

Ultrasound-Assisted Anatomy Teaching in Preclinical and Early Clinical Medical Education: A Scoping Review of Teaching Models, Outcomes, and Implementation Gaps

Naaven Kumar Anantharao

Monash University Malaysia

Yasith Mathangasinghe

Monash University

Vidya Kushare

Monash University Malaysia

Norfarahin Abdullah Sani

Monash University Malaysia

Amudha Kadirvelu

Monash University Malaysia

Thirupathirao Vishnumukkala

IMU University

Narendra Pamidi

`pamidi.narendra@monash.edu`

Monash University Malaysia

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Abstract

Background

Ultrasound is increasingly used in undergraduate medical education to support anatomy learning by enabling real-time visualisation of living anatomy and linking preclinical knowledge with clinical examination, imaging interpretation, and procedural reasoning. However, approaches to curricular integration vary substantially, and the durability of reported educational benefits remains uncertain. This scoping review aimed to map the available evidence on ultrasound-assisted anatomy teaching for preclinical and early undergraduate medical students. Specifically, it sought to identify the teaching models used, the learner outcomes assessed, the reported educational effects, and the gaps requiring further research and curriculum development.

Methods

A scoping review was conducted according to the PRISMA Extension for Scoping Reviews (PRISMA-ScR) guidelines.

Eligibility criteria: Studies were eligible if they involved undergraduate medical students in Years 1-3 and evaluated ultrasound as a component of anatomy teaching. Peer-reviewed English-language primary studies published between 2015 and 2026 were included. Studies were excluded if they focused solely on clinical skills or procedural training without an anatomy-learning component, involved only postgraduate learners or non-medical students, or were review articles, editorials, commentaries, or other non-primary literature.

Sources of evidence: A structured search was conducted in PubMed, Ovid MEDLINE, Scopus, and Web of Science. The search combined terms related to ultrasound, anatomy, medical students, undergraduate medical education, preclinical education, and early clinical learning.

Charting methods: Data were charted using a structured extraction form. Extracted variables included author, publication year, country, study design, learner level, sample size, ultrasound teaching model, curriculum components, outcomes assessed, major findings, and reported limitations.

Results

The search identified 138 records, of which 11 studies met the inclusion criteria. Teaching models included small-group hands-on scanning, blended or flipped learning, gamified team-based activities, near-peer teaching, live ultrasound demonstrations, and simulation-linked ultrasound training. Ultrasound-assisted anatomy teaching was most consistently associated with improved learner confidence, engagement, teamwork and perceived clinical relevance. Several studies reported short-term improvements in knowledge, image interpretation, or anatomical identification; however, evidence for long-term retention, summative examination improvement, and transfer to later clinical performance was limited and inconsistent. Common limitations included single-institution designs, small or self-selected samples, heterogeneous outcome measures, reliance on self-reported outcomes, and limited follow-up.

Conclusions

Ultrasound-assisted anatomy teaching appears to be a feasible and valuable adjunct to preclinical medical education, particularly when delivered through structured, hands-on, small-group, blended, gamified, or near-peer models. Current evidence mainly supports short-term improvements in engagement, confidence, and applied anatomical understanding. Future research should use standardised outcome measures, longitudinal follow-up, competency-based assessment, and multi-institutional designs to determine how ultrasound can be integrated sustainably into undergraduate anatomy curricula.

BACKGROUND

Ultrasound is increasingly used in undergraduate medical education because it allows students to visualise living anatomy in real time and connect anatomical structures with clinical examination, physiology, imaging interpretation, and procedural reasoning.^{1,2,3} Unlike donor dissection, prosection, models, or static imaging, ultrasound introduces learners to dynamic anatomy, including movement, vascular flow, organ relationships, and surface-to-deep anatomical correlation.² These features make ultrasound particularly attractive in preclinical anatomy education, where students are expected to build foundational anatomical knowledge while beginning to understand its clinical relevance. Beyond the acquisition of foundational knowledge, early preclinical exposure to ultrasound education may enhance acute clinical decision-making, patient health awareness, and professional engagement.^{4,5}

The use of ultrasound in medical education has expanded alongside the growing availability of portable and hand-held devices, repeatability, lower cost, multiplanar capability, and lack of ionising radiation.^{6,7,8} In undergraduate curricula, ultrasound has been used to support gross anatomy, surface anatomy, cardiovascular physiology, musculoskeletal anatomy, neuroanatomy, physical examination, and early clinical

skills.² It has also been delivered through diverse educational formats, including live demonstrations, small-group hands-on scanning, flipped classroom models, near-peer teaching, team-based learning, gamified sessions, and simulation-linked teaching. This diversity reflects the flexibility of ultrasound as an educational tool, but it also creates difficulty in determining which models are most appropriate for anatomy learning in the early years of medical training.^{9, 10, 11}

