

ULTRASOUND-GUIDED REGIONAL ANESTHESIA: ADVANCES, SAFETY, AND EMERGING TECHNIQUES (2020–2026)

A Narrative Review Based on Recent Published Literature

Hina Gul¹, Sawera Sahar², Muhammad Salar³, Hafsa Hayye⁴, Abdul Aziz⁵, Habeeba Khan⁶,
Ayesha Malik⁷, Arbab Wajahat Ullah^{*8}

¹Lecturer Radiology Technology, Department of Allied Health Sciences IQRA National University, Peshawar

²Lecturer/Head of Program, Radiology Technology, Department of Allied Health Sciences IQRA National University, Peshawar

³Anesthesia Technologist, Hafeez Institute of Medical Sciences, Peshawar

⁴Registered Radiographer Ireland

⁵Anesthesia Technologist

⁶Registered Nurse (RN)

⁷BS Medical Imaging Technology, Master in Public Health, Superior University Lahore

⁸Anesthesia Technologist at Rehman Medical Institute-RMI Peshawar

¹hinaatta0@gmail.com, ²sawerasahar96@gmail.com, ²sawerasahar96@gmail.com, ³salar670@gmail.com,

⁴hafsahayye23@gmail.com, ⁵azizhan.htn@gmail.com, ⁶habeebakhan7788@gmail.com,

⁷ayeshamalak789@gmail.com, ⁸arbabwajahat165@gmail.com

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Corresponding Author: *

Arbab Wajahat Ullah

Abstract

Background: Ultrasound-guided regional anesthesia (UGRA) has become an established component of contemporary perioperative care. Between 2020 and 2026, advances in ultrasound imaging, fascial-plane techniques, needle visualization, local anesthetic strategies, education, and artificial intelligence (AI) have expanded its clinical applications. Objective: This review summarizes major advances in UGRA from 2020 through 2026, with emphasis on clinical effectiveness, safety, emerging techniques, and technology-assisted practice.

Methods: A narrative literature review was developed from recent peer-reviewed evidence indexed in major biomedical databases, with emphasis on PubMed/MEDLINE, Embase, Scopus, Web of Science, and the Cochrane Library. Publications from January 2020 through August 2026 were prioritized, including systematic reviews, meta-analyses, randomized and observational studies, narrative reviews, and technology-focused studies.

Results: Recent literature supports the use of UGRA as an important component of multimodal analgesia and enhanced recovery. Fascial-plane blocks, including erector spinae plane, quadratus lumborum, transversus abdominis plane, serratus anterior, pectoral, and other interfascial approaches, have broadened the range of procedures amenable to regional analgesia. Evidence also supports opioid-sparing effects for selected procedures, although comparative efficacy varies by block and surgical population. Safety depends on accurate sonoanatomical interpretation, continuous needle-tip visualization, appropriate local-anesthetic dosing, monitoring, and preparedness for local anesthetic systemic toxicity. High-

definition and microultrasound technologies may improve visualization of fascicles and tissue compartments. AI-assisted image interpretation and needle guidance are emerging rapidly, but clinical validation, standardization, dataset diversity, and outcome-based evidence remain limited.

Conclusion: UGRA has progressed from ultrasound-assisted nerve localization toward increasingly precise, anatomy-informed, and technology-supported regional anesthesia. Future research should prioritize clinically meaningful outcomes, standardized reporting, safety surveillance, training, cost-effectiveness, and rigorous evaluation of AI and advanced ultrasound technologies.

1. Introduction

Regional anesthesia has evolved substantially with the widespread adoption of ultrasonography. Unlike landmark- or nerve-stimulation-based approaches, ultrasound allows the operator to visualize relevant anatomy, identify vessels and target structures, observe needle advancement, and assess local anesthetic spread in real time. This has supported broader use of peripheral nerve and fascial-plane techniques and has contributed to the integration of regional anesthesia into multimodal analgesia and enhanced recovery pathways.

From 2020 onward, the field has expanded beyond conventional peripheral nerve blocks. Fascial-plane blocks have become prominent in thoracic, breast, abdominal, orthopedic, obstetric, and chronic-pain practice. Reviews have highlighted both their clinical promise and uncertainty regarding exact mechanisms and comparative effectiveness. The increasing number of named blocks also creates a need for rigorous evaluation rather than assuming that every technical modification represents a clinically superior intervention.

