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Artificial intelligence on prenatal ultrasound: advantages and limitations

Inteligência artificial na ecografia pré-natal: vantagens e limitações

Jader Cruz[1], Luís Guedes-Martins[1]
Associação Portuguesa de Diagnóstico Pré-Natal

Abstract

The integration of artificial intelligence (AI) into prenatal ultrasound represents one of the most promising innovations in contemporary Fetal Medicine. This opinion article examines the main advantages and limitations of AI application in this context, highlighting advances in the automation of biometric measurements, reduction of clinicians' cognitive workload, and diagnostic support for fetal anomalies - particularly cardiac and central nervous system malformations. The use of convolutional neural networks has shown high efficacy in the segmentation and detection of fetal structures, enhancing both efficiency and consistency in screening. However, several challenges remain, including the need for large and diverse datasets, technical constraints, ethical considerations, and difficulties in effective implementation within clinical practice. The widespread adoption of these technologies will depend on continued research, appropriate regulatory frameworks, and close collaboration between clinicians and engineers, ensuring safe, effective, and equitable integration across varied healthcare settings.

Keywords: Artificial intelligence; Prenatal ultrasound; Fetal medicine; Automated diagnosis.

Resumo

A integração da inteligência artificial (IA) na ecografia pré-natal constitui uma das mais promissoras inovações na Medicina Fetal contemporânea. Este artigo de opinião analisa as principais vantagens e limitações da aplicação da IA neste contexto, salientando os avanços na automatização das medições biométricas, a redução da carga cognitiva dos profissionais de saúde e o apoio ao diagnóstico de anomalias fetais, com especial destaque para as malformações cardíacas e do sistema nervoso central. A utilização de redes neuronais convolucionais tem demonstrado elevada eficácia na segmentação e deteção de estruturas fetais, promovendo maior eficiência e consistência no rastreio. Contudo, subsistem desafios relevantes, nomeadamente a necessidade de bases de dados amplas e diversificadas, constrangimentos técnicos, questões éticas e dificuldades na integração efetiva na prática clínica. A plena adoção destas tecnologias dependerá de investigação contínua, regulamentação adequada e da colaboração entre clínicos e engenheiros, de forma a assegurar uma implementação segura, eficaz e equitativa em diferentes realidades assistenciais.

Palavras-chave: Inteligência artificial; Ecografia pré-natal; Medicina fetal; Diagnóstico automatizado.

INTRODUCTION

Artificial intelligence (AI) refers to the capability of systems to interpret and learn from external data to achieve specific objectives through adaptive processes. A prominent area within AI is machine learning (ML), a powerful set of computational techniques that train models based on patterns derived from human inference. However, a significant challenge in ML is that training relies heavily on statistical insights and human expertise. This limitation has led to the development of deep learning. As a subset of ML, deep learning employs convolutional neural networks (CNNs), which are among the most effective methods for image-related tasks. These networks offer better performance even with limited training data, enabling more abstract feature representations[1].

Although AI has recently gained considerable attention, it is not a novel subject; the conceptual foundation of machine intelligence was established in the mid-20th century by Alan Turing. In his 1950 paper, "Computing Machinery and Intelligence," Turing introduced the idea of machine intelligence and proposed the "Turing Test" as a standard for assessing AI capabilities. Research linking early forms of AI to medicine began in 1951 and has since evolved significantly, playing an increasingly important role in various aspects of our lives[1-3].

Ultrasound (US) is the cornerstone of Fetal Medicine. It allows doctors to obtain essential information on fetal anatomy, development, and general health. Additionally, it is non-invasive, real-time, and has minimal contraindications, making it the most used image technique. However, it is time-consuming and depends largely on doctor's experience and updated equipment. Moreover, it requires extensive training to achieve optimal results, therefore it is subject to operator variability[1,4]. Significant research has been conducted on the application of artificial intelligence in medical image techniques, with AI-assisted diagnosis becoming a focal point in general US and other imaging methods. Numerous studies have demonstrated some success in diagnosis liver, thyroid, and breast diseases using AI assisted ultrasound. However, the application of AI in prenatal ultrasound remains in its early stages[5-7]. In recent years, the integration of AI-driven tools in major ultrasound systems dedicated to Fetal Medicine has been progressively adopted. These advancements primarily focus on automated measurements and assistance on image analysis, aiming to contribute to anomaly detection and workflow efficiency.