Existing reviews have already examined the broader use of ultrasound in undergraduate medical education and anatomy teaching. Kenny et al. conducted a systematic review with narrative synthesis on the use of ultrasound in undergraduate medical anatomy education, highlighting the expanding role of ultrasound as an anatomy-learning tool.² Other reviews have also addressed undergraduate ultrasound education more broadly, including point-of-care ultrasound and clinical ultrasound training across medical curricula. More recent syntheses have continued to show that ultrasound anatomy teaching is delivered through diverse formats, but that evidence for anatomical knowledge and skills outcomes remains variable and long-term assessment is underrepresented.³

As ultrasound competency is highly operator-dependent and requires continuous, deliberate practice, an effective integrated curriculum should be evidence-based, grounded in educational theory, and aligned with learner-level and institutional goals.^{12,13} This is particularly important if the focus is skills acquisition for later clinical practice, particularly for point-of-care ultrasound (POCUS).¹⁴ These integration strategies involve embedding of ultrasound within clinical skills courses, including block system-based models, e-learning, and hands-on practice, which can be associated with improved physical examination confidence and procedural efficiency.^{14,15,17} Early integrated ultrasound imaging education among preclinical-year medical students appears to strengthen anatomical understanding and to bridge preclinical knowledge with patient care.^{16,18,19} However, the evidence does not provide clear guidance on how to best incorporate ultrasound in preclinical and early clinical curricula focusing on anatomy education.

Although many ultrasound-based educational interventions claim to enhance anatomy learning, the literature is difficult to translate into curriculum design. Interventions vary widely in the anatomical content addressed, teaching format, degree of hands-on scanning, facilitator expertise, outcome measures, and timing of assessment.^{20,21,22} In addition, reported outcomes are often heterogeneous: some studies assess short-term knowledge gains, others measure confidence or satisfaction, and others rely on broader course examinations that may not specifically evaluate ultrasound-mediated anatomical reasoning.^{23,24,25} As a result, it remains unclear which components of ultrasound teaching contribute most directly to anatomy learning. This uncertainty is compounded by persistent implementation barriers, including equipment cost and availability, limited curricular time, shortages of trained instructors, tutor time constraints, and broader institutional resource limitations.^{26,27} Together, these issues limit the guidance available to curriculum designers regarding what ultrasound should teach, when it should be introduced, how learning should be reinforced, and how ultrasound should be integrated with anatomy education rather than treated solely as a longitudinal scanning and image-interpretation skill.

Here, we aimed to assess how ultrasound-assisted anatomy teaching interventions for preclinical and early-clinical medical students have been designed, delivered, assessed, and implemented, and what gaps remain in the evidence base? The specific objectives were to: (1) synthesise reported learning outcomes associated with ultrasound-assisted anatomy teaching; (2) characterise the pedagogical models used to integrate ultrasound into early medical education; (3) examine the assessment strategies used to evaluate anatomy learning; and (4) identify gaps in the evidence relevant to curriculum design, implementation, and future research.

METHODS

Design

This study was conducted as a scoping review to map the available primary evidence on ultrasound-assisted anatomy teaching in preclinical and early-clinical medical education. A scoping review design was selected because the aim was to clarify how ultrasound anatomy teaching has been designed, delivered, assessed, and integrated, rather than to estimate a pooled intervention effect. The review was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews, PRISMA-ScR, where applicable. PRISMA-ScR recommends that scoping reviews identify themselves as such and provide structured reporting of background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions.

Protocol and registration

Protocol and registration

The review protocol was registered with the Open Science Framework (OSF; DOI: 10.17605/OSF.IO/JV5GH) to provide a transparent record of the review methodology.

Eligibility criteria

Studies were included if they met the following criteria: (1) involved undergraduate medical students in Years 1–3 or an equivalent preclinical or early undergraduate phase; (2) evaluated ultrasound as part of anatomy teaching, living anatomy instruction, or anatomy-linked image interpretation; (3) reported primary data; (4) described how ultrasound was integrated into the curriculum as opposed to being delivered as a standalone activity; and (5) were published in English between 2015 and 2026. Eligible study designs included randomised educational studies, non-randomised studies, cohort studies, crossover studies, quasi-experimental studies, mixed-methods studies, pre-post intervention studies, and descriptive educational studies.

Studies were excluded if they focused solely on clinical skills, procedural training, or point-of-care ultrasound without a clear anatomy-learning component; involved only postgraduate learners, residents, clinicians, allied health students, or non-medical students; were not peer-reviewed; or were review articles, editorials, commentaries, opinion pieces, conference abstracts without full text, or other non-primary literature.