Technology is another major direction. Recent work has explored high-definition and microultrasound, AI-based image interpretation, automated landmark recognition, needle tracking, and decision-support systems. A 2024 scoping review found rapid growth in AI research but substantial heterogeneity in evaluation methods and limited clinical evidence. More recent work has proposed standardized reporting for AI evaluations in regional anesthesia.

The objective of this review is therefore to synthesize the principal advances in UGRA

published from 2020 through 2026, focusing on contemporary techniques, safety, opioid-sparing analgesia, imaging advances, AI-assisted practice, education, limitations, and future research priorities.

2. Methods

2.1 Review design

This article was structured as a narrative review using an IMRAD framework. The review period was January 2020 to August 2026. Because the purpose was to provide a broad clinical and technological synthesis rather than a quantitative pooled estimate, a narrative approach was used.

2.2 Literature search

The literature search framework included PubMed/MEDLINE, Embase, Scopus, Web of Science, and the Cochrane Library. Search concepts included combinations of: “ultrasound-guided regional anesthesia,” “peripheral nerve block,” “fascial plane block,” “erector spinae plane,” “quadratus lumborum,” “transversus abdominis plane,” “opioid-sparing,” “local anesthetic systemic toxicity,” “microultrasound,” “high-definition ultrasound,” “artificial intelligence,” “machine learning,” “needle tracking,” and “regional anesthesia education.” Reference lists of relevant reviews were also considered.

2.3 Eligibility and selection

Priority was given to peer-reviewed systematic reviews, meta-analyses, randomized controlled trials, prospective and observational studies, and authoritative narrative or technology reviews published between 2020 and 2026. Older landmark publications were considered only when necessary to explain established

principles. Publications were excluded when they were unrelated to UGRA, lacked clinical or methodological relevance, or provided only non-substantive commentary.

2.4 Data synthesis

Findings were synthesized thematically under: technical advances; fascial-plane and peripheral nerve techniques; analgesic and opioid-sparing outcomes; safety; imaging innovations; AI and automation; education and implementation; limitations; and future research. As this was a narrative review, no meta-analysis was performed and no pooled effect estimate was calculated.

3. Results

3.1 Evolution of ultrasound-guided regional anesthesia

The 2020–2026 literature demonstrates continued movement toward real-time, anatomy-guided regional anesthesia. Ultrasound is now central to many peripheral nerve block practices and has facilitated techniques that target nerves, plexuses, fascial compartments, and interfascial planes. The practical advantages include visualization of target structures, identification of nearby vascular structures, dynamic assessment of needle position, and observation of injectate distribution.

However, ultrasound guidance does not eliminate complications. Operator skill, image quality, anatomical variation, needle visibility, injection pressure, local-anesthetic dose, patient comorbidity, and post-procedure monitoring remain important determinants of safety. Thus, UGRA should be regarded as a risk-reduction and precision tool rather than a guarantee of complication-free anesthesia.

3.2 Fascial-plane blocks and emerging clinical techniques

Fascial-plane blocks have been among the most visible developments during the review period. Erector spinae plane, quadratus lumborum, transversus abdominis plane, serratus anterior plane, pectoral, fascia iliaca, rectus sheath, and related techniques have been investigated across a wide range of procedures. Their appeal includes relative technical simplicity, broad

potential analgesic fields, and compatibility with multimodal analgesia.

Evidence remains heterogeneous. A 2024 review of fascial-plane blocks emphasized that clinical benefits differ according to block type, surgery, and comparator. Mechanistic uncertainty is particularly relevant because injectate spread along fascial planes can be variable, and the sensory targets may not always be anatomically consistent. Therefore, block nomenclature should not substitute for evidence of patient-centered benefit.

For chest-wall and abdominal surgery, fascial-plane techniques may provide effective analgesia with fewer selected side effects than some traditional neuraxial approaches. Evidence from systematic reviews of individual blocks, such as transversalis fascia plane block, suggests reductions in postoperative opioid requirements in selected populations. Nevertheless, further adequately powered randomized trials are needed to establish which blocks should be considered core techniques for particular procedures.

3.3 Opioid-sparing analgesia and enhanced recovery

The opioid-sparing role of regional anesthesia has become increasingly important because perioperative care increasingly emphasizes multimodal analgesia and enhanced recovery. UGRA can reduce nociceptive input and thereby decrease reliance on systemic opioids. Benefits may include lower opioid exposure, reduced nausea and vomiting, improved mobilization, and improved patient satisfaction in selected settings.

