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Artificial intelligence technologies in nuclear medicine

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Abstract

The use of artificial intelligence plays a crucial role in developing precision medicine in nuclear medicine. Artificial intelligence refers to a field of computer science aimed at imitating the performance of tasks typically requiring human intelligence. From machine learning to generative adversarial networks, artificial intelligence automized the workflow of medical imaging. In this mini-review, we encapsulate artificial intelligence models and their use in nuclear medicine imaging workflow.

Key Words: Artificial intelligence; Machine learning; Deep learning; Artificial neural networks; Convolutional neural networks; Generative adversarial networks

Core Tip: Artificial intelligence is a distinguished tool for creating tailor-made medicine. Artificial intelligence (AI) consists of machine learning, deep learning, artificial neural networks, convolutional neural networks, and generative adversarial networks. These AI applications affect all phases of a routine medical imaging workflow in nuclear medicine: planning, image acquisition, and interpretation. The integration of AI into clinical workflow and protocols of medical imaging will provide the opportunity to decrease the error rate of physicians and eventually lead to improved patient management.

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INTRODUCTION

Personalized medicine (precision medicine) is a developing medical practice that develops tailor-made approaches for individual patients, leading to increased reliability and a significant impact on preventative, diagnostic, and therapeutic pathways[1]. Artificial intelligence (AI) integration plays a significant role in achieving precision medicine in nuclear medicine[2]. It refers to a field of computer science aimed at imitating the performance of tasks typically requiring human intelligence[3]. Advancements in AI have allowed for precision medicine models to be developed for individual patients (Figure 1, Table 1). The advancements in AI have been in the order of machine learning (ML), deep learning (DL), artificial neural networks (ANNs), convolutional neural networks (CNNs), and generative adversarial networks (GANs)[4,5].

AI MODELS

Machine learning is not a singular algorithm, but a subset of AI. It processes a set of training data and constructs a model that carries the associations among the variables that are relevant to a particular outcome. It usually needs handcrafted features, requiring more human intervention, for data extraction and filtration[2]. There are many ML methods, some of which are supervised learning, unsupervised learning, semi-supervised learning, and reinforcement machine learning[5,6]. DL is a subset of ML, automating many parts of input extraction, enabling less human intervention. In contrast, ML requires more human intervention for data extraction and filtration[2,5,6].

Artificial Neural Networks are a subfield of DL. ANNs are connected nodes with weighted paths. Each node has parent nodes that influence it, an activation function, firing threshold, and an output value. ANNs are analogous to neurons and their intercommunication[4,5].

Convolutional Neural Networks are made up of convoluting series of pooling layers. CNNs apply a neural-network layer to a part of an image and systematically traverse over the image. CNNs downsample and summarize features by alternating convolutional layers with pooling layers. Their computational requirements are much lower because they operate on a small subset of an image[4,5].

Generative Adversarial Networks are made up of two networks, a generator, and a discriminator, that are in a zero-sum game. Generators generate fake input data to minimize the difference between counterfeits and real inputs. The discriminator classifies the real and counterfeit inputs, attempting to maximize efficiency. Over time, the generator will be good at generating input data and the discriminator will be good at classification[5].

APPLICATIONS

AI advancements in the last decade have improved AI's application in medical imaging. The myriad of applications of AI in nuclear medicine includes all steps of a typical medical imaging workflow: planning, image acquisition, and interpretation. In the future, even patient admission and payment could be included[7-9].

For medical imaging planning, AI will automatically check for specific contraindications, such as allergies and drug interference, or eliminate needless repetition of exams by evaluating past examinations before any examination is done on a patient[10,11].

In nuclear medicine, attenuation maps and scatter correction remain relevant topics for image scanning, thus AI research focuses on these topics intensively. Hwang *et al*[10] generated attenuation maps for whole-body positron emission tomography/magnetic resonance imaging (PET/MRI) using a modified U-Net, a specialized convolutional network architecture for biomedical image segmentation. They compared the CT-derived attenuation map to the Dixon-based 4-segment technique[10,11].