1. Associação Portuguesa de Diagnóstico Pré-Natal.

The application of artificial intelligence (AI) in medicine encompasses a wide range of uses. In the near future, it is anticipated that nearly every technical aspect of medical practice will be supported by some form of AI. This includes assistance with patient history, documentation, and prescriptions, as well as more complex tasks such as surgery and diagnostics. This opinion article aims to provide a brief overview and insights into the role of AI in imaging detection during prenatal ultrasound.

ADVANTAGES

Workflow efficiency and cognitive load

Automatic measurement of fetal biometry has been available for a long time. The primary benefit of this technology is the ability to minimize inter- and intra-observer variation in precise measurements like nuchal translucency[8]. Nevertheless, with such tool, the operator is responsible for searching the correct planes, identifying the correct anatomic landmarks to be measured, freezing and saving images, which is as laborious and time consuming as a manual measurement. The latest evolution in this area, and probably the most known AI driven advance in prenatal ultrasound, is the ability to perform all the described steps completely automatic in real-time while the operator is performing the scan. This profoundly changes the methodology in which the examination is conducted, removing from the doctors the need to go through all the described process, resulting in fewer interruptions and a more streamlined workflow. The use of such technology allows for a focused assessment of fetal structure without distractions. A randomised controlled trial demonstrated that the use of this type of AI reduces significantly the duration of the ultrasound examination in about 40%[9,10]. A reduction of this magnitude can significantly improve scan quality allowing more time to actually assess fetal structures or even imaging a particular anatomical area of concern. Shorter scan durations may also offer economic benefits by potentially reducing scan costs. This fact might attract the attention of bureaucrats, though it is by far a much less important benefit when compared to the possibility of improving the quality of assessments for patients.

Cognitive load (CL) refers to the amount of mental effort required to complete a task. It is a key concept in cognitive psychology and may have significant implications in medical imaging. Cognitive load theory suggests that human working memory has limited capacity, and when too much information or complexity is introduced, performance may decline[11]. From the operator's perspective, ultrasound is a very demanding technique. It is often multitasking, complex and requires extreme focus to be able to identify subtle nuances in a grayscale 2D image of a complex 3D moving subject, the fetus. The cognitive toll to perform such technique properly can be high specially among less experienced doctors. It is known that in medical imaging CL is a crucial factor affecting diagnostic accuracy, decision-making, and overall efficiency. The NASA-TLX scale evaluates six dimensions of cognitive workload: mental demand, physical demand, temporal demand, effort, performance, and frustration[12,13]. Studies found that AI-assisted ultrasound significantly reduced CL across all these dimensions, by automating the detection and selection of standard anatomical planes and biometric measurements. The reduction in cognitive load is particularly relevant given the increasing demands on doctors, who must perform a high volume of scans while maintaining the highest accuracy and consistency. High CL has been linked to fatigue, increased error rates, and decreased diagnostic confidence. By streamlining the scanning process, AI assistance could help mitigate these risks, making fetal anomaly screening more efficient while reducing the impact on CL[9,10,14,15].

Diagnostic assistance

The primary goal of prenatal ultrasound is to diagnose fetal structural abnormalities, nonetheless this often subjective and success varies with operator. Research into computer-assisted diagnostic tools could eventually provide a more objective assessment, diminishing the impact of the inherent operator-dependent nature of this technique, attempting for more consistent and reliable diagnostic outcomes. At the moment, significant efforts are being made, using deep learning techniques particularly convolutional neural networks (CNNs) with image and videos of different normal and abnormal structures, to improve the detection of major defects [16]. However, machine learning of abnormal cases requires extensive training data, and few studies currently address this complexity.

Cardiac anomalies represent, to date, the most studied group of congenital abnormalities, likely due to their significant clinical impact, high prevalence, and diagnostic complexity. At present, a collaborative approach that combines human expertise with artificial intelligence appears to be the most effective strategy for integrating this technology into clinical practice, therefore CNNs are primarily trained to assist in the detection of various congenital heart defects and to perform the standard cardiac biometric assessments. Reported detection rates vary across studies, with some indicating accuracies as high as 95% during mid-trimester ultrasound examinations[17]. Furthermore, the detection rate for coarctation of the aorta (CoA) has been reported to reach 90% at the same stage, with a false positive rate of approximately 11% and an area under the curve (AUC) of 0.96[18,19]. While highly specialised clinicians may achieve comparable detection rates, the key advantage of AI integration lies in its potential to enable similar performance levels among less experienced operators.