The magnitude of benefit varies. A technically successful block does not automatically translate into superior recovery if baseline multimodal analgesia is already effective or if the block does not cover the principal sources of surgical pain. Procedure-specific selection and integration with non-opioid analgesics, local infiltration, acetaminophen, non-steroidal anti-inflammatory drugs when appropriate, and other multimodal strategies are therefore important.

3.4 Safety and complications

Safety remains a central issue in UGRA. Important complications include vascular puncture, local anesthetic systemic toxicity (LAST), nerve injury, infection, hematoma, pneumothorax, and unintended motor or diaphragmatic blockade. Ultrasound can help identify relevant anatomy and guide needle placement, but safe practice requires systematic technique.

Risk-reduction measures include appropriate patient assessment, identification of contraindications, aseptic technique, visualization of the needle tip, incremental injection, aspiration according to local protocols, use of the lowest effective local-anesthetic dose, hemodynamic and neurologic monitoring, and immediate access to resuscitation equipment and lipid emulsion when clinically indicated. LAST is uncommon but potentially life-threatening; inadvertent intravascular injection and excessive dosing are important risk factors.

Phrenic nerve involvement is a particular concern with certain brachial plexus approaches. Contemporary practice therefore increasingly considers diaphragm-sparing alternatives when respiratory reserve is limited. Similarly, high-volume fascial-plane blocks require careful dose calculations because systemic absorption can contribute to toxicity.

3.5 High-definition and microultrasound

Recent ultrasound advances are intended to improve resolution and tissue characterization. Conventional probes used in regional anesthesia may not reliably distinguish fine fascicular structures in all patients. A 2025 review of high-definition ultrasound described microultrasound systems operating at frequencies above 30 MHz and reported that these technologies can reveal multiple nerve fascicles and distinct adipose compartments that may be difficult to appreciate with conventional systems.

The clinical promise of microultrasound is considerable, particularly for understanding nerve architecture and local-anesthetic distribution. However, higher frequency can reduce penetration depth, limiting utility for deeper targets. Future studies need to establish

whether improved image resolution produces measurable improvements in block success, nerve safety, analgesic duration, or patient-centered outcomes.

3.6 Artificial intelligence and machine learning

AI is one of the most rapidly developing areas in UGRA. Potential applications include automatic identification of nerves and vessels, image optimization, segmentation of anatomical structures, needle tracking, prediction of relevant landmarks, automated scanning assistance, and educational feedback.

A 2024 scoping review identified a large body of interdisciplinary AI literature but found substantial variation in accuracy metrics and limited clinical data on efficacy and safety. Another 2024 review reported promising findings for anatomical identification, correct block views, needle tracking, and reductions in certain procedural measures, while emphasizing that evidence remains early-stage. A 2025 narrative review similarly concluded that AI could reduce inter-operator variability but that data bias, narrow anatomical coverage, and limited outcome validation remain major barriers.

In 2025, an international multidisciplinary group proposed GRAITE-USRA, a consensus reporting framework intended to improve comparability and reproducibility of AI studies in ultrasound scanning for regional anesthesia. This development is important because standardized reporting will be necessary before AI systems can be compared reliably and incorporated safely into routine practice.

AI should currently be viewed as assistive rather than autonomous. The anesthesiologist remains responsible for patient selection, interpretation of clinical context, confirmation of anatomy, needle control, dosing, recognition of complications, and final decision-making.

3.7 Education and training

UGRA requires both knowledge of sonoanatomy and psychomotor skill. Simulation, standardized scanning protocols, image libraries, and AI-assisted educational systems may help trainees develop pattern-recognition and needle-handling skills.

Technology may shorten the learning curve, but it should not replace supervised clinical training.

Competency-based education should include image acquisition, identification of target and at-risk structures, needle-tip visualization, injection monitoring, complication recognition, and documentation. Assessment should focus on demonstrated competence rather than procedure counts alone.

3.8 Emerging directions

The next phase of UGRA is likely to combine advanced imaging, AI decision support, improved needles and tracking systems, continuous catheter technology, and personalized local-anesthetic strategies. Other emerging directions include remote or telementored ultrasound, robotic assistance, automated scanning, and integration of

regional anesthesia data into enhanced-recovery pathways.