Another hot topic for research is the enhancement of image quality; Hong *et al*[12] improved the picture resolution and noise properties of PET scanners using large pixelated crystals with a deep residual convolutional neural network[12,13]. Kim *et al*[14] demonstrated that Iterative PET reconstruction employing denoising CNNs and local linear fitting enhanced picture quality and robustness to noise-level disparities.

For the interpretation of images, studies on an AI-based triage system for identifying artifacts have been published recently[15]. In the near future, similar systems will be able to detect directly using raw data, such as sinograms, and issue alarms throughout the scanning process, even before reconstruction, so that technicians can adjust or prolong the scheduled scan procedure to accommodate an unexpected discovery[16]. Automated identification of pathologies provides additional intriguing potential in identifying overlooked results and secondary discoveries, saving time and effort[17].

Table 1 Artificial intelligence techniques in nuclear medicine

Machine learning (ML)
Deep learning (DL)
Artificial neural networks (ANNs)
Convolutional neural networks (CNNs)
Generative adversarial networks(GANs)

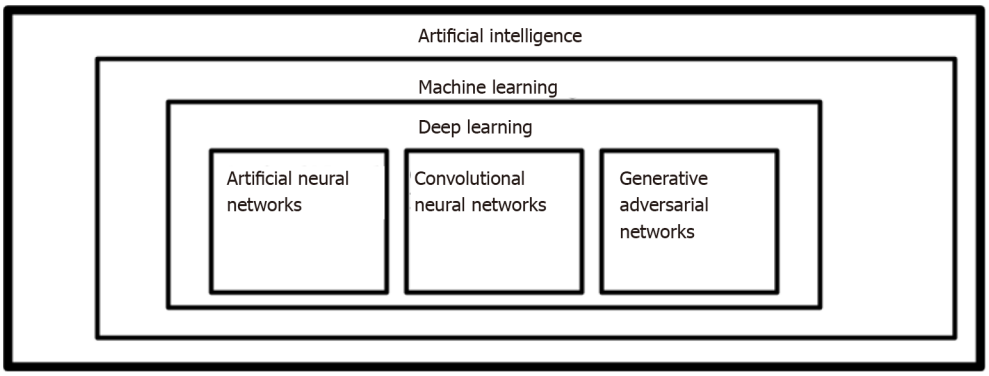

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Figure 1 Current artificial intelligence subfields studied in the field of nuclear medicine.

ETHICAL CONSIDERATIONS, DATA PROTECTION, REGULATIONS, AND PRIVACY

Despite the improvements that the field of AI brings to nuclear medicine, there are drawbacks. Ethical considerations, data protection, legal regulations, privacy, and education are among these problems. According to Hagendorf, the ethical concerns of AI in healthcare can be summarized in the "fairness, accountability, and transparency paradigm of AI ethics"[18,19]. Moreover, AI requires considerable sensitive data in healthcare, thus standards for data protection and privacy raise issues that must be dealt with. Furthermore, for AI to generalize large numbers, large amounts of data with variability are needed. This raises more questions about consent, data anonymization, and de-identification[19]. There are promising techniques being developed on top of DL algorithms such as federative learning that might mitigate some of these issues[20]. Additionally, traditional regulatory pathways are lagging behind the recent advancements, creating difficulties regarding regulations and laws. Lastly, insufficient education about AI both from patients, physicians, and academia causes mistrust of AI applications in healthcare. Physicians and academia need familiarity with AI and the rudimentary knowledge necessary to provide patients with the necessary information[19].

CONCLUSION

The integration of AI into clinical practice will transform the medical profession and nuclear medicine imaging in particular. New abilities, such as clinical data science, computer science, and ML will be considered a necessity when AI is applied to medical imaging workflow and protocols. This could provide the opportunity to decrease the error rate of physicians and eventually lead to improved patient management.

FOOTNOTES

Author contributions: Tamam MO performed the majority of the writing, prepared the figures and tables; Tamam MC performed data accusation and writing; Tamam MC provided the input in writing the paper; Tamam MC designed the outline and coordinated the writing of the paper.

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