Another area of increasing interest in AI research is the prenatal diagnosis of central nervous system (CNS) defects. AI models, particularly CNNs and U-Net architectures (a convolutional neural network specific design for image segmentation), are utilized to automatically delineate various structures within the fetal brain in both ultrasound and magnetic resonance imaging (MRI). This automated segmentation enables quantitative analysis of brain volumes and facilitates the identification of structural abnormalities. Studies employing deep learning techniques on fetal brain ultrasound images have demonstrated high diagnostic accuracy, with reported sensitivities of up to 97% and specificities reaching 96% in distinguishing between normal and abnormal cases. For the detection of major anomalies, such as encephalocele and holoprosencephaly, the AUC has been reported to range from 0.85 to 0.89[20-22]. One anticipated challenge in fetal brain analysis lies in the dynamic nature of brain development throughout gestation, necessitating large and diverse datasets to effectively train models across different developmental stages. Nevertheless, this system may ultimately derive the greatest benefit from the integration of emerging technologies into clinical practice.

Challenges and limitations

The advancements in AI assisted tools are promising, however as with any other emerging technology, some limitations and challenges persists. The performance of the AI models is highly dependent on the quality of the data provided, in other words, suboptimal image quality, which can arise due to many well-known factors, can negatively impact the accuracy of AI-driven diagnoses. Another significant challenge is the need for large and diverse training datasets to develop robust and generalizable AI models. Presently, the availability of such comprehensive datasets, encompassing a wide spectrum of normal and abnormal structures across different organs and systems, wide gestational ages spectrum and populations, is yet limited. This has a direct impact on the AI ability to detect highly complex or more rare defects due to the lack of sufficient training data for these conditions[21,22]. Nevertheless, such challenges will be surpassed over time.

The successful integration of AI tools into routine clinical practice also requires addressing technical and logistical challenges, including seamless integration with existing ultrasound equipment and clinical workflows. Understanding the reasoning behind the predictions made by AI models in fetal brain imaging is crucial for building trust among clinicians and for identifying potential biases or limitations within the models themselves. Moreover, ethical considerations related to data privacy, algorithmic bias, and the potential impact on the physician-patient relationship, along with navigating the necessary regulatory approval processes, can impede the widespread adoption of AI in this field[7,15].

CONCLUSION

The future of healthcare holds tremendous potential for innovation through the continued advancement and integration of artificial intelligence. The incorporation of AI into prenatal diagnosis will work as a powerful tool that amplifies the capabilities of healthcare professionals, the collaboration with clinicians can potentially improve diagnostic ability. Furthermore, AI can contribute to the standardization of fetal medicine care reducing variability and ensuring more consistent assessments across different operators and healthcare settings including essential prenatal diagnostic services in resource-limited regions.

Addressing the current limitations in data availability is crucial. Establishing larger, more varied, and well-annotated datasets of fetal ultrasound images will allow for developing robust and generalisable models. Improving the interpretability and explainability of AI models is important to acquire trust from clinicians and also facilitate identification of potential biases. Streamlining the integration of these new tools into clinical workflows and ensuring user-friendly interfaces will facilitate their widespread adoption. Furthermore, as artificial intelligence becomes more essential in fetal medicine, it is imperative to establish clear ethical guidelines and regulatory frameworks. These measures will be decisive in addressing concerns related to data privacy, algorithmic bias, and accountability.

Future research in the field of fetal medicine should concentrate on broadening the applications of AI to encompass the detection of all possible fetal anomalies, integration of multi-modal data beyond imaging, eventually incorporating genomic and maternal health records, lifestyle data, and environmental exposures for a more complete approach to risk assessment and diagnosis. The future may also see AI playing a role in guiding prenatal interventions and treatments.

Finally, long-term studies are needed to comprehensively evaluate the impact of AI-assisted prenatal diagnosis on maternal and child health outcomes.

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CONFLICT OF INTEREST

We have no conflicts of interest in this review.

CORRESPONDENCE TO:

Luís Guedes-Martins
E-mail: guedesmartins.obstetricia@ulssa.min-saude.pt
https://orcid.org/0000-0002-0491-0752

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