Precision regional anesthesia may ultimately involve patient-specific selection of block, local-anesthetic concentration and volume, catheter strategy, and expected duration based on surgical characteristics, anatomy, comorbidity, and recovery goals. These concepts remain promising but require rigorous clinical validation.

3.9 Bibliometric Summary of Included Literature

To complement the narrative synthesis, the literature base underlying this review (n = 17 cited sources, Section 8) was summarized quantitatively by publication year and by thematic category. This descriptive summary is intended to illustrate the distribution of the evidence base rather than to provide a pooled statistical estimate of clinical effect.

Table 1. Distribution of Cited Sources by Publication Year (2020–2026, n = 17)

Publication Year	Number of Sources	Percentage of Total
2021	1	5.9%
2022	2	11.8%
2023	2	11.8%
2024	7	41.2%
2025	4	23.5%
2026	1	5.9%
Total	17	100%

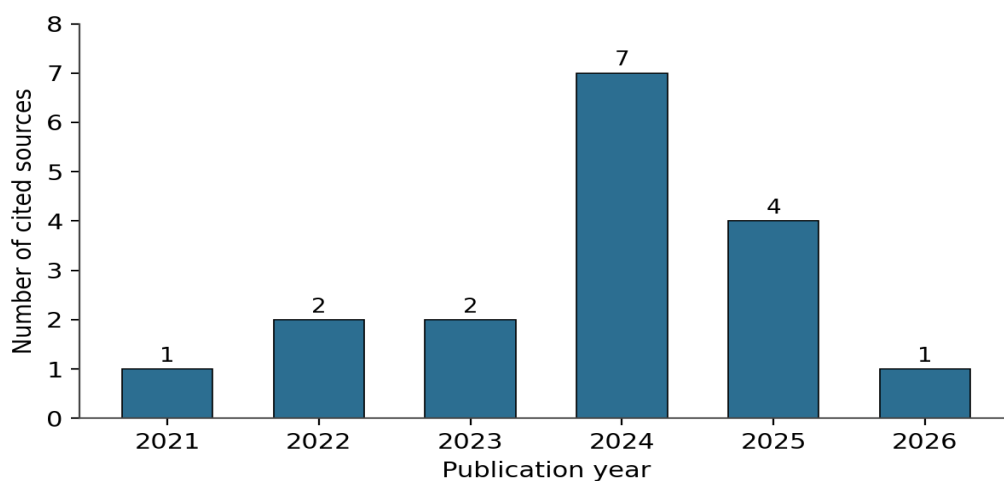


Figure 1. Histogram of Included References by Publication Year (2020–2026)

Table 2. Thematic Categorization of Reviewed Literature (n = 17)

Thematic Category	No. of Sources	Percentage	Representative Focus
Fascial-plane blocks	7	41.2%	ESP, QL, TAP, serratus anterior, pectoral, fascia iliaca, rectus sheath, transversalis fascia plane
Artificial intelligence / machine learning	7	41.2%	Image interpretation, needle tracking, scoping reviews, GRAITE-USRA reporting framework
Safety and complications	1	5.9%	LAST, nerve injury, procedural risk
Imaging technology (HD / microultrasound)	1	5.9%	Fascicular and tissue-compartment resolution
General advances in regional anesthesia	1	5.9%	Broad technique and practice update

