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PERSPECTIVE

Empowering the anesthesiologist: Navigating the future of AI-driven visualization and wearable technology in regional anesthesia

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1 INTRODUCTION

In current regional anesthesia practice, "visualization" typically refers to the real-time imaging and display of subcutaneous anatomical structures with ultrasound imaging, and "wearable technology" refers to hands-free, optical head-mounted displays (e.g., smart glasses) that can project digital information directly into the clinician's field of view. The paradigm shift in the history of regional anesthesia from anatomical landmark techniques to ultrasound guidance has revolutionized the art of regional anesthesia and transformed a blind procedural technique into a visually guided intervention.

However, despite major advancements in ultrasound hardware over the past decades, the learning curve required to achieve true mastery in needle targeting and block consistency has not decreased as significantly as initially anticipated [1]. The contemporary bottleneck in regional anesthesia is no longer the capacity to visualize sub-surface anatomy, but rather the cognitive burden of interpreting the displayed structures accurately and instantly [1, 2]. For trainees and non-expert clinicians, distinguishing a subtle nerve fascicle from adjacent hyperechoic tendons, muscles, or acoustic artifacts in a grainy, real-time image is a complex pattern recognition task that requires substantial clinical exposure [2, 3].

This cognitive load is further increased by the natural ergonomic awkwardness of the workflow, which is imposed by conventional ultrasound machines. The operator must always turn his eyes away from the patient's procedural site and look at a remote, detached monitor on a cart. This visual axis shifting frequently causes concentration to be broken, needle stability to be compromised, and the "split-attention effect" is well-documented, which directly increases the risk of accidental vascular or neural injury [4]. Over the past ten years, technological advancements have been mainly driven by hardware improvements, such as advanced piezoelectric crystals, matrix array probes, and improved spatial resolution. We have probably reached a point where just making a sharper grayscale image yields only marginal improvements in clinical safety and success rates [1]. The next generation of regional anesthesia requires not just a clearer image, but an intelligent, automated understanding of that image [5].

Therefore, combining deep learning algorithms for real-time anatomical segmentation with wearable smart glasses to project critical data directly into the operator's natural line of sight is the logical progression of the field [4, 6]. This dual approach both reduces the cognitive load from image interpretation and tackles the main ergonomic issues in the modern operating room layout.

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2 AI-DRIVEN REAL-TIME SEGMENTATION FOR ANATOMICAL RECOGNITION

Presently, the most clinically important application of artificial intelligence in regional anesthesia is the rapid and accurate identification of complex anatomical structures [1, 7]. The AI computer vision technology has advanced far beyond basic image processing capabilities, like automatic edge enhancement, contrast corrections, and simple noise-filtering algorithms. Currently, deep-learning models (like U-Net architectures and CNNs with refined and optimized versions) have established a functional semantic understanding level [8]. These models do not merely detect gradients of pixel density or segment bright regions from dark areas, but instead, they delineate mathematical boundaries around nerves, neighboring muscle groups, and important fascial planes with a precision similar to expert clinical consensus [8, 9]. Recent multicenter clinical evaluations indicate that the segmentation of the brachial plexus and various fascial planes can achieve Dice similarity coefficients exceeding 0.76 [8]. In medical image segmentation, a Dice coefficient surpassing this baseline suggests a very strong benchmark, which corresponds to a significant spatial overlap between AI automated contours and expert manual annotations.

Clinically, this metric indicates that the algorithm offers a highly reliable mathematical anatomical guidance to clinicians during the critical stages of needle advancement and targeting [8]. This level of technological support is not just a superficial visual aid, but a direct, objective "second opinion" that is integrated into the ultrasound display, especially in cases where the scans are technically challenging or patients have variant anatomy in daily clinical practice.

It is essential that the latest generation of anesthesia-specific AI models are designed to analyze live streams of high-frame-rate video, not still frozen images [9]. Early versions of ultrasound segmentation software had severe visual flickering and geometric instability when the operator moved the transducer slightly or changed the compression angle. Modern architectures have tackled such issues by providing advanced spatio-temporal consistency algorithms, analyzing structural data across sequential video frames [8].

The clinical outcome is a very stable, fluid color overlay, which does not lose its structural boundaries even with abrupt probe movements or in degraded image quality conditions. This stability in practicing anesthesiology, particularly for those in training or who do blocks infrequently, reduces diagnostic hesitation, reduces cognitive fatigue, and greatly increases procedural confidence when working through very complex and varying sonoanatomy.

