Editorial

Top 1 Vascular Ultrasound in 2025: From Anatomy to Autonomy – Artificial Intelligence and Carotid Ultrasound

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Introduction

In recent years, we have witnessed a universal and unprecedented advancement of artificial intelligence (AI) across diverse medical scenarios, with a particularly relevant impact on diagnostic imaging, especially ultrasonography.

Ultrasonography is a widely available, low-cost, real-time method with rapid image acquisition and no exposure to ionizing radiation. Despite these advantages, ultrasonography remains limited by its operator- and equipment-dependent nature, which contributes to significant interobserver and interinstitutional variability, in addition to hindering large-scale standardization.[1,2]

In this editorial for *ABC Imagem Cardiovascular*, we discuss the revolutionary findings of the UltraBot system, as described in the article "Towards expert-level autonomous carotid ultrasonography with large-scale learning-based robotic system" by Jiang et al., published in *Nature Communications* in 2025.[3] The study illustrates a structural shift in the field, demonstrating the transition from rigid rule-based robotic systems to a fully autonomous model, driven by large-scale deep learning and imitation learning (Figure 1).

Discussion

Ultrasound examination traditionally depends on manual operation by a professional. This process requires not only prolonged technical training, but also a high capacity for motor and visual coordination, combined with clinical reasoning, to define the ideal positioning of the transducer in real time. Each examination requires individualized strategies adjusted to patients' anatomical and clinical variations.

This strong dependence on the operator's experience results in greater variability between examinations, compromising the standardization of results, with a potentially negative impact on diagnostic accuracy. In contrast, the advancement of highly autonomous medical robots has emerged as a promising solution, reducing the direct influence of human examiners and promoting greater uniformity in the diagnostic process.

In this context, the study by Jiang et al.[3] aimed to develop and validate a fully autonomous vascular ultrasound robot capable of operating at a level comparable to that of human specialists, which dynamically analyzes ultrasound signals collected from patients, adjusts probe trajectories and poses in real time, and accomplishes scanning and measurement tasks in real clinical scenarios. The authors opted for carotid artery ultrasonography due to its strong clinical relevance in detecting atherosclerotic plaques and its association with risk factors for cardiovascular diseases, which are responsible for the highest mortality rates worldwide.[4, 5]

UltraBot differs from previous approaches by adopting a large-scale imitation learning framework trained on real examinations performed by specialists.[6-8] Unlike approaches based on predefined rules or simulated environments, the system simultaneously learns anatomy, navigation, and decision-making during acquisition, thus constituting a truly end-to-end model, from perception to action, with a high capacity for clinical generalization. The authors believe that their study not only highlights the system's potential but also charts a viable path to bridge the gap between theoretical research and real-world clinical adoption.

Large-scale data were collected from carotid artery examinations performed on real individuals, comprising 247,297 pairs of ultrasound images and encompassing a wide range of structural tissue variations observed in the real world as well as adaptation actions by expert operators.

The scanning success rate was greater than 90% in a diverse population (age: 19 to 70 years; body mass index: 16.5 to 30.8; both sexes), confirming strong generalization performance across anatomical variations, including successful scanning of patients with plaques.

UltraBot controls the transducer in six degrees of freedom, continuously adjusting its trajectory based solely on visual ultrasound signals, in a process that mimics sonographers' "hand-eye-brain" coordination. In addition, the system automatically measures intima-media thickness and lumen diameter, as well as screening for atherosclerotic plaques. It is interesting to note that the robot uses force sensors and external cameras, thus guaranteeing patient comfort and safety during the procedure.

Prior studies have also demonstrated the automatic processing of arterial segmentation, extracting parameters

Keywords

Doenças das Artérias Carótidas; Ultrassonografia; Inteligência Artificial.