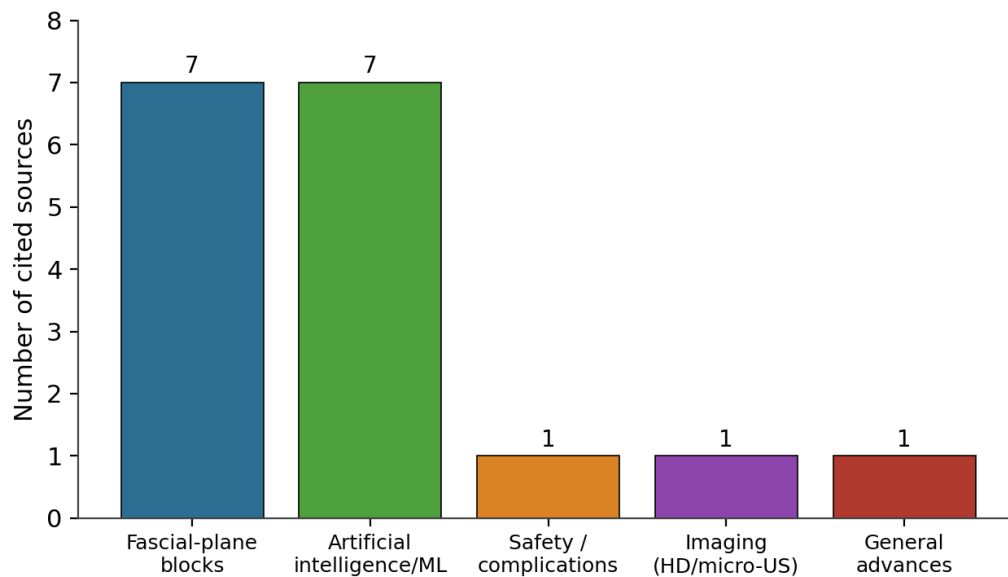


Figure 2. Bar Chart of Thematic Distribution of Reviewed Literature

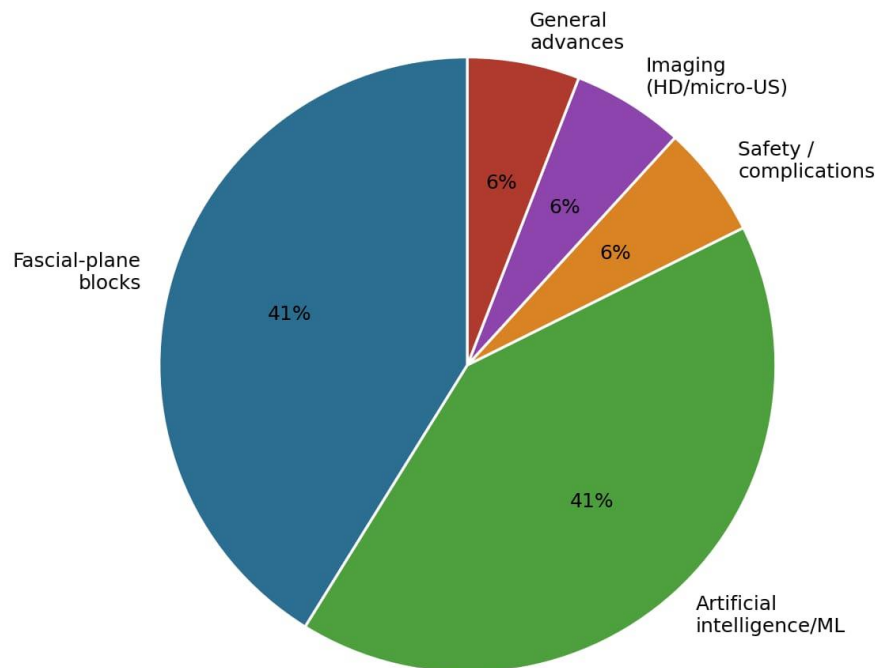


Figure 3. Pie Chart Showing Proportional Share of Reviewed Literature by Theme

Table 3. Fascial-Plane Blocks Discussed in the Reviewed Literature

Block	Anatomical Target / Plane	Reported Clinical Application
Erector spinae plane (ESP)	Paraspinal fascial plane	Thoracic, abdominal, and chronic-pain analgesia
Quadratus lumborum (QL)	Posterior abdominal wall	Abdominal and hip surgery
Transversus abdominis plane (TAP)	Anterior abdominal wall	Abdominal surgery
Serratus anterior plane	Lateral chest wall	Thoracic and breast surgery
Pectoral (PECS) blocks	Anterior chest wall	Breast surgery
Fascia iliaca	Anterior thigh / hip region	Hip and lower-limb surgery
Rectus sheath	Anterior abdominal wall (midline)	Abdominal and umbilical surgery
Transversalis fascia plane	Deep anterior abdominal wall	Abdominal surgery; opioid-sparing effect reported in systematic review/meta-analysis

Table 4. Reported Complications and Corresponding Risk-Reduction Measures in UGRA

Reported Complication	Risk-Reduction Measure
Vascular puncture	Careful sonoanatomical assessment; needle-tip visualization
Local anesthetic systemic toxicity (LAST)	Lowest effective dose; incremental injection; aspiration; immediate access to lipid emulsion and resuscitation

	equipment
Nerve injury	Continuous needle visualization; avoidance of intrafascicular injection; injection-pressure awareness
Infection	Aseptic technique
Hematoma	Vascular structure identification; careful needle trajectory
Pneumothorax	Careful probe/needle orientation for thoracic-level blocks
Unintended motor or diaphragmatic blockade	Diaphragm-sparing technique selection; awareness of local-anesthetic volume/spread

Overall, the bibliometric pattern shows a concentration of recent literature (2024–2026 accounting for 70.6% of cited sources) in two dominant themes—fascial-plane blocks and artificial intelligence—consistent with the qualitative synthesis presented in Sections 3.2 through 3.6.