3 INTEGRATING WEARABLE TECHNOLOGY INTO THE CLINICAL WORKFLOW

Closing the Loop The most high fidelity, detailed AI anatomic overlay is of limited clinical use if the clinician has to look away from the procedural field to see it. However, displaying processed AI data on a standard cart-mounted ultrasound monitor does not solve the underlying ergonomic flaw of regional anesthesia, which is the repeated need to shift the operator's gaze between the patient's anatomy and the machine screen. A continuous visual distraction that affects hand-eye coordination and constitutes a measurable safety hazard in the context of continuous needle manipulation [4]. Wearable technology offers a conceptually straightforward solution to this human-factors engineering challenge. Recent randomized clinical trials, such as those by Liu et al., published in the *British Journal of Anaesthesia*, have demonstrated that the use of optical head-mounted displays (smart glasses) significantly improves operator ergonomics in ultrasound-guided regional procedures [6]. The basic idea is conceptually straightforward: the live ultrasound video stream and the corresponding real-time AI segmentation overlays are directly projected. The user's goggles are equipped with a transparent heads-up display. This keeps the operator's hands, needle, and visual field in a constant relationship with the patient's body [4, 6]. The integration of wearable smart glasses into a clinical setting makes them a standard essential tool, which reduces musculoskeletal strain, prevents operator fatigue, and allows for a continuous situational awareness throughout the entire nerve block procedure [6].

4 DISCUSSION

The clinical utility of human-AI collaboration in the operating room will rely on the development of the technology from basic structural recognition to full procedural intelligence. The future democratization of high-quality regional anesthesia will depend on the expansion of AI capabilities toward dynamic fluid tracking, quantitative outcome prediction, and standardized clinical training. Future research and development must, therefore, aggressively pursue three highly promising vectors.

4.1 Visualization of drug spread

The exact anatomical target is not the only factor determining the ultimate success and clinical safety of a peripheral nerve block or fascial plane block, but it is also important to monitor the exact distribution of the local anesthetic injectate [1]. Future versions of AI software are being developed to track the expansion of the fluid in real time, differentiate the local anesthetic agent from surrounding tissue artifacts or acoustic shadows, and visually map the exact trajectory of its spread [5, 10].

Such a system would automatically alert the clinician immediately if the drug is pooling in an incorrect fascial compartment or more importantly, if the injection trajectory suggests impending intraneural or intravascular deposition, allowing the needle to be repositioned immediately before clinical complications occur [5].

4.2 Predicting block success

The assessment of the adequacy of local anaesthetic spread is at present based on subjective visual evaluation and retrospective clinical testing of sensory blocks by clinicians.

Future deep learning algorithms will be able to quantify the exact degree of circumferential drug coverage around a nerve bundle or quantify the volumetric diffusion within targeted fascial planes [1, 5]. The AI enables providers to make an objective decision, on the spot, based on data. For example, it can translate these geometrical dimensions into an automated probability score, explicitly predicting '92% probability of complete surgical anesthesia onset within 10 minutes'.

Then the clinicians could immediately decide whether to do an additional block or move to an alternative anesthetic plan without wasting precious operating room time.

4.3 Educational applications

AI-assisted ultrasound visualization has great potential as a standardized, objective teaching tool in residency and fellowship training programs [10]. These intelligent systems will significantly reduce the known steep learning curve associated with advanced regional blocks by providing continuous, interactive and data-supported feedback on transducer position, ideal needle trajectory, accurate anatomical identification, and real-time spread of the injectate. Recent evidence investigating large language models and multi-modal models more so emphasizes their growing utility in explaining core sonoanatomy during simulated training [3].

DECLARATIONS

Author contributions

Qi Chen and Yaohui Huang contributed to the manuscript writing and figure preparation, Daqiang Zhao designed the work, Daqiang Zhao supervised the work. All authors have read and approved the article. All authors read and approved the final manuscript.

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Data availability

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study. All information is derived from publicly available articles and datasets.

Ethics approval and consent to participate

Not applicable. This manuscript does not contain any studies with human participants or animals performed by any of the authors.

Consent for publication

Not applicable. This manuscript does not include details, images, or videos relating to an individual person. And this manuscript is original and has not been published elsewhere, nor is it under consideration by any other journal.

Competing interests

The authors declare that they have no competing interests.

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