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in a standardized, fast, and reproducible manner. He et al.[9] used a database with more than 3,000 three-dimensional images of carotid arteries, training a multitasking model for automatic wall segmentation, plaque detection, and vulnerability classification. Accuracy was 94%, with an area under the curve of 0.94, and a reduction of more than 80% in analysis time compared to manual review, demonstrating that AI was functional within real clinical workflows. Another relevant study is a follow-up of the UK database, the UK Biobank, which brings together images, genetic analyses, and clinical data, making it possible to correlate plaque phenotype with these variables.[10]

These findings pave the way for a truly integrated risk assessment, in which carotid ultrasound, for example, integrates with predictive models based on multimodal AI.

Deep learning is breaking down the cost and hardware complexity barriers.

Traditionally, measuring arterial stiffness and plaque morphological characteristics requires the use of high-resolution equipment, dedicated elastography devices, ultrasound enhancing agents, and three-dimensional transducers. With the advancement of deep learning algorithms, it is now possible to extract this information directly from conventional two-dimensional images.

A very interesting example is the concept of virtual elastography. AI analyzes subtle patterns of movement and pixel dispersion in conventional ultrasound videos and estimates tissue stiffness non-invasively, without requiring dedicated elastography hardware. In a recent study, Tang et al.[11] showed a correlation of 0.85 between the virtual technique and real elastography, with an average error of < 10%. This allows us to infer that we are close to transforming any ultrasound device into a tool capable of measuring arterial stiffness based on AI.

Modern deep learning models are able to run on simple hardware, such as clinical laptops, because they have been optimized for low computational demand. This allows advanced image analysis to be employed in clinical settings and even portable examinations.

Perhaps we are already part of an era in which deep learning can democratize high technology, in which AI not only assesses a single variable, but understands how each "layer" is related to risk of vascular events. This is a new concept known as "imaging at scale," which may be the next step in revolutionizing cardiovascular prevention.

Conclusion

UltraBot signals that high-precision autonomous ultrasound has ceased to be a distant promise and become a viable technical reality. For the cardiovascular imaging community, this advancement suggests a future in which technology does not replace physicians, but rather enhances their expertise, raising the standard of care through standardization, reproducibility, and democratization of access to accurate diagnoses.

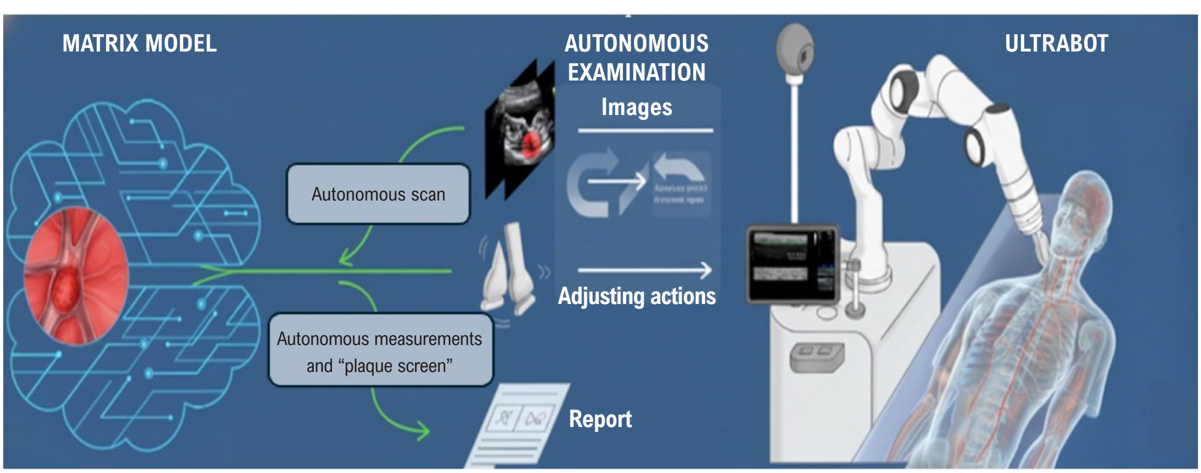

Figure 1 – *Autonomous robotic ultrasound examination. Employing a model based on deep learning and imitation learning, the robotic system automatically performs vascular scanning, biometric measurements, and atherosclerotic plaque screening, generating reports and demonstrating potential clinical applicability. Source: Adapted from Jiang et al.[3]*

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