4. Discussion

This review indicates that UGRA has progressed substantially during 2020–2026. The most important shift has been from simply using ultrasound to locate a nerve toward using ultrasound as a comprehensive platform for anatomical assessment, dynamic needle guidance, assessment of injectate spread, and increasingly, computational assistance.

Fascial-plane blocks have expanded the clinical reach of regional anesthesia. Their relatively accessible sonoanatomy and broad analgesic potential have encouraged adoption in thoracic, breast, abdominal, orthopedic, obstetric, and chronic-pain settings. However, enthusiasm should be balanced against evidence limitations. Some blocks remain supported predominantly by small trials, case series, or heterogeneous comparative studies. The field therefore needs procedure-specific evidence based on pain, opioid consumption, functional recovery, complications, length of stay, and patient-reported outcomes rather than technical success alone.

Safety is another area in which technological progress should be interpreted carefully. Ultrasound improves visualization, but complications can still occur. The safety benefit depends on the quality of image acquisition, interpretation, needle visualization, dosing, injection technique, monitoring, and rescue

capability. Training and standardized safety protocols remain as important as equipment.

AI is particularly promising but should not yet be considered a substitute for expertise. Recent reviews demonstrate rapid technological development, but clinical validation is less mature than technical validation. Different datasets, anatomical targets, devices, image settings, and performance metrics make direct comparison difficult. Standardized reporting frameworks such as GRAITE-USRA are therefore valuable for moving the field toward reproducible evidence.

For resource-constrained settings, including many hospitals in low- and middle-income countries, adoption must also consider equipment cost, training, maintenance, availability of trained personnel, and sustainability. High-end AI and microultrasound systems may not be immediately feasible everywhere. Basic high-quality ultrasound equipment, standardized training, appropriate monitoring, and robust safety systems may provide greater immediate value than expensive advanced platforms.

5. Limitations of the Review

This review has limitations. It is a narrative rather than systematic review and therefore does not provide a formal risk-of-bias assessment or quantitative pooled effect estimates. The literature is heterogeneous in terms of surgical populations, block techniques, local-anesthetic regimens, comparator interventions, and outcome definitions. Technology-focused evidence, particularly AI and microultrasound, is evolving rapidly and may change after the search period. These limitations should be considered when interpreting the conclusions.

6. Conclusions

Between 2020 and 2026, ultrasound-guided regional anesthesia has evolved into a broader precision-oriented field incorporating peripheral nerve blocks, fascial-plane techniques, advanced imaging, multimodal analgesia, and emerging AI assistance. Current evidence supports UGRA as an important component of opioid-sparing perioperative care, while also demonstrating that ultrasound alone does not eliminate complications. Fascial-plane blocks offer important opportunities but require stronger procedure-specific evidence. High-definition and microultrasound may improve anatomical visualization, whereas AI-assisted systems could support image interpretation, needle tracking, education, and standardization. Future research should prioritize clinically meaningful outcomes, standardized definitions, robust safety surveillance, cost-effectiveness, equitable implementation, and prospective clinical validation of emerging technologies.

7. Recommendations for Future Research

- Conduct adequately powered randomized trials comparing contemporary fascial-plane blocks with established regional and systemic analgesic strategies.
- Use standardized patient-centered outcomes, including opioid consumption, functional recovery, sleep, quality of recovery, adverse events, and patient satisfaction.
- Establish standardized definitions for block success, analgesic duration, and complications.
- Develop prospective registries for rare complications such as nerve injury and LAST.
- Evaluate microultrasound and high-definition imaging against conventional ultrasound in clinically meaningful outcomes.
- Validate AI systems across diverse populations, ultrasound platforms, operators, and anatomical targets.
- Use standardized AI reporting frameworks to improve reproducibility and facilitate regulatory and clinical evaluation.

- Study cost-effectiveness and implementation barriers in low- and middle-income healthcare systems.
- Strengthen competency-based UGRA education using simulation, supervised scanning, and objective assessment.

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