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Artificial intelligence in endodontics: relevant trends and practical perspectives

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Abstract

Background. Overall pool of studies regarding artificial intelligence (AI) implementation in dentistry is increasing every year, while possibilities for using AI methods within everyday endodontic practice is still quite confined and not always enough affirmed.

Objective. To systematize and depict principal data regarding use of virtual artificial intelligence for various endodontic-related clinical purposes.

Materials and Methods. Targeted literature search was provided within National Center for Biotechnology Information databases using pre-specified Mesh-terms algorithm. The following information was extracted from each publication during content analysis: diagnostic and treatment planning aspects of endodontic practice for which AI methods could be applied; accuracy levels registered for AI models used for different endodontic-related purposes; limitations of using AI within endodontic practice.

Results. AI features could be used in endodontic practice for the following reasons: analysis of root canal morphology, identification of root fractures, verification of periapical lesions, estimation of root canal working length, root canal treatment planning, prediction of pain development during post-treatment period, predication of endodontic interventions success. The most prevalently used artificial intelligence methods for different endodontic diagnostic and treatment planning objectives were the following: convolutional neural network, artificial neurons network, case-based reasoning, deep learning, machine learning, neuro-fuzzy inference system, probabilistic neural network.

Conclusion. Main advantage of using AI models in endodontic practice associated with improvement of diagnostic accuracy within reduced amount of time needed for X-ray images and clinical data analysis. AI application for apical foramen detection and working length determination demonstrates the highest level of accuracy compared to AI performance for other clinically related objectives in endodontics.

Introduction

Progression of digital technologies is changing routine dental approaches of treatment and diagnostics [1, 2, 3, 4]. Nowadays improvements of dental practice in many clinical scenarios based on the principles and advances of different artificial intelligence (AI) models, which not only assist, but sometimes help to form completely new efficient “roadmap” for patient’s dental rehabilitation [1, 2, 3,

4, 5]. Usage of deep learning and convolutional neural networks may help to process available diagnostic information in the most objective manner, while minimizing effect of human observer bias. On the other hand, such computer algorithms need to be "taught" in correct manner to mimic human brain decision making and produce further reliable and clinically-argumented results [2, 3, 4, 5]. Previous experience has shown that artificial intelligence systems demonstrated efficient usage for diagnostics of dental caries, periodontitis, maxillofacial tumors, while also for planning complex orthognathic interventions [1].

Significant part of treatment planning and diagnostics in endodontics relies on the analysis of intraoral radiographs, cone-beam computed tomography scans and orthopantomography images. Analysis of X-ray images with the use of AI could be improved by convolutional neural networks with multiple layers, since such approach is based on verifying adaptive image features and performing image classification at the same time, thus excluding a need to input predefined image signs for identification process calibration [6]. Meanwhile other artificial intelligence methods including artificial neurons network, machine learning and deep learning were also described to be effectively used as assistant for different purposes during diagnostics of endodontic pathologies and planning of future root canal treatment in experimental conditions [1, 2, 7, 8].

Overall pool of studies regarding AI implementation in dentistry is increasing every year, while possibilities for using AI methods within everyday endodontic practice is still quite confined and not always enough affirmed. Also, there is only a limited amount of data regarding practical performance, usability, and clinical significance of applying AI for various endodontic objectives [3, 5, 6]. On the other hand, considering few recent systematic reviews it may be resumed that evidences about accuracy and expediency of applying AI for various endodontic-related purposes still updating [1, 2, 5, 8], so it seems justified to systematize such at the present time period in the form of targeted literature review.

Objective

To systematize and depict principal data regarding use of virtual artificial intelligence for various endodontic-related clinical purposes.

Materials and Methods

Literature search protocol

Targeted literature search was provided within National Center for Biotechnology Information databases (https://www.ncbi.nlm.nih.gov/) using pre-specified Mesh-terms algorithm: ("artificial intelligence"[MeSH Terms] OR ("artificial"[All Fields] AND "intelligence"[All Fields]) OR "artificial intelligence"[All Fields]) AND ("endodontics"[MeSH Terms] OR "endodontics"[All Fields]) [9, 10, 11].

Restriction for publication date was applied by taking into account studies published within following 6-year period: 2017-2023. Also, only publication written in English were considered for further in-depth content analysis. The primary literature search was performed on 25th of February 2023, based on which main data array for content analysis was formulated.