Information sources

A structured search was conducted in PubMed, Ovid MEDLINE, Scopus, and Web of Science. The final search was conducted on 01/02/2026. Reference lists of relevant included studies and existing reviews were also screened where appropriate.

Search Strategy

Search terms combined concepts related to ultrasound, anatomy, undergraduate medical education, and preclinical learning. The core search string was: “ultrasound” AND “anatomy” AND (“medical students” OR “undergraduate medical education”) AND (“early clinical years” OR “preclinical”). The Boolean operators and database-specific syntax were used to adapt the search for each database. Searches were limited to English-language peer-reviewed publications from 2015 to 2026.

Selection of sources of evidence

Retrieved records were exported, and duplicates were removed. Titles and abstracts were screened against the eligibility criteria, followed by full-text assessment of potentially eligible reports. Reasons for exclusion at the full-text stage were recorded and summarised in the flow diagram. Titles, abstracts, and full texts were screened by one reviewer and checked by a second reviewer for consistency.

Data Extraction

Data were charted using a structured extraction form developed for this review. Detailed data were extracted from the selected studies, including author, publication year, geographical location, study design, participants' level of medical training, ultrasound curriculum components and teaching modalities, assessment outcomes, major findings, curriculum integration and reported limitations. Curriculum integration data were extracted to characterise how ultrasound was incorporated within medical education, including timing of implementation within the curriculum, relationship with concurrent anatomy or organ-system teaching, longitudinal versus single-session delivery, reinforcement activities, and integration with clinical skills or clerkship training where reported.

Data items and conceptual categories

Data items were organised according to the review objectives. Teaching models were grouped into experiential or hands-on learning, blended or flipped learning, gamified or team-based learning, near-peer or peer-assisted teaching, live demonstration, and simulation-linked teaching. Outcomes were grouped into cognitive outcomes, psychomotor outcomes, affective outcomes, and retention or transfer outcomes. Assessment alignment was considered by comparing the stated anatomy-learning purpose of each intervention with the outcome measures used. Curriculum integration varied across studies, with some programmes adopting longitudinal ultrasound exposure across preclinical years, while others incorporated ultrasound as short, focused sessions embedded within anatomy modules. Implementation approaches included concurrent teaching alongside regional or organ-system anatomy, reinforcement of anatomical concepts through living anatomy demonstrations, and hybrid models combining asynchronous preparation with supervised hands-on scanning. However, the extent of integration with physiology, clinical skills teaching, and subsequent clerkship training was inconsistently reported across studies.

Critical appraisal of individual sources of evidence

Formal risk-of-bias appraisal was not undertaken because the purpose of this scoping review was to map the extent, characteristics, and gaps of the available evidence rather than to determine the certainty of intervention effectiveness. However, methodological limitations reported by the included studies were charted and considered when interpreting the evidence.

Synthesis of results

Quantitative pooling was not performed because the included studies differed substantially in learner level, teaching model, intervention duration, anatomy content, assessment method, and follow-up timing. Findings were synthesised narratively and mapped thematically according to the teaching model, outcome domain, assessment alignment, feasibility considerations, and evidence gaps.

RESULTS

Selection of sources of evidence

Figure 1 illustrates the process of selection of sources of evidence. The database search identified 138 records: PubMed (n = 26), Ovid MEDLINE (n = 18), Scopus (n = 28), and Web of Science (n = 66). After the removal of 8 duplicates, 130 records were screened by title and abstract. Ninety-seven records were excluded at this stage. Thirty-three reports were sought for retrieval and assessed for eligibility by full-text review. Twenty-two reports were excluded because they did not meet the eligibility criteria, most commonly because they lacked a clear anatomy-teaching focus, involved learners outside the preclinical undergraduate medical population, or were not primary educational studies. Eleven studies were included in the final scoping review.

Characteristics of included sources of evidence

The 11 included studies were published between 2015 and 2025 and were conducted in the United States, Taiwan, the United Kingdom, and Italy. Study designs included randomised educational studies, prospective and retrospective cohort studies, quasi-experimental comparative studies, crossover educational interventions, mixed-methods evaluations, pre-post intervention studies, and descriptive educational studies. Participants were undergraduate medical students in Years 1-3, with sample sizes ranging from 18 to 360. The studies evaluated a range of ultrasound-assisted anatomy teaching approaches, including short workshops, longitudinal blended curricula, gamified team-based activities, near-peer instruction, live demonstrations, and simulation-linked ultrasound training. The extracted data from these studies were analysed and grouped into 4 main domains: ultrasound teaching models, outcomes and assessment alignment, synthesised pattern findings, and limitations across studies.

Table 1 List of study characteristics

Author (Year)	Country	Learner Level (sample size, n)	Study Design	Ultrasound Teaching Method	Outcomes Measured	Major Findings	Limitations
Haidar et al (2022) ¹⁸	USA	1st year medical students n = 178	Retrospective cohort study	A longitudinal blended curriculum integrating small-group, hands-on ultrasound training with organ-system blocks, supported by asynchronous videos	Secondary analysis of academic records, including preclinical anatomy scores, block exam results, clerkship shelf exams (internal medicine, surgery, neurology), and USMLE Step 1 scores.	- Significantly improved cardiovascular anatomy scores - No significant effect on cumulative cardiovascular, gastrointestinal, neurology exams, clerkship shelves, or USMLE Step 1	- Single institution study - Potential volunteer selection bias - Limited sample size - Unequal instructional time between groups - Ultrasound exposure limited to first year - Limited generalizability
Shah et al (2020) ²⁸	USA	1st year medical students n = 360	Quasi-experimental comparative study	Short, small-group, station-based ultrasound workshop combining hands-on training with brief didactic teaching	Secondary analysis of institutional records, including neurologic unit totals, anatomy practical scores, and final written exam scores	Ultrasound workshop participation was not significantly associated with improvements in neurologic unit totals, anatomy practical scores, or final written exam scores	- Voluntary participation with potential selection bias - Single institution study - Curricular timing differences across cohorts - Small intervention group - Limited statistical power - High baseline academic performance limits detectable differences
Russell et al (2022) ²⁹	USA	2nd year medical students n = 132	Prospective cohort study	Blended learning combining asynchronous videos, one-on-one hands-on training, case-based simulation, and small-group clinical integration	- Pre- and post-workshop knowledge and confidence assessments - Instructor-rated image acquisition quality - Group performance in a standardised simulated clinical case	- Significant improvement in identifying pericardial effusion on ultrasound - Successfully obtained parasternal long axis views and diagnosed cardiac tamponade in simulation after brief training	- Group-based simulation limited individual performance assessment - Short instructional duration - Incomplete pre/post survey participation - Simulator performance

							exposure among participants may have confounded results - Lack of long-term retention assessment
Chen et al (2022) ¹⁹	Taiwan	3rd year medical students <i>n</i> = 140	Crossover educational intervention study	Experiential “learning by doing” model using parallel ultrasound instruction with brief didactics and checklist-guided, small-group hands-on workshops supported by real-time tutor feedback	- Targeted anatomy scores from midterm and final written exams and cadaver lab tests - Post-course self-efficacy survey across cognitive, affective, and psychomotor domains	- Pre-midterm course students scored significantly higher on written anatomy for target structures - No significant differences in cadaver lab or final exam scores - Overall self-efficacy improved, with the greatest gains in the cognitive domain	- Voluntary participation with potential self-selection bias - Cadaveric laboratory assessments not fully aligned with ultrasound content - Inability to isolate effects of additional lectures versus ultrasound training - Ultrasound competency not directly assessed - Findings may not generalise beyond motivated learners
Danila et al (2024) ³³	USA	1st year medical students <i>n</i> = 54	Pre-post educational intervention study	Flipped, team-based learning model with self-directed pre-work, independent and group readiness assurance testing, near-peer small-group cardiac POCUS practice, and application-based learning with immediate feedback	- Pre- and post-session multiple-choice knowledge tests - Pre- and post-session Likert-scale surveys on confidence, attitudes, and perceptions - Comparison of cardiovascular physiology final exam scores between participants and non-participants, stratified by prior performance	- Post-session knowledge scores were significantly higher - Team-based learning ultrasound participants outperformed non-participants on the cardiovascular physiology final exam across performance levels - Confidence, perceived importance of POCUS, teamwork, and communication significantly improved	- Voluntary participation with selection bias - Single-institution study - Limited ultrasound equipment leading to a suboptimal facilitator-to-student ratio - Short-term outcome assessment - Inability to isolate the individual contributions of team-based learning versus ultrasound components
Patten et al	UK	1st & 2nd	Mixed-methods	Experiential, active learning	- Post-module Likert-scale	- High student satisfaction with	- No objective pre-/post-

(2014) ³⁴		year medical students	case study	using living anatomy demonstrations and small-group ultrasound focused on visualisation, clinical context, and guided sonoanatomy interpretation rather than scanning skill	student evaluations - Qualitative data from tutor interviews, student focus groups, curriculum documents, and structured observations - Non-parametric analysis using Mann-Whitney U tests	improved anatomical understanding and surface anatomy confidence - Ultrasound reinforced anatomy, but had limited impact on cross-sectional interpretation; smaller groups and peer scanning enhanced learning - Tutor expertise and training significantly shaped student experience	testing of anatomy or ultrasound skills - Reliance on self-reported perceptions - Unequal qualitative sampling between institutions - Limited assessment of long-term knowledge retention or clinical transfer
		<i>n</i> = 167					
DesJardin et al (2017) ³⁵	USA	1st year medical students	Prospective cohort study	Near-peer experiential model in which trained second-year students delivered small-group, hands-on ultrasound aligned with anatomy and physiology blocks, supported by independent study and supervised clinical scanning	- Pre- and post-intervention 14-item MCQ on anatomy, physiology, and pathology - Pre- and post-intervention Likert-scale perception and self-reported skill surveys - Post-intervention comparison with control group	- Both groups improved significantly in knowledge scores - POCUS group showed greater, but not statistically significant, improvement - POCUS participants reported higher confidence in teaching ultrasound, greater appreciation of its clinical value, and perceived benefits for anatomy learning	- Small sample size - Incomplete post-assessment response rates (especially among controls) - Short-term outcome assessment - Reliance on self-reported skill measures - Limited statistical power to detect between-group differences
		<i>n</i> = 18					
Paganini & Rubini (2016) ³⁶	Italy	2nd year medical students	Descriptive educational intervention study	Didactic-experiential visualization model using a large-group lecture with live ultrasound on a volunteer to demonstrate cardiovascular anatomy, physiology, and reflexes, co-taught by a physiologist and sonographer	- Anonymous post-lecture survey with 7 positive and 3 negative Likert items (5-point scale) and two open-ended questions - Internal consistency measured with Cronbach's alpha (α = 0.72)	- Very high acceptance: 99% found the lecture interesting - 95% reported improved understanding of anatomy and physiology - 100% would recommend the session - In vivo visualisation of physiology and reflexes was highly valued	- No control or comparison group - Reliance on self-reported perceptions only - No objective assessment of knowledge gain or retention - Single institution implementation - Short-term evaluation only
		<i>n</i> = 111					

Ultrasound teaching models

The included studies, as shown in Table 1, used diverse teaching models, but most could be grouped into four domains.

First, experiential or hands-on learning was the most common approach. These interventions typically used small-group scanning, structured stations, checklists, and real-time tutor feedback.^{29,30} The educational purpose was to help students visualise living anatomy, connect probe movement with anatomical planes, and identify structures dynamically rather than relying solely on static cadaveric or textbook representations.

Second, several studies used blended or flipped learning. In these models, students completed preparatory materials, such as asynchronous videos or brief didactic content, before attending in-person ultrasound sessions.^{29,19} This structure was intended to reduce cognitive load during hands-on teaching and preserve face-to-face time for scanning, anatomical identification, and clinical correlation.

Third, gamified and team-based models incorporated competition, station-based tasks, group problem-solving, and integration of anatomy with physiology, radiology, or physical examination.³⁰ These approaches appeared particularly suited to increasing student engagement and teamwork, although their effect on durable anatomy knowledge was less clear.

Fourth, near-peer and peer-assisted models used trained senior students as facilitators. These models were reported as feasible and, in some studies, produced outcomes comparable to faculty-led teaching.³¹ This suggests that near-peer teaching may support scalability, particularly where faculty time and ultrasound expertise are limited. However, these models require structured tutor training, competency checks, and faculty oversight.

Outcomes and assessment alignment

The included studies assessed cognitive, psychomotor, affective, and retention-related outcomes. Cognitive outcomes were commonly assessed using pre- and post-session multiple-choice questions, anatomy practical scores, written examination results, or organ-system block assessments.¹⁸ Several studies reported immediate improvements after ultrasound teaching, especially when teaching involved structured hands-on scanning, flipped preparation, or gamified tasks.^{18,30,33} However, improvements were less consistent when assessed using broader summative examinations or course-level outcomes.

Psychomotor and applied anatomy outcomes included image acquisition, anatomical identification, recognition of sonographic anatomy, and ability to obtain diagnostically useful views. These outcomes were more directly aligned with the intended learning goals of ultrasound-assisted anatomy teaching, particularly when the intervention aimed to develop living anatomy understanding or basic scanning familiarity.²⁹ However, not all studies assessed individual scanning competence directly.

Affective outcomes, including confidence, self-efficacy, engagement, perceived clinical relevance, satisfaction, and teamwork, were among the most consistently positive findings.¹⁹ These outcomes support the value of ultrasound as a motivating and clinically contextualising tool, but they do not by themselves establish durable anatomy learning.

Assessment alignment varied across studies. Some interventions aimed to improve anatomy understanding but assessed mainly satisfaction or self-confidence.^{29,30} Others used broad course examinations that may not have captured the specific skills promoted by ultrasound, such as spatial reasoning, probe-image orientation, dynamic anatomical interpretation, or applied living anatomy. Few studies used assessments that directly measured the full pathway from ultrasound exposure to anatomy learning, image interpretation, retention, and later clinical transfer.³³

Synthesised Pattern Findings

Across the ultrasound teaching modalities and the analysed measured outcomes, four consistent patterns were synthesised. First, short-term knowledge gains were improved, particularly following experiential learning and a gamified approach. Immediate post-test scores improved significantly in active learning sessions, including competitive team-based models and structured hands-on workshops with pre-learning materials.³³ These findings indicate that ultrasound-assisted teaching enhances immediate knowledge acquisition. Second, long-term knowledge retention on summative examinations was inconsistent, as some studies used delayed post-tests or final examination comparisons; there were no observable differences in teaching modalities.³⁰ Furthermore, the integration of ultrasound workshops did not correlate with improved performance on anatomy practical or written final examinations.²⁸ Third, there is consistent improvement in confidence, engagement, and teamwork. This suggests strong motivational and experiential benefits among preclinical medical students through ultrasound-assisted teaching despite written assessments.²⁹ Finally, near-peer teaching models demonstrated similar effectiveness to faculty-led approaches, with no significant differences in ultrasound teaching outcomes.³¹ These patterns are crucial to consider when forming an effective integrated ultrasound-based anatomy teaching framework.

Limitations Across Studies

Across studies, several methodological limitations were recurrent. Some studies had small sample sizes, which limited statistical power and reduced the generalisability of the results.^{30,35} Furthermore, single-institution study designs restrict external validity, as diverse teaching curricular modalities across institutions.¹⁹ Voluntary participation across the studies introduced selection bias, while reliance on self-reported confidence and self-efficacy measures led to detection bias.^{26,32} Moreover, there was limited long-term follow-up on students' progression beyond short, delayed tests.³⁶ Apart from this, the limited number of instructors and differences in instructors' competencies may cause non-standardised teaching and burnout in faculty-intensive models.²⁸ Additionally, variability in curriculum integration represented an important limitation across studies. Although ultrasound was incorporated through diverse approaches, including standalone workshops, organ-system-based teaching, longitudinal curricula, and blended learning models, reporting of implementation details was inconsistent.^{15,18,19}

DISCUSSION

Interpretation of Educational Impact

Based on the thematic analysis, short-term knowledge scores, hands-on performance, image acquisition quality, and learner confidence have consistently demonstrated improvement following the ultrasound-based teaching modalities.¹⁵ These patterns most likely reflect the high instructional intensity incorporated with active psychomotor engagement, real-time visual feedback, immediate tutor feedback, and contextual integration with anatomy. These features align with active learning principles, in which tutor-centred learning shifted to a student-centred approach. In contrast, evidence for sustained long-term retention on summative examinations and year-end anatomy practicals remains inconsistent. One of the possible explanations is misalignment between teaching modalities and assessment. Ultrasound experiential learning often targets anatomical interpretation and reasoning based on image acquisition, while summative examinations may heavily rely on theoretical knowledge. Moreover, curricular crowding may reduce learning efficiency, as new ultrasound content may not be systematically introduced alongside parallel anatomy modules. In addition, when ultrasound teaching modalities are implemented as an isolated module, medical students may struggle to integrate them into a broader knowledge spectrum.

Apart from that, the consistent success of hands-on ultrasound teaching models strongly aligns with experiential learning theory as the students engage in concrete experience when scanning living anatomy using ultrasound, have reflective observation when reviewing images, have an abstract conceptualisation when linking the images to anatomy, and are able to initiate active experimentation through re-attempting ultrasound probe positioning.¹³ As for cognitive load considerations, ultrasound teaching modalities may pose a high risk due to knobology, complex spatial orientation and hand-eye coordination demands. However, instructional strategies such as small-group teaching and guided checklists may help manage these cognitive demands by providing structured scaffolding, directing learner attention towards essential tasks, and enabling repeated supervised practice.^{15,34} This also provides students with an opportunity to optimise their learning through repeated scanning. Ultrasound also enables students to integrate anatomy with clinical reasoning and observe physiological motion in real time, rather than memorising static diagrams, which indicates an advantage of contextual learning.

Pedagogical Implications

As for the pedagogical implications of a structured ultrasound-integrated teaching model, as shown in Fig. 2, near-peer teaching demonstrates educational outcomes comparable to faculty-led instruction, including anatomical identification accuracy, ultrasound performance, and learner confidence, without significant differences in overall teaching effectiveness.^{30,31} This finding has major implications, as this approach can reduce reliance on limited physician or faculty tutors, enhance scalability, promote dynamic leadership development among senior students, and, most importantly, overcome increasing faculty workload and burnout.²⁶ Furthermore, flipped and blended models can be implemented alongside asynchronous learning platforms, including pre-workshop learning materials and lectures, to preserve in-person time for high-yield skill practice during on-site active learning sessions. This approach can reduce in-session cognition overload, improve procedural repetition, and utilise faculty resources efficiently. Moreover, gamification and team-based models enhance learners' attention and engagement, especially when completing assigned tasks at each game station. This strategy should be considered a motivation for students' imaging education rather than a strategy for knowledge retention. Last but not least, as studies suggest, short workshops are effective for short-term memory retention but not for long-term benefits; a longitudinal, vertically integrated ultrasound curriculum could be a better option. Continuous integration enables assessment of students' recall memory from previous sessions, reinforces their learning through spaced repetition, and improves their ability to sustain long-term knowledge retention.

Resource & Feasibility Considerations

On the other hand, resource and feasibility considerations pose implementation barriers to these integrated ultrasound teaching modalities. Although portable ultrasound devices are increasingly affordable, this teaching strategy requires multiple machines, appropriate

maintenance and storage, and access to technical support. Effective learning sessions often require 3 to 5 students per machine in a small group, increasing logistical complexity.²⁶ Moreover, near-peer and facilitator effectiveness should be assessed in structured training and competency to prevent any deviation from required ultrasound knowledge.

Implications for Curriculum Design

Based on the available evidence, a proposed curriculum model would incorporate early preclinical exposure to ultrasound integrated into organ-system anatomy teaching, followed by longitudinal reinforcement during a subsequent hybrid approach comprising asynchronous preparatory learning, near-peer-facilitated small-group scanning, simulation-based deliberate practice, and clinical case contextualisation, which appears educationally promising. However, insufficient comparative evidence exists to recommend the optimal timing, frequency, or spacing of ultrasound teaching sessions, highlighting an important area for future curriculum research.¹⁵

Research Gaps & Future Directions

The current literature demonstrates methodological heterogeneity, indicating priority areas for research gaps and future research directions. Since most studies are single-centre institution-based, multi-institution randomised controlled trials need to be initiated to produce reliable generalisable outcomes, taking into account standardised outcome measures, including knowledge requirements and image acquisition quality. Furthermore, long-term retention studies should consider follow-up beyond immediate post-workshop tests by assessing clinical performance endpoints on clerkship evaluations, diagnostic accuracy, and real patient outcomes in clinical-year studies. Moreover, a structured objective competency framework should be developed to determine the 'must know' and 'good to know' competencies, based on organ system blocks and years of medical training, to provide baseline guidance for medical students. And not to forget, with the booming of the artificial intelligence (AI) era, emerging AI-assisted ultrasound education may provide automated image quality feedback, reduce tutor burden, and standardise performance assessment.

Strengths and limitations of this review

This review has several strengths. It searched multiple major databases, used predefined eligibility criteria, charted study characteristics systematically, and focused specifically on anatomy-related ultrasound teaching in preclinical medical education. It also adds to existing reviews by emphasising curriculum design, assessment alignment, and implementation gaps rather than only summarising whether ultrasound improved learner outcomes.

Several limitations should also be acknowledged. First, only English-language peer-reviewed studies were included, which may have excluded relevant studies in other languages or grey literature. Second, no formal risk-of-bias appraisal or certainty-of-evidence grading was performed, consistent with the mapping purpose of a scoping review. Third, the included studies were heterogeneous in design, learner level, teaching model, anatomy content, assessment method, and follow-up duration. Fourth, because most included studies were small, single-institution interventions, the findings should be interpreted as a map of available evidence rather than definitive evidence of effectiveness. Finally, existing reviews were used to contextualise the rationale but were not included as primary sources of evidence.

CONCLUSION

Ultrasound-assisted anatomy teaching plays a major role in enhancing preclinical medical students' knowledge and clinical correlation through contextualised clinical cases. This scoping review demonstrated that undergraduate ultrasound education consistently improves short-term knowledge acquisition with experiential, small-group and hands-on models. Both faculty-led and near-peer-led facilitation, as well as blended and flipped learning models, improve time efficiency and educational effectiveness without compromising outcomes. However, the evidence for long-term knowledge retention remains limited and inconsistent. Isolated workshops show less sustained impact compared to longitudinal curricula.

Therefore, longitudinal, vertically integrated, and repeated-exposure models offer greater opportunities for long-term competency development. Beyond cognitive gains, ultrasound teaching enhances affective outcomes more positively and makes education more meaningful. Overall, a multimodal, structured curriculum design is recommended for optimal implementation, with room for improvement in future research that focuses on standardised outcome measures, long-term retention, and clinical performance outcomes to guide sustainable implementation and curricular optimisation.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Data availability

The dataset supporting the conclusions of this article is included within the article.

Competing interest

The authors declare no competing interests.

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Author contributions

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Author details

¹Jeffrey Cheah School of Medicine & Health Sciences, Monash University Malaysia, Selangor, Malaysia

²Centre for Human Anatomy Education, Department of Anatomy and Developmental Biology, Faculty of Medicine, Nursing and Health Sciences, Monash University, Clayton, Australia

³School of Medicine, IMU University, Federal Territory of Kuala Lumpur, Malaysia

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Figures

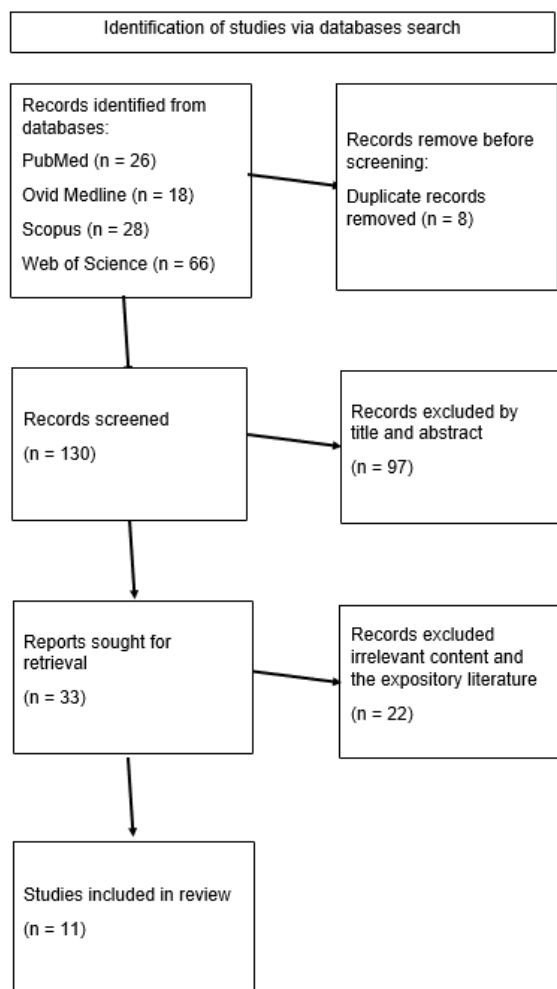


Figure 1

PRISMA flowchart showing the selection of studies

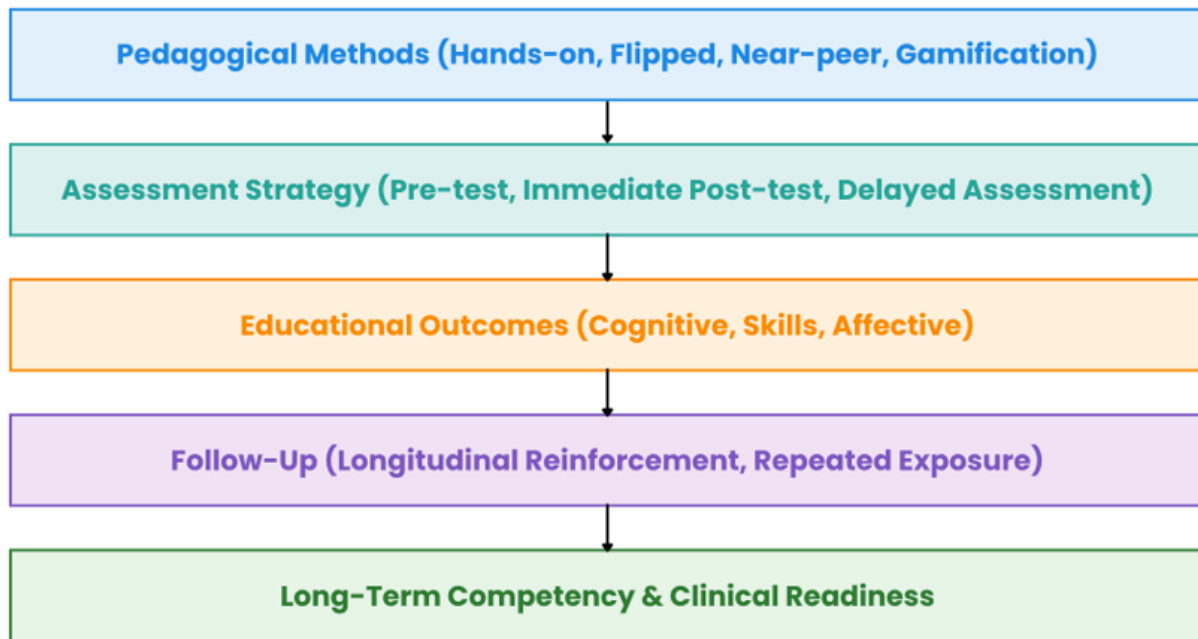


Figure 2

Teaching Modalities for Ultrasound-assisted Undergraduate Anatomy Learning