as evaluating all blood tests, recording and evaluating the patient's history, and patient follow-up. However, using artificial intelligence, changes between blood tests and risky situations can be identified more quickly, and customized treatment protocols can be prepared for the patient instead of stereotyped treatment applications. The research necessary for these "personalized" therapies that will provide the most accurate treatment will be possible only with artificial intelligence systems that can process and summarize huge amounts of medical data quickly and accurately [13, 17].

The use of AI to calculate target areas for head and neck radiotherapy more accurately and faster than a human being is a topic that is being worked on. Interventional radiologists are still responsible for providing treatments, but AI has deeper and more accurate data to protect the patient from harmful radiation [18 - 20].

In addition, as artificial intelligence systems can monitor millions of data simultaneously, they will have an important role in preventive medicine. Artificial intelligence may offer early consultation to specialists as the patient may recognize the risk of developing a particular diabetic complication early [13, 17, 21 - 23].

Artificial Intelligence (AI) can be used for daily clinical problems and is applied across all dentistry departments thanks to machine learning (ML). The accurate diagnosis of deep learning algorithms in radiology and pathology keeps improving with every update, and software is being improved rapidly to be the "person-in-charge" in upcoming days [3, 4, 6, 7, 9, 10].

All departments of dentistry have various applications of AI. For example [3, 4, 6 - 12]:

In Orthodontics

Prediction of unerupted canines and premolars' sizes
Necessity of extractions before orthodontic treatment
Evaluation of maxillary canines
Evaluation of lateral cephalograms
Prediction of mandibular morphology in Class 1-2-3 patients

In Prosthodontics and Restorative Dentistry

Prediction of the ongevity of dental restorations
Prediction of color matching
Prediction of color change after bleaching

In Endodontics

Detection of minor apical foramen

In Periodontology

Prediction of aggressive periodontitis with immunologic parameters
Evaluation of oral malodor with saliva samples
Prediction of recurrent apthous ulcerations

In Maxillofacial Surgery

Detection of vertical root fractures
Clinical decision support systems for dental implants and treatments

In Oral Diagnosis and Dentomaxillofacial Radiology

Oral Cancer Prognosis
Assessment of Oral Cancer Risk
Determination of Temporomandibular Joint Disorders Progression
Determination of Temporomandibular Internal Derangements
Interpretation of Conventional 2D-Imagings (Periapical-BiteWin--Orthopantomographic Radiographs)
Interpretation of Cone-beam Computed Tomography and other 3D-imagings

AI models which are used in DMFR applications have been increasing since 2006. Since periapical radiography, orthopantomography, and lateral cephalometric radiographs are the most common modalities in DMFR, most of the studies were planned to solve dental clinical problems, which involve jaws and teeth [11]. One of the first studies with an AI model for a 3D-Imaging aimed to differentiate granulomas and radicular cysts [24].

According to the review of Hung et al., cephalometric landmark localization, osteoporosis diagnosis, jaw lesion classification, and identification of periapical and periodontal diseases are the most common focus of the AI studies in DMFR [11].

Cephalometric Landmark Localization

In order to achieve more accurate orthodontic treatment planning, landmark localization is essential. The majority of anatomical landmark localization is done by computer-aided tracing or manual tracing methods. While manual cephalometric tracing requires a high experience and takes a significant time, computer-aided tracing is faster and easier. Computer-aided tracing is not a perfect way to use since errors can occur due to minor tracing differences between the observers.

In order to prevent any errors, fully automated methods with AI techniques were designed and published.

Osteoporosis

Osteoporosis is a metabolic bone disease that affects dental procedures such as implant dentistry. Since low-density bone is brittle and weak, most surgical procedures are contraindicated in those patients. Thanks to recent algorithms for osteoporosis, specificity, sensitivity, and accuracy reached more than 95%, indicating optimistic results for routine clinical practice.

Maxillofacial Cysts and Tumours

Although no fully automated model that can identify maxillofacial cysts and tumors by itself, some AI models trained for conventional 2D radiographs, and advanced 3D radiographs have promising results for differential diagnosis. Since a vast knowledge is required for the differential diagnosis of all maxillofacial lesions, these AI models can help practitioners and dentistry students have hard times. AI models follow these four steps to classify the lesions; lesion detection, segmentation of the lesion, extraction of texture features, and classification.

Currently, lesion detection must be done manually to complete the following three steps; however, researchers are developing their models to automate the first step.

Periapical and Periodontal Diseases

Periapical lesions and horizontal-vertical alveolar bone resorption are common diseases that are treated in routine dentistry practice. AI models for both 2D and 3D imaging are being developed for the following features [4, 11, 24]:

Classification of the extent of periapical lesions
Prediction for hopeless molars and premolars
Identification of periodontally compromised molars and premolars
Measurement of both vertical and horizontal bone resorptions.
Differentiation of radicular cysts from apical granulomas

Those applications will not solely improve the diagnosis rate but also improve the treatment success rates. For instance, differentiation of apical granulomas from radicular cysts is essential since granulomas can be healed with a root-canal treatment while radicular cysts have to be removed surgically [11, 24 - 26].

Dental Caries

Prevention, early detection, and early treatment are essential in order to fight against the most common oral disease, dental caries. Most of the AI models were developed using extracted teeth and 2-D imaging methods, which cause limitations. Since radiographs of extracted teeth do not have any superpositions or artifacts, it is possible to say that the AI models will be less successful when they are tested with orthopantomographs. Moreover, since it is impossible to differentiate buccal or lingual caries on 2-D images, only occlusal and interproximal caries can be detected with high accuracy. Last but not least, all studies were done with permanent teeth; thus, it is still not known if those AI models can be used for dental caries at deciduous teeth [10, 11].

Dental AI Softwares

Various Dental AI software “such as Diagnocat, Promotion, Orca” are ready to diagnose dental problems using DICOM data. This software combines machine learning and AI technologies which can suggest treatment plans and predict clinical outcomes. First, AI software was just for voice commands, but nowadays, they can process large amounts of data, and recognize specific patterns to diagnose pathologies. For radiologist, AI will also play a crucial role for periodontists, prosthodontists, and orthodontists since it is an excellent development for all disciplines [4].

AI applies both to 2D and 3D images; however, 3D imaging systems may require more time to get to significant diagnostic accuracy rates due to the large dataset.

Radiology is the vanguard of AI applications in dentistry since numerous 2D and 3D images can be evaluated and processed retrospectively to teach-improve and test software.

Teeth recognition is one of the most fundamental applications of AI, and Zhank et al. and Tuzoff et al had a diagnostic accuracy of almost 96% and 98%, respectively [12]. Another study with periapical radiographs was done with Chen et al. also had high precision [26]. Advanced studies with similar CNN algorithms were also done for detection of various pathologies such as [3 - 12]:

- dental caries on periapical radiographs
- dental lesions and caries in trans illumination images
- interproximal caries on bitewing radiographs
- root caries on bitewing radiographs

apical lesions on orthopantomographic lesions
maxillary sinusitis on orthopantomographic images
osteoporosis on orthopantomographic images
lymph node metastases on computed tomography images
Sjögren's syndrome on computed tomography images

As an example of such software for CBCT, let us look closer for one of them, Diagnocat.

Diagnocat works a neural network while processing Dicom files of CT images, finds and segments the main anatomical regions (jaws, teeth, periapical space). This AI identifies various conditions and disorders by 50 signs (normal appearance, filling, crown, treated root canals, implants, periodontitis). It helps the professions quickly diagnose the region of interest, evaluate the overall state of the teeth and jaws, and select images for preparation for dental implant placement or root canal treatment. The software has a convenient, intuitive interface:

Cloud Service

To use the service, a desktop, laptop, or tablet will all be suitable. CBCT images and obtained reports are stored in the Personal Account.

The doctor thus gets a data storage system platform that may be structured by patient name, medical condition, creation, and modification dates. CT images may be transferred from doctor to doctor in a protected protocol involving no file transfer procedure.

Immediately after uploading files, the doctor obtains access to Viewer, which automatically produces:

1. panoramic reformats of various thicknesses (Fig. **1**)
2. a set of slices in three planes for each tooth (Fig. **2**)
3. a treatment motivation report for the patient (Fig. **3**)

Apart from a panoramic image, a treatment motivation report contains the dental formula with colored marks: teeth with "findings" requiring the doctor's attention are red.

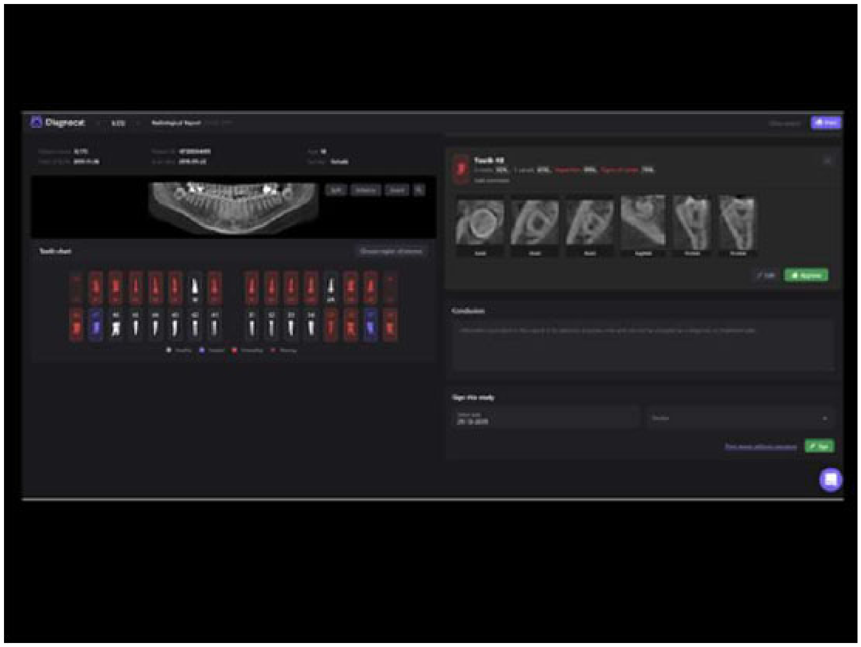

Fig. (1). Separate panoramic images, 5 mm.

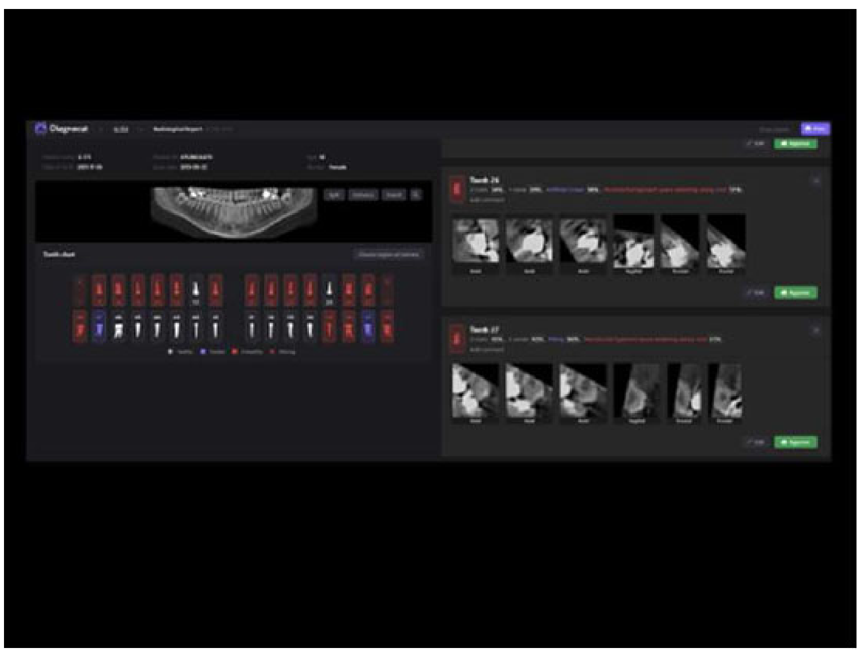

Fig. (2). An extended visualization print screen image WITHOUT description.

Other interactive report formats can be:

Report

In addition to tooth slices, the system generates a textual description of each tooth after analyzing over 50 parameters: anatomical structure, status post-treatment, and signs of crown, root, canal, periapical space abnormalities. The doctor has an opportunity to define a “dental interest area” so that only selected teeth are included in the printout. The dentist can also make changes in the descriptions.

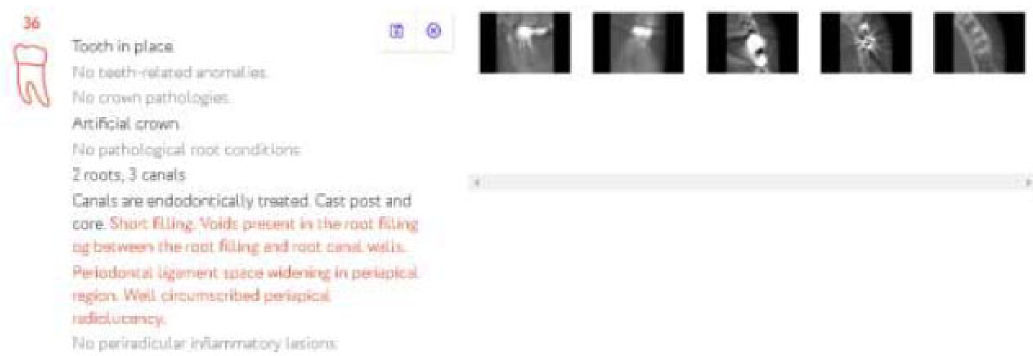

Fig. (3). A tooth field print screen image).

Implant Module

The most frequent indication for CBCT is implant planning. The software automatically generates images that an implant surgeon would need. The only thing to be done is to select a region of interest. It will illuminate the mandibular canal and the bottom of the maxillary sinus and will make measurements between key points (Fig. **4**) .

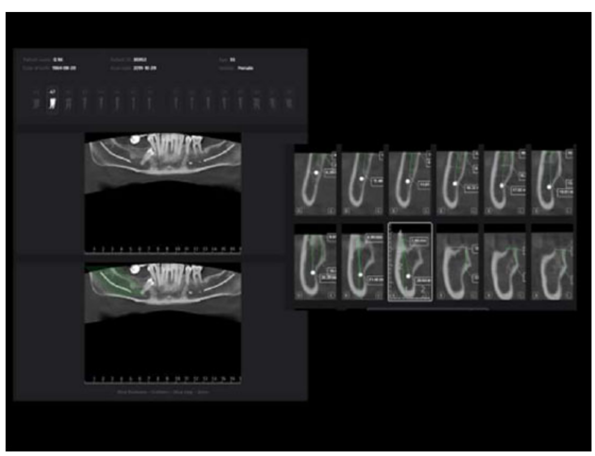

Fig. (4). Diagnocat Implant Module.

Endo Module

The complicated anatomical structure of roots and canals requires careful studying of the images by the dentist. However, it is not easy to understand 3D views. When the tooth is selected, all images regarding teeth (roots, canals, apical damaged areas) is ready with even volumetric calculation of apical pathology (Figs. **5** - **7**) .

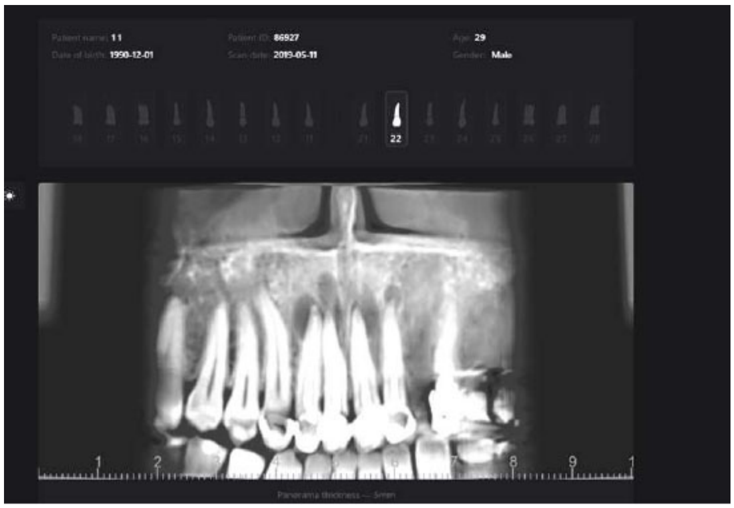

Fig. (5). Diagnocat Endo.

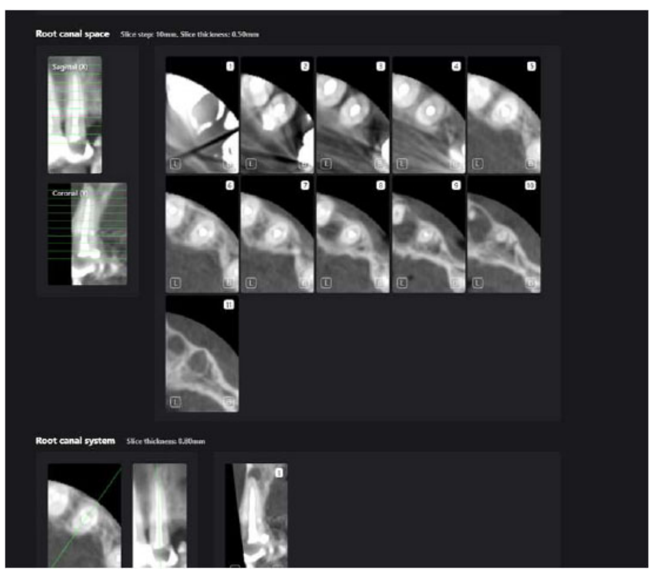

Fig. (6). Diagnocat Endo.

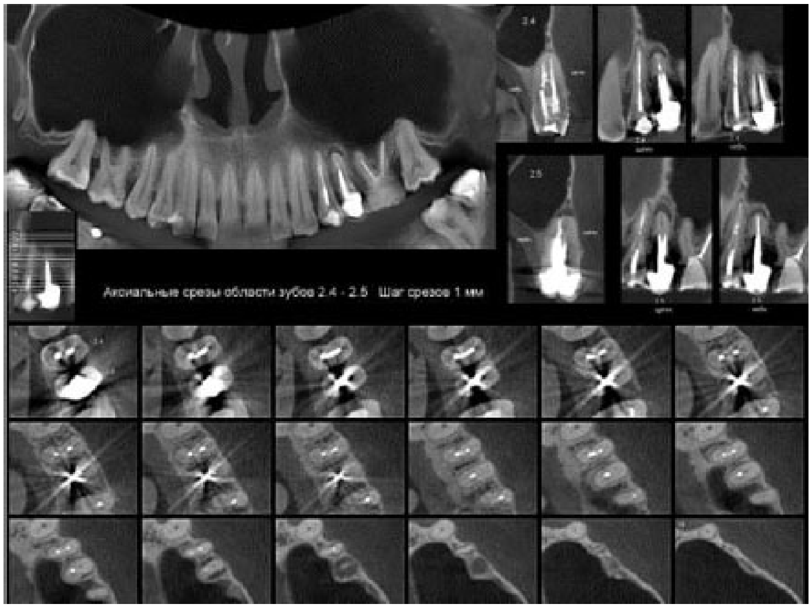

Fig. (7). Diagnocat Endo.

Third Molar and Mandibular Canal Module

Another frequent indication for CBCT is third molar surgery and relationship with a third molar and mandibular canal. The software automatically generates images that an implant surgeon would need. It traces the mandibular canal and the third molar (Fig. **8**) .

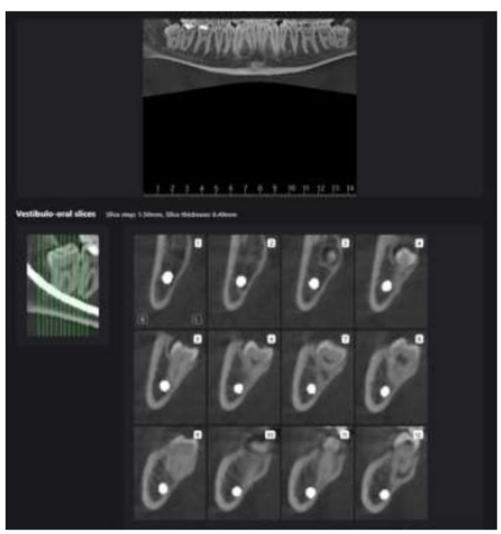

Fig. (8). Diagnocat Mandibular canal tracing.

DISCUSSION

The majority of the studies in DMFR are about the "localization" and "basic features of teeth" rather than general evaluation. Although the focus is on 3-Dimension radiographs such as cone beam computed tomography (CBCT) and 2-Dimension radiographs such as orthopantomographic and periapical radiographs, there are various studies involve intra-oral scanners, quantitative, fluorescence and other new modalities.

Most of the studies nowadays are regarding dentomaxillofacial radiology, and several companies made investments to apply AI in radiological diagnosis. Since most of the data used in testing are private and confidential, the lack of public datasets may remain a challenge. Only one publication evaluated the accuracy of various networks and more is needed to develop software that can be used in clinics.

Another problem is the most studies have fewer than 1000 samples in both test and control groups with less than 90% of diagnostic accuracy. The diagnostic accuracy and sample size fall short since any score lower than 98% are not desirable. Increasing the sample size is crucial in order to achieve this goal.

CBCT is an essential tool for dentistry since it has broadly relevant usage. Intraosseous lesions, TMJ's bony pathologies, maxillary sinus pathologies can be diagnosed with it, and also it is essential in implant dentistry. However, CBCT does not reliable Hounsfield Units (HU) values due to the differences in exposure parameters, measurement position in central and periphery, and the volume inside and outside the FOV. Contrary to CBCT, helical CBCT has reliable HU and pixel values.

Panoramic radiograph is the most used imaging in dentistry; however, to achieve acceptable diagnosis accuracy with AI, higher standardization protocols must be applied to avoid any failure due to image quality, patient positioning, and magnification. Radiographs that were taken with different orthopantomography devices should be evaluated together in order to ensure a reliable data set construction.

A common mistake with the current studies is collecting data from a single radiography device which will cause a problem since different models are created for each machine, and It is, likely, that a model for a device will not apply to other machines.

Manually cropped radiographs with the region of interest are also another challenge since the newly-developed software will not interpret the whole image.

Due to inadequate computational power, some researchers tended to use "decimation" or "downsampling" for sample-rate reduction, resulting in the loss of clinically essential details of the image. Moreover, for a more accurate diagnosis, it is crucial to use non-cropped radiographs without any alterations to achieve better AI results.

As the DMFR society, we need:

- a better standardization for both 2D and 3D imaging (such as patient positioning)
- a bigger dataset (>1000)
- public datasets from multiple institutions
- higher computational power
- unsupervised/semi-supervised learning instead of a supervised learning
- prospectively collected data instead of retrospectively collected and preprocessed data
- randomized controlled trials

CONCLUSION

Artificial Intelligence Applications in Dentomaxillofacial Radiology is a fast processing branch with exceptional success in its early stage. With faster and automated diagnoses on 2D and 3D dental images, dentists will have higher diagnosis rates in a shorter time. Although AI applications are not routine in dental clinics, future clinics will be integrated with most of those implementations.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The author declares no conflict of interest, financial or otherwise.

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REFERENCES

[1] A.S. Ahuja, "The impact of artificial intelligence in medicine on the future role of the physician", *PeerJ,* vol. 7, p. e7702, 2019. [http://dx.doi.org/10.7717/peerj.7702] [PMID: 31592346]

[2] A. Hosny, C. Parmar, J. Quackenbush, L.H. Schwartz, and H.J.W.L. Aerts, "Artificial intelligence in

radiology", *Nat. Rev. Cancer,* vol. 18, no. 8, pp. 500-510, 2018. [http://dx.doi.org/10.1038/s41568-018-0016-5] [PMID: 29777175]

[3] H. Amasya, D. Yildirim, T. Aydogan, N. Kemaloglu, and K. Orhan, "Cervical vertebral maturation assessment on lateral cephalometric radiographs using artificial intelligence: comparison of machine learning classifier models", *Dentomaxillofac. Radiol.,* vol. 49, no. 5, p. 20190441, 2020. [http://dx.doi.org/10.1259/dmfr.20190441] [PMID: 32105499]

[4] K. Orhan, I.S. Bayrakdar, M. Ezhov, A. Kravtsov, and T. Özyürek, "Evaluation of artificial intelligence for detecting periapical pathosis on cone-beam computed tomography scans", *Int. Endod. J.,* vol. 53, no. 5, pp. 680-689, 2020. [http://dx.doi.org/10.1111/iej.13265] [PMID: 31922612]

[5] A.B. Krishna, A. Tanveer, P.V. Bhagirath, and A. Gannepalli, "Role of artificial intelligence in diagnostic oral pathology-A modern approach", *J. Oral Maxillofac. Pathol.,* vol. 24, no. 1, pp. 152-156, 2020. [http://dx.doi.org/10.4103/jomfp.JOMFP_215_19] [PMID: 32508465]

[6] M.E. Machoy, L. Szyszka-Sommerfeld, A. Vegh, T. Gedrange, and K. Woźniak, "The ways of using machine learning in dentistry", *Adv. Clin. Exp. Med.,* vol. 29, no. 3, pp. 375-384, 2020. [http://dx.doi.org/10.17219/acem/115083] [PMID: 32207586]

[7] D. Tandon, and J. Rajawat, "Present and future of artificial intelligence in dentistry", *J. Oral Biol. Craniofac. Res.,* vol. 10, no. 4, pp. 391-396, 2020. [http://dx.doi.org/10.1016/j.jobcr.2020.07.015] [PMID: 32775180]

[8] Y.W. Chen, K. Stanley, and W. Att, "Corrigendum: Artificial intelligence in dentistry: current applications and future perspectives", *Quintessence Int.,* vol. 51, no. 5, p. 430, 2020. [PMID: 32423192]

[9] F. Schwendicke, W. Samek, and J. Krois, "Artificial Intelligence in Dentistry: Chances and Challenges", *J. Dent. Res.,* vol. 99, no. 7, pp. 769-774, 2020. [http://dx.doi.org/10.1177/0022034520915714] [PMID: 32315260]

[10] Y.W. Chen, K. Stanley, and W. Att, "Artificial intelligence in dentistry: current applications and future perspectives", *Quintessence Int.,* vol. 51, no. 3, pp. 248-257, 2020. [PMID: 32020135]

[11] K. Hung, C. Montalvao, R. Tanaka, T. Kawai, and M.M. Bornstein, "The use and performance of artificial intelligence applications in dental and maxillofacial radiology: A systematic review", *Dentomaxillofac. Radiol.,* vol. 49, no. 1, p. 20190107, 2020. [http://dx.doi.org/10.1259/dmfr.20190107] [PMID: 31386555]

[12] S.B. Khanagar, A. Al-ehaideb, P.C. Maganur, S. Vishwanathaiah, S. Patil, and H.A. Baeshen, "Developments, application, and performance of artificial intelligence in dentistry - A systematic review", *J. Dent. Sci.,* 2020. [PMID: 33384840]

[13] J. Li, J. Huang, L. Zheng, and X. Li, "Application of Artificial Intelligence in Diabetes Education and Management: Present Status and Promising Prospect", *Front. Public Health,* vol. 8, p. 173, 2020. [http://dx.doi.org/10.3389/fpubh.2020.00173] [PMID: 32548087]

[14] Ahmed Z, Mohamed K, Zeeshan S, and Dong X, "Artificial intelligence with multi-functional machine learning platform development for better healthcare and precision medicine", *Database(Oxford).,* 2020. [http://dx.doi.org/10.1093/database/baaa010]

[15] A. Lin, M. Kolossváry, I. Išgum, P. Maurovich-Horvat, P.J. Slomka, and D. Dey, "Artificial intelligence: improving the efficiency of cardiovascular imaging", *Expert Rev. Med. Devices,* vol. 17, no. 6, pp. 565-577, 2020. [http://dx.doi.org/10.1080/17434440.2020.1777855] [PMID: 32510252]

[16] Y. Xiong, X. Ba, A. Hou, K. Zhang, L. Chen, and T. Li, "Automatic detection of mycobacterium tuberculosis using artificial intelligence", *J. Thorac. Dis.,* vol. 10, no. 3, pp. 1936-1940, 2018. [http://dx.doi.org/10.21037/jtd.2018.01.91] [PMID: 29707349]

[17] S. Abhari, S.R. Niakan Kalhori, M. Ebrahimi, H. Hasannejadasl, and A. Garavand, "Artificial Intelligence Applications in Type 2 Diabetes Mellitus Care: Focus on Machine Learning Methods", *Healthc. Inform. Res.,* vol. 25, no. 4, pp. 248-261, 2019. [http://dx.doi.org/10.4258/hir.2019.25.4.248] [PMID: 31777668]

[18] G. Francolini, I. Desideri, G. Stocchi, V. Salvestrini, L.P. Ciccone, P. Garlatti, M. Loi, and L. Livi, "Artificial Intelligence in radiotherapy: state of the art and future directions", *Med. Oncol.,* vol. 37, no. 6, p. 50, 2020. [http://dx.doi.org/10.1007/s12032-020-01374-w] [PMID: 32323066]

[19] S. Siddique, and J.C.L. Chow, "Artificial intelligence in radiotherapy", *Rep. Pract. Oncol. Radiother.,* vol. 25, no. 4, pp. 656-666, 2020. [http://dx.doi.org/10.1016/j.rpor.2020.03.015] [PMID: 32617080]

[20] C. Wang, X. Zhu, J.C. Hong, and D. Zheng, "Artificial Intelligence in Radiotherapy Treatment Planning: Present and Future", *Technol. Cancer Res. Treat.,* vol. 18, p. 1533033819873922, 2019. [http://dx.doi.org/10.1177/1533033819873922] [PMID: 31495281]

[21] M. Cetinkaya, F.T. Oz, A.I. Orhan, K. Orhan, B. Karabulut, D.C. Can-Karabulut, and O. Ilk, "Prevalence of oral abnormalities in a Turkish newborn population", *Int. Dent. J.,* vol. 61, no. 2, pp. 90-100, 2011. [http://dx.doi.org/10.1111/j.1875-595X.2011.00020.x] [PMID: 21554278]

[22] P. Schneider, W.P. Walters, A.T. Plowright, N. Sieroka, J. Listgarten, R.A. Goodnow Jr, J. Fisher, J.M. Jansen, J.S. Duca, T.S. Rush, M. Zentgraf, J.E. Hill, E. Krutoholow, M. Kohler, J. Blaney, K. Funatsu, C. Luebkemann, and G. Schneider, "Rethinking drug design in the artificial intelligence era", *Nat. Rev. Drug Discov.,* vol. 19, no. 5, pp. 353-364, 2020. [http://dx.doi.org/10.1038/s41573-019-0050-3] [PMID: 31801986]

[23] C.L. Manning, *Artificial intelligence could bring relevant guidelines into every consultation.* Bmj-Brit Med J., 2019, p. 366.

[24] A. Flores, S. Rysavy, R. Enciso, and K. Okada, "Non-invasive differential diagnosis of dental periapical lesions in cone-beam CT", *2009 IEEE International Symposium on Biomedical Imaging: From Nano to Macro,* 2009 [http://dx.doi.org/10.1109/ISBI.2009.5193110]

[25] K. Orhan, I.S. Bayrakdar, M. Ezhov, A. Kravtsov, and T. Özyürek, "Evaluation of artificial intelligence for detecting periapical pathosis on cone-beam computed tomography scans", *Int. Endod. J.,* vol. 53, no. 5, pp. 680-689, 2020. [http://dx.doi.org/10.1111/iej.13265] [PMID: 31922612]

[26] H. Chen, K. Zhang, P. Lyu, H. Li, L. Zhang, J. Wu, and C.H. Lee, "A deep learning approach to automatic teeth detection and numbering based on object detection in dental periapical films", *Sci. Rep.,* vol. 9, no. 1, p. 3840, 2019. [http://dx.doi.org/10.1038/s41598-019-40414-y] [PMID: 30846758]