Initial selection of targeted publications was held considering their title and abstract. Secondary selection of publications from primary formulated sample was realized with in-depth analysis of articles' texts, while taking into account their correspondence with following eligibility criteria (topics of interest):

- presence of principally new data regarding usage of AI for various endodontic-associated reasons;
- description of specific accuracy levels of using AI for different endodontic-related purposes;
- description of specific limitations for using AI within endodontic practice;
- description of approaches to improve AI clinical significance for endodontics.

Publications with generalized descriptive information, repetitive facts, deficiently formulated statements, lack of evidences and personal opinions were excluded from the study sample. Also, among all collected publications only such related with virtual artificial intelligence were included for further content analysis, while researches about physical artificial intelligence were not included into present review.

Control literature search was provided on the 25th of March 2023 to depict the publications published between 26th of February and 25th of March 2023, and based on which additional data array was formulated. Analysis of formulated additional data array was held as per algorithm described above. Results of content analysis provided over additional data array was added to the already structured information in the form of pre-prepared manuscript.

No specified quality analysis of the selected studies was provided considering that the objective of present literature was to systematize and depict principal data regarding the use of virtual artificial intelligence for various endodontic-related clinical purposes, while maximizing representation of relevant evidences and clinically- and research-significant statements.

Data extraction and content-analysis

The following information was extracted from each publication during content analysis of articles' full texts due to the formulated content-analysis categories:

- diagnostic and treatment planning aspects of endodontic practice for which AI methods could be applied;
- AI methods used for various endodontic reasons and their analytical specifications;
- accuracy levels registered for AI models used for different endodontic-related purposes;
- limitations of using AI within endodontic practice;
- approaches to improve AI clinical significance for endodontics.

Data categorization and analysis

Categorization of data, extracted from selected publications, was held within Microsoft Excel 2019 spreadsheet software (Microsoft Office, Microsoft, United States) due to the previously formulated content-analysis categories. Entity-relationship model method was used to describe inter-correspondences between different categories of content-analysis and to structure them in correct manner for representation in the form of scientific publication.

Results

Targeted literature search realized within PubMed database due to the pre-formed Mesh-terms algorithm resulted into total of 181 articles. Primary analysis of each article's title and abstract helped to exclude 114 publications from the primary cohort, while in-depth analysis of rest of the articles helped to formulate final study sample which included 24 publications corresponded with eligible criteria (topics of interest). Out of 24 articles included into study sample for content-analysis, 4 were represented in the form of systematic review, 1 – in the form of scoping review, 4 – in the form of review or comprehensive review of literature, 15 – in the form of experimental studies with the use of AI.

Based on the provided literature analysis it was found that AI features may be used in endodontic practice for the following reasons: analysis of root canal morphology, identification of root fractures, verification of periapical lesions, estimation of root canal working length, root canal treatment planning, prediction of pain development during post-treatment period, predication of endodontic interventions success. [2, 7, 12] (Figure 1).

Recent systematic review demonstrated that majority of AI models applied for endodontics were targeted on automated diagnostics and treatment planning [1].

The most prevalently used artificial intelligence methods for different endodontic diagnostic and treatment planning objectives were the following: convolutional neural network, artificial neurons network, case-based reasoning, deep learning, machine learning, neuro-fuzzy inference system, probabilistic neural network (Figure 2).

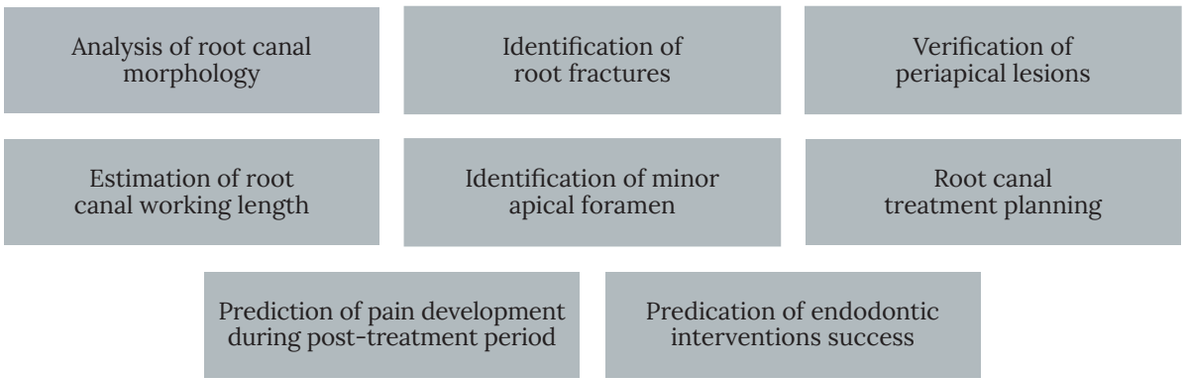

Figure 1. Endodontic objectives for which AI methods could be used based on provided literature analysis

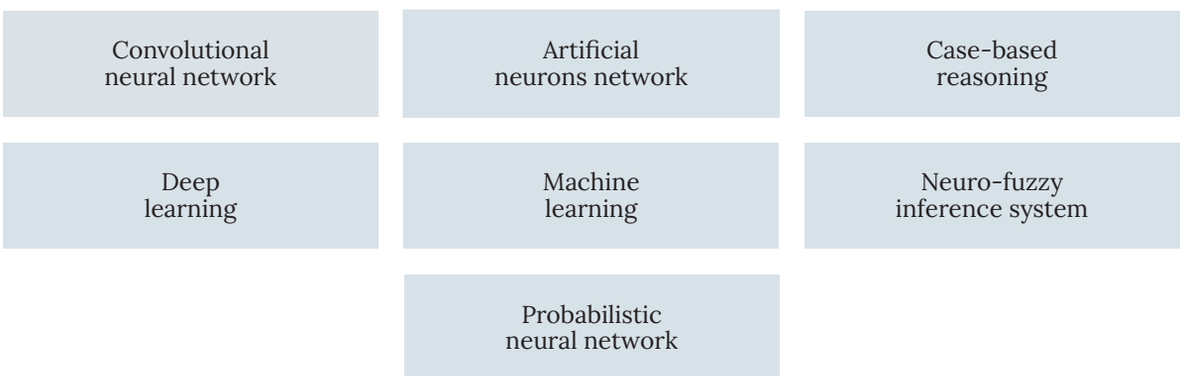

Figure 2. Artificial intelligence methods that may be used within endodontic practice

Discussion

Considering that provided literature review revealed that AI models in the most endodontic cases were used for analysis of root canal morphology, identification of root fractures, verification of periapical lesions, working length estimation and future treatment planning, it was reasonable to objectify accuracy and limitations of such in detailed manner to understand their practical clinical relevance.

AI demonstrated 96% accuracy in determining the working length, and 93% accuracy for locating minor apical foramen [1]. Approbation of AI over cadaver study model demonstrated 93-96% of accuracy, by which it outperformed experienced endodontists [8]. Considering such outcome usage of AI may be suggested for the non-experienced dentists or dentists without endodontic specialization as an additional support for working length verification and apical foramen detection during root canal treatment. In the most relevant comprehensive review performance of AI for apical foramen detection and working length determination was characterized with the highest accuracy levels (93-96%) in comparison to the AI application for the other endodontic-related objectives [2].

AI helped to gain 96.6% of diagnostic accuracy during vertical root fracture detection on the received CBCT scans [1]. In in vivo study of CBCT scans demonstrated that AI could detect vertical root fracture with accuracy up to 97.8%, sensitivity – up to 97.0%, and specificity – up to 98.5% [13]. Ex vivo study highlighted that detection performance of probabilistic neural network for vertical root fracture is much higher for cases of using CBCT scans, than for cases of periapical radiographs [14]. High detection performance of convolutional neural network also was registered during identification of displaced root fracture on cone-beam computed tomographic images (98.5%, 100%, and 96.9% for accuracy, specificity, and sensitivity correspondingly while using manual cropping approach) [15]. Comprehensive review demonstrated that accuracy range for vertical root fracture detection with the use of AI varies within 73-96.6% range, while also AI application over CBCT results was characterized with higher level of accuracy for non-treated root canal cases [2]. On the other hand, AI application over conventional radiographs demonstrated better performance for root fracture detection in obturated root canal cases [2]. On the panoramic images AI root fracture detection performance was characterized with recall of 0.75, precision of 0.93 and F-measure of 0.83 [16].

Orhan et al. reported 92.8% reliability of periapical pathosis identification on the CBCT scans with the use of AI, while volumetric parameters calculated with AI were the same at those calculated by radiologist [17]. In the study of Setzer et al. AI performed detection accuracy of 0.93 while using deep learning segmentation for the periapical lesions identification [18]. Convolutional neural networks supported 70% accuracy of automated periapical lesion classification system, while such level was higher for the datasets of images with large lesions and without such in comparison to the datasets of images with small lesions and without such (81.25% vs. 66.67%) [19]. Comprehensive review provided by Karobari et al. revealed that different methods of artificial intelligence could help to gain 72-93% accuracy during X-ray based endodontic diagnostics [2]. Analysis of results presented in comprehensive review helped to establish that combination of AI with CBCT results supported higher accuracy of periapical lesions diagnostics compare to cases where AI method was applied for assessment of periapical radiographs with the same purpose [2]. Performance of AI models for periapical pathosis may be altered by the presence of adjacent periodontal pathology and too close localization of some anatomical structures (mental foramen, nasal fossa etc.) [1].

While combining results of training and testing sets AI demonstrated effective performance regarding identification of second mesio-buccal canal within maxillary molar (sensitivity – 0.71; specificity – 0.98; accuracy – 0.84) [20]. AI effectiveness for MB2 identification were comparatively higher for the cases with non-

obturated root canals, since obturation of such causing development of beam-hardening effect, which in turn compromise performance of artificial intelligence detection algorithm [20]. AI analysis of panoramic images with using CBCT data as a gold standard demonstrated 86.9% diagnostic accuracy for the differentiation of single or extra distal roots of mandibular molar, while radiologist's performance for the same objective has shown 81.2% accuracy [6].

Convolutional neural network was characterized with high levels of accuracy and sensitivity (84.37 ± 2.79 and 81.26 ± 4.79 correspondingly) for the detection of broken endodontic file within the root canal based on the panoramic images analysis [21]. Analogically AI helped to predict presence of C-shaped distal canal within mandibular molar based on the analysis of panoramic images with the accuracy of 95.1% and sensitivity of 92.7% [22]. Analogical results regarding C-shaped prediction within mandibular molars by AI model were approved in the study of Yang et al. [23], in which authors proved efficiency of AI during the analysis of periapical and panoramic images.

In 2021 back propagation (BP) artificial neural network model was proposed for prediction of pain after provided root canal treatment, which assured 95.60% of accuracy [24].

Case-based reasoning paradigm with the use of AI possibilities have been introduced to predict outcomes of root canal treatment and to make a substantial conclusion regarding expediency for secondary endodontic interventions [26]. AI-based models for predicting failures of endodontic treatment and prognosis of endodontic microsurgery interventions were also developed and undergone experimental approbation [1].

Another important perspective of AI application for root canal treatment is possibility to evaluate viability and survival level of stem cells during endodontic regenerative procedures [26]. Hybrid machine learning method helped to evaluate that viability of pulp stem cells cultured within human platelet lysate was higher than within fetal bovine serum or human platelet-rich plasma [26]. On this matter perspective for endodontics focused at developing artificial intelligence guided dental pulp stem cells regeneration protocols, which further potentially may be used for clinical practice [27].

Combination of AI features regarding possibilities for in-depth analysis of molecular biomarkers and large-sized databased models could be used for the improvement of research methods and experimental approaches to study pulpitis pathology[28].

Studies analyzed in recent systematic review demonstrated performance of AI in endodontic practice at the level similar to the experienced specialists, while some researchers pointed that AI could be even better for some diagnostic scenarios compare to dental professionals [8].

Several gaps have been systematized, which need to be solved in the nearest time to expand AI incorporations into specifically endodontic practice:

• absence of adapted complex software for endodontic patients scheduling based on the clinical need and objectified endodontic status, while also taking into account specificity of health care system functioning in general [7];

• deficiency of prediction models regarding success of endodontic treatment while taking into account not only X-ray images, but also clinical findings [7];

• identification of some anatomical variations especially in already endodontically treated teeth with the use of AI may be complicated, since it requires appropriate data preparation and implementation of corresponding manual segmentation, which is time-consuming procedures [20].

Improvements of available AI models targeted for the implementation within the endodontic practice could be achieved by constant training on heterogeneous and sufficiently sized datasets of dental patients [1]. Most of used AI methods for endodontic objectives previously were trained over small number of marked images, which may cause effect of "data overfitting" associated with a loss of generalizability and sample representativeness characteristics [29]. Image segmentations also seems to be needed for the machine learning-based classification systems used in endodontics [19]. Also, many of already approbated AI models designed to assists diagnostics in endodontics were approved using only high-quality images, nevertheless if AI is designed to be used in real clinical conditions it should at least detect low-quality images and point on their non-reliable diagnostic significance [29].

There is also a relevant need to develop adapted guidelines for reporting and interpretating results obtained after AI incorporation for different clinical and diagnostic objectives within endodontic practice [12].

Conclusion

Main advantage of using AI models in endodontic practice associated with improvement of diagnostic accuracy within reduced amount of time needed for X-ray images and clinical data analysis. AI application for apical foramen detection and determination of working length demonstrates the highest level of accuracy compared to AI performance for other clinically related objectives in endodontics. Nevertheless, before implementation of any of AI models into the clinical practice such should undergo repetitive approbation and thorough validation. So far AI models should be interpreted as additional instruments for potential optimization of decision-making process in endodontic practice. Features of AI may be successfully implemented into the study process of future endodontic specialists.

Progressive improvements of AI methods, which could be potentially used within endodontics should be based on using large-sized heterogenous datasets formulated from real clinical practice for further in-depth machine learning.

Conflict of Interest

Authors do not have any potential conflict of interests that may influence the decision to publish this article.

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Штучний інтелект в ендодонтії: актуальні тренди та практичні перспективи

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A – розробка концепції та дизайну дослідження, B – збір та або систематизація даних дослідження, C – аналіз та тлумачення даних дослідження, D – написання публікації, E – критичне доопрацювання тексту публікації, F– остаточне затвердження.

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штучний інтелект, ендодонтія, огляд, обробка зображень, комп'ютерна обробка даних

Анотація

Вступ. Загальний пул досліджень щодо впровадження штучного інтелекту (ШІ) у стоматології збільшується з кожним роком, тоді як можливості використання методів ШІ, у повсякденній ендодонтичній практиці, все ще досить обмежені та не завжди достатньо підтверджені.

Мета. Систематизувати та виокремити основні дані щодо використання віртуального штучного інтелекту для різноманітних клінічних цілей в ендодонтичній практиці.

Матеріали та методи. Цільовий пошук літератури здійснювався в базах даних Національного центру біотехнологічної інформації за допомогою попередньо визначеного алгоритму Медичних предметних рубрик (Mesh-terms). Під час аналізу контенту з кожної публікації було вибрано наступні дані: аспекти діагностики та планування ендодонтичного лікування, для яких можна застосувати методи ШІ; рівні точності, зареєстровані для моделей ШІ, які використовуються для різних ендодонтичних цілей; обмеження використання ШІ в ендодонтичній практиці.

Результати. Функції штучного інтелекту можна використовувати в ендодонтичній практиці в наступних цілях: аналіз морфології кореневого каналу, ідентифікація переломів кореня, верифікація періапікальних уражень, оцінка робочої довжини кореневого каналу, планування лікування кореневого каналу, прогнозування розвитку болю в період після лікування, прогнозування успішності ендодонтичних втручань. Найбільш поширеними методами штучного інтелекту, які можуть бути використані для різних цілей діагностики та планування лікування в ендодонтичній практиці, є наступні: згорткова нейронна мережа, штучна нейронна мережа, аргументація на основі прецедентів, глибинне навчання, машинне навчання, нейромережа на основі системи нечіткого виведення, ймовірнісна нейронна мережа.

Висновки. Основна перевага використання моделей штучного інтелекту в ендодонтичній практиці пов'язана з підвищенням рівня діагностичної точності та редукцією затрат часу, необхідних для опрацювання рентгенологічних зображень та аналізу клінічних даних. Застосування штучного інтелекту для верифікації апікального отвору та визначення робочої довжини характеризується виражено вищим рівнем точності порівняно з продуктивністю моделей ШІ, застосовуваних для інших клінічних цілей в ендодонтичній практиці.

Конфлікт інтересів
Автори не мають потенційного конфлікту інтересів, який може вплинути на рішення про публікацію цієї статті.

Заява про фінансування
Автори не отримували фінансової підтримки від жодної організації для проведення свого дослідження.

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