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Variant Anatomy Literacy as a Patient-Safety Competency in Surgical Training: A Title-Informed Conceptual Review and Competency Framework

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ABSTRACT

Surgical safety depends on recognition of patient-specific anatomy when encountered structures depart from population norms. Knowledge of anatomical variations is often treated as supplemental rather than as a safety-relevant necessity. This article aims to translate a title-informed map of literature on anatomical variation, surgical education, and patient safety into a practical competency framework for surgical training. A targeted, title-informed conceptual review was conducted in March 2026. PubMed was searched using anatomical-variation terms combined with surgery, education, patient safety, curriculum, assessment, simulation, reporting, and competency terms. PubMed Central, publisher pages, DOI landing pages, and cross-indexed scholarly sources were used for retrieval and verification. Titles and formal source descriptions were screened for signals linking anatomical variation with clinical risk, surgical error, curriculum, assessment, terminology, reporting, visualization, simulation, patient safety, or competency-based education. This method was designed for conceptual synthesis rather than prevalence estimation, effect-size analysis, or a complete evidence map. Six recurrent framings were identified: anatomical variation as a clinical hazard, curriculum and assessment gap, terminology and reporting problem, visualization and simulation challenge, team-communication and systems issue, and competency-based training target. These framings support defining variant anatomy literacy as the capability to anticipate, identify, interpret, adapt to, communicate, document and learn from clinically consequential anatomical variation before, during and after operative care. Surgical curricula should move beyond recall of rare variants and assess observable safety behavior under anatomical uncertainty. Practical implementation can integrate patient-specific imaging, donor contrast, simulation, operative observation, briefing and debriefing, operative-note audit, and morbidity-and-mortality learning.

Abbreviations: ACGME, Accreditation Council for Graduate Medical Education; AVQAT, Anatomical Variation Quality Assessment Tool; CBME, Competency-based Medical Education; CT, Computed Tomography; DOI, Digital Object Identifier; LLM, Large Language Model; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; PRISMA-ScR, Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews; WHO, World Health Organization.

1 | Background

Surgery is taught through the promise of anatomical order: planes can be developed, ducts can be identified, nerves can be preserved, and vessels can be controlled when the surgeon knows what to expect. Patient safety is challenged when that expectation becomes unreliable. Anatomical variation refers to a naturally occurring difference in morphology, number, topography, course, branching pattern, or spatial relationship of anatomical structures that remains compatible with normal function but differs from the most commonly taught or expected pattern. A normal configuration may become clinically consequential when a procedure depends on precise identification, safe exposure, or preservation of a structure (Alraddadi 2021; Kachlik et al. 2020; Kimmorley et al. 2024).

A surgeon who continues to search for the expected structure, or who interprets an unexpected structure as expendable, can cause irreparable damage to a patient. This is not simply a deficit in factual knowledge; it is a safety problem in perception, intraoperative decision-making, team communication, escalation, and documentation. Knowledge of anatomical variations should, therefore, not be treated as supplemental after mastery of the "real" anatomy. It must be at the forefront of surgical reasoning during any surgical procedure or exposure.

The modern patient-safety movement has emphasized standard operating procedures, checklists, reporting systems, quality improvement, and team communication. The World Health Organization safe-surgery program positioned surgical safety as a teachable systems domain, and the surgical safety checklist trial showed the value of structured team communication in reducing postoperative complications and mortality (Haynes et al. 2009; World Health Organization 2026a, 2026b). Preoperative checklist and briefing research has also shown that structured interprofessional briefings can reduce operating-room communication failures (Lingard et al. 2008). Yet a checklist does not, by itself, ensure that the team has anticipated, for instance, an aberrant cystic artery, a non-recurrent laryngeal nerve, a replaced hepatic artery, a variant venous confluence, or an altered abdominal wall plane.

Anatomy education has faced sustained pressure from reduced curricular time, compressed courses, and disparate access to donor learning. Turney (2007) argued that anatomy remains central to modern clinical practice. Sugand et al. (2010) reviewed the need to modernize anatomy education, and Estai and Bunt (2016) emphasized clinically integrated, active, and multimodal anatomy teaching. These debates matter for surgery because the operating room tests anatomical knowledge under time pressure, uncertainty, and irreversible technical consequences.

A growing plethora of education literature asks not only whether anatomical variation exists but how it should be taught, assessed, described, and translated into clinical behavior. Raikos and Smith (2015) examined how surgical and radiology programs teach and assess anatomical variation. Nzenwa et al. (2023) reviewed its inclusion in medical education. Kimmorley et al. (2024) framed anatomical variation as the norm within a curriculum framework, and Vieno-Corbett et al. (2025) mapped teaching approaches and learning objectives in gross anatomy courses. In parallel, Kachlik et al. (2020), Wysiadecki et al. (2024), and Kunc et al. (2026) treated terminology, reporting standards, and quality assessment as central problems in anatomical variation research.

The clinical stakes are explicit in surgical literature. Kowalczyk and Majewski (2021) reviewed surgical errors associated with anatomical variations relevant to general surgery. Safe-cholecystectomy guidance emphasizes anatomic identification and avoidance of misidentification before irreversible action (Brunt et al. 2020). Recurrent laryngeal nerve variants in thyroid surgery illustrate how a structure that must be protected may not follow the expected route (Chiang et al. 2010). Competency-based medical education provides the educational logic for responding to this problem: competence should be developmental, contextual, observable, and linked to patient outcomes (Frank et al. 2010).

This article advances a practical thesis: variant anatomy literacy should be formalized as a patient-safety competency in surgical training. The term literacy is used deliberately. It does not mean rote recall of isolated variants. It means the ability to read anatomical uncertainty in context, use available evidence and imaging, adapt safely, communicate risk, correctly document the variant, and learn from the encounter. The purpose of this article is to define that competency, justify its relevance, and propose teaching and assessment strategies that can be embedded in existing surgical curricula.

2 | Methods

2.1 | Design and Reporting Stance

This article uses a title-informed conceptual review. Mapping reviews and scoping studies are useful when a field is heterogeneous and the aim is to clarify concepts, categories, and research directions rather than estimate a pooled effect (Arksey and O'Malley 2005; Grant and Booth 2009; Levac et al. 2010). The present work was informed by that logic but had a deliberate focus that was narrower than a full scoping review. It was not designed or reported as a systematic review, meta-analysis, bibliometric study, or PRISMA-ScR review (Page et al. 2021; Tricco et al. 2018).

The analytic premise was that titles and formal source descriptions reveal how authors and organizations frame problems. In this manuscript, a title signal means visible wording that frames anatomical variation as a clinical hazard, educational gap, assessment problem, terminology problem, simulation opportunity, reporting duty, patient-safety concern, or competency target. A title-informed map can identify the conceptual shape of a field and generate curriculum implications, but it cannot establish frequency, causality, effectiveness, or the relative strength of evidence.

2.2 | Search Strategy and Eligibility

The structured bibliographic search was conducted in PubMed in March 2026. PubMed Central, publisher pages, DOI landing

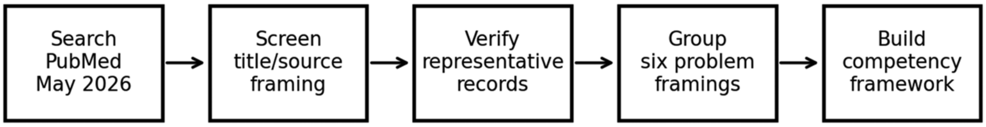

FIGURE 1 | Mapping and translation workflow. The workflow summarizes a conceptual, title-informed map rather than a systematic-review count flow. Because the article is not a systematic review, no PRISMA count diagram is reported.

pages, and cross-indexed scholarly sources were used for retrieval and bibliographic verification. The core strategy was: (“anatomical variation” OR “anatomical variations” OR “variant anatomy” OR “anatomical variants”) AND (“surgery” OR “surgical training” OR “surgical education” OR “patient safety” OR “surgical errors” OR “curriculum” OR “assessment” OR “gross anatomy education” OR “3D printing” OR “simulation” OR “reporting standards” OR “quality assessment” OR “competency-based education”). Targeted supplementary searches were run for procedure- and risk-specific topics: (“safe cholecystectomy” OR “bile duct injury” OR “recurrent laryngeal nerve” OR “hepatobiliary variants” OR “vascular variants”) AND (“anatomy” OR “variation” OR “variant”).

Records were prioritized when the title or formal source description linked anatomical variation with at least one of the following domains: clinical risk, surgical error, surgical technique, curriculum, learning objectives, assessment, terminology, reporting quality, visualization, simulation, patient safety, or competency-based training. Pure prevalence reports were not prioritized unless the title or abstract indicated educational or safety relevance. Non-human anatomy, purely historical descriptions without training relevance, unverified records, and purely pathological anomalies were excluded from the final interpretive set.

2.3 | Screening and Synthesis

The mapping process occurred in four steps (Figure 1), and the methodological profile of the title-informed conceptual review is summarized separately (Table 1). First, titles and formal source descriptions were screened for visible signals linking anatomical variation with clinical, educational, methodological, technological, safety, or competency language. Second, representative records were grouped into recurring problem framings. Third, abstracts or full texts were consulted for cited records to verify bibliographic accuracy, confirm relevance, and reduce the risk of overinterpreting title wording. Fourth, the categories were translated into a competency framework and assessment blueprint for surgical training.

No human participants, patient data, or unpublished institutional data were used; therefore, ethics approval was not required. The method is transparent about its limits: it identifies how the literature frames a set of problems, but it cannot determine the full prevalence of those problems, the quality of all available evidence, publication trajectories, or the effect size of any educational intervention.

TABLE 1 | Methodological profile of the conceptual review.

Element	Specification
Purpose	Identify curriculum and patient-safety lessons from the way literature titles and formal guidance frame anatomical variation.
Period	2000 through March 2026, with searches and reference verification completed in March 2026.
Sources	PubMed structured search; PubMed Central, publisher pages, DOI landing pages, and cross-indexed scholarly sources for retrieval and verification.
Screening unit	Title or formal source signal, supported by abstract or full-text verification for representative cited records.
Included signals	Clinical risk, surgical error, curriculum, teaching, assessment, patient safety, reporting standards, quality assessment, 3D printing, simulation, procedure-specific variants, and competency.
Excluded emphasis	Unverified records, non-human anatomy, purely pathological anomalies, and pure prevalence reports without educational or safety relevance.
Analytic output	Six interpretive problem framings plus an operational definition, competency framework, implementation guidance, and assessment blueprint.
Main limitation	Titles can hide relevant content, exaggerate novelty, or use inconsistent terminology; the map is hypothesis-generating and curriculum-oriented, not exhaustive.

Note: The map was designed to support a conceptual patient-safety argument, not to estimate effect sizes, variant prevalence, complication rates, publication counts, or longitudinal trends.

3 | Results

The title-informed map identified six recurrent problem framings (Table 2). These framings are not mutually exclusive. They describe overlapping ways in which the literature connects anatomical variation with surgical risk, curriculum design, terminology, visualization, systems safety, and competency-based assessment. Because the method did not quantify all eligible records, the framings should be interpreted as conceptual categories rather than ranked themes.

TABLE 2 | Literature framings and training lessons.

Problem framing	Representative sources	Training lesson
Clinical hazard	Anatomical-variation reviews, surgical-error analyses, safe cholecystectomy guidance, and recurrent laryngeal nerve variation literature (Alraddadi 2021; Kowalczyk and Majewski 2021; Brunt et al. 2020; Chiang et al. 2010).	Teach trainees to anticipate variation, recognize absent or conflicting landmarks, pause before irreversible action, and escalate when anatomy cannot be safely resolved.
Curriculum and assessment gap	Training-program surveys, medical-education reviews, curriculum frameworks, and scoping reviews of variation pedagogy (Kimmorley et al. 2024; Raikos and Smith 2015; Nzenwa et al. 2023; Vieno-Corbett et al. 2025).	Convert variation into explicit learning objectives, assessment tasks, and developmental expectations rather than relying on chance exposure.
Terminology and reporting problem	Work on variant terminology, reporting standards, and AVQAT (Kachlik et al. 2020; Wysiadecki et al. 2024; Kunc et al. 2026).	Use shared language for variant description, clinical relevance, imaging correlates, operative implications, uncertainty, and documentation quality.
Visualization and simulation challenge	Narrative reviews and empirical teaching work on 3D printing and hepatobiliary variants (Li et al. 2017; Myles et al. 2025).	Use models, imaging, cadaveric contrast, operative photos, and simulation to expose learners to legitimate alternatives and decision points.
Team and systems issue	World Health Organization safety materials and ACGME Common Program Requirements (World Health Organization 2026a, 2026b; Accreditation Council for Graduate Medical Education, n.d.-a).	Embed variation in preoperative briefings, intraoperative pause points, handoffs, operative notes, and morbidity-and-mortality learning.
Competency target	Competency-based education, ACGME Surgery Milestones, and outcomes-linked milestone research (Frank et al. 2010; Accreditation Council for Graduate Medical Education, n.d.-b; Smith et al. 2024).	Define variant anatomy literacy as an observable, developmental, specialty-specific safety capability.

Note: Representative sources summarize title-level and source-level framings. The table is not an exhaustive evidence map.
Abbreviations: ACGME, Accreditation Council for Graduate Medical Education; AVQAT, Anatomical Variation Quality Assessment Tool.

3.1 | Anatomical Variation as a Clinical and Surgical Hazard

The first framing is explicit in titles linking anatomical variation with clinical significance, surgical errors, and procedure-specific hazards. Alraddadi (2021) treated anatomical variation as a clinically significant phenomenon requiring identification and teaching strategies. Kowalczyk and Majewski (2021) directly connected anatomical variation with surgical errors in general surgery. In hepatobiliary surgery, safe-cholecystectomy literature foregrounds anatomic identification as a strategy for preventing bile-duct injury (Brunt et al. 2020). In thyroid surgery, recurrent laryngeal nerve variants create a safety problem because the nerve that must be protected may not follow the expected route (Chiang et al. 2010). These sources support the central claim that anatomical variation is not merely descriptive; it becomes an operative hazard when it is unanticipated, misidentified, or handled without adequate uncertainty management.

3.2 | Anatomical Variation as a Curriculum and Assessment Gap

The second framing is educational. Raikos and Smith (2015) made teaching and assessment of anatomical variation the central question for surgical and radiology programs. Later work sharpened the concern by examining how anatomical variation is included in medical education and by mapping learning objectives across gross anatomy courses (Nzenwa et al. 2023; Vieno-Corbett et al. 2025). Kimmorley et al. (2024) advanced the idea that variation should be embedded as normal anatomy rather than isolated as rare anatomy. Together, these sources shift the question from whether learners might incidentally encounter variation to how programs intentionally teach, assess, and sequence it.

3.3 | Anatomical Variation as a Terminology and Reporting Problem

The third framing is terminological and methodological. Kachlik et al. (2020) made terminology itself the object of analysis in work on variant anatomy. Wysiadecki et al. (2024) asked whether unified standards and a checklist should be established for anatomical studies and case reports. Kunc et al. (2026) extended this direction by introducing the Anatomical Variation Quality Assessment Tool (AVQAT) for anatomical case reports. These sources matter for surgical education because trainees cannot reliably learn, search, discuss, communicate, or document variants that have no stable descriptive language. A safety curriculum requires shared terms for variant frequency, clinical consequence, operative exposure, imaging correlates, and uncertainty.

3.4 | Anatomical Variation as a Visualization and Simulation Problem

The fourth framing is technological and pedagogical. Literature on 3D printing, digital anatomy, and simulation suggests that trainees need repeated exposure to legitimate anatomical alternatives, not only one canonical atlas image. Li et al. (2017) reviewed the role of 3D printing in anatomy education and surgical training. Myles et al. (2025) specifically studied teaching and assessing hepatobiliary variants using 3D printed models. The pedagogical point is not that technology automatically improves learning. It is that variation can be made visible, manipulable, repeatable, and assessable when models are deliberately designed around clinical decision points.

3.5 | Anatomical Variation as a Team-Communication and Systems Issue

The fifth framing is implicit in patient-safety guidance and accreditation documents. World Health Organization safety materials emphasize structured communication, reporting, and systems of care (World Health Organization 2026a, 2026b). Accreditation Council for Graduate Medical Education (ACGME) Common Program Requirements emphasize learning environments, outcomes, supervision, teamwork, and patient safety (Accreditation Council for Graduate Medical Education 2026a). Variant anatomy literacy belongs in this system's space because a variant structure becomes more dangerous when it is not anticipated, communicated, escalated, handed off, or documented.

3.6 | Anatomical Variation as a Competency-Based Training Target

The final framing emerges from the intersection of competency-based education and surgical outcomes. Competency-based medical education defines training around observable abilities and outcomes rather than time served (Frank et al. 2010). The ACGME Surgery Milestones include recognition and identification of anatomical variations as elements of operative competence (Accreditation Council for Graduate Medical Education 2026b). Outcomes-linked milestone research reinforces the importance of connecting training ratings with real clinical performance (Smith et al. 2024). These sources support treating variant anatomy literacy as more than content knowledge: it should be observed, coached, documented, and entrusted.

3.6.1 | Operational Definition

Variant anatomy literacy is the integrated capability to anticipate, identify, interpret, adapt to, communicate, document, and learn from clinically consequential anatomical variation in patient care. The construct combines knowledge of normal anatomical distributions with the operative judgment required when encountered anatomy differs from the expected pattern. It is broader than anatomical knowledge and narrower than general surgical expertise. It focuses on a specific safety problem: how clinicians behave when anatomy is uncertain, variant, or unexpectedly configured.

Seven action verbs make competency observable (Table 3). Trainees should anticipate which variants are clinically consequential for the planned procedure; identify cues that expected anatomy may not be present; interpret structures through safe exposure, imaging, consultation, and anatomy-based reasoning; adapt the operation by changing approach or choosing a bailout strategy; communicate uncertainty and variant findings to the team; document the variant and its future-care implications; and learn from each case by connecting experience with literature, reporting standards, and teaching files.

4 | Discussion

4.1 | Educational and Implementation Implications

4.1.1 | Move From Catalogue Knowledge to Adaptive Performance

The most important educational shift is from content coverage to adaptive performance. A curriculum cannot teach every possible variant in every body region. It can, however, teach residents to identify high-consequence variants, use patient-specific imaging, compare expected and encountered anatomy, communicate uncertainty, choose safe alternatives, and document findings. This is the difference between a catalog model and a literacy model. The catalog model asks, “How many variants can the learner's name?” The literacy model asks, “Can the learner behave safely when anatomy varies?”

4.1.2 | Embed the Competency Instead of Adding Another Course

The implementation challenge is not to add an isolated course called variant anatomy. Surgical curricula are already overloaded. The stronger strategy is to embed variant anatomy literacy into existing structures: anatomy teaching, radiology rounds, simulation, preoperative planning conferences, operative entrustment, and morbidity-and-mortality review. Competency becomes visible when trainees are repeatedly asked not only “What is the anatomy?” but also “What else could it be, how would you know, and what would you do next?”

4.1.3 | Build Specialty-Specific High-Consequence Variant Maps

A practical program could begin with a specialty-specific list of high-consequence variants. The list should not be exhaustive.

TABLE 3 | Variant anatomy literacy framework.

Domain	Observable trainee behaviors	Assessment evidence
Preoperative anticipation	Reviews patient-specific imaging; names variant structures at risk; identifies missing or inadequate imaging; states a variant-risk plan.	Preoperative case conference; image-based objective structured clinical examination; written operative plan.
Intraoperative recognition	Verbalizes uncertainty; avoids division of unidentified structures; uses reliable landmarks; requests exposure or supervision when anatomy conflicts with expectation.	Direct observation; operative entrustment note; simulation station.
Anatomical disambiguation	Uses safe exposure, alternative views, imaging, neuromonitoring, consultation, or a time-out before irreversible action.	Procedure-specific checklist; simulation debrief; faculty narrative assessment.
Technical adaptation	Uses accepted bailout strategies; changes approach; pauses when expected anatomy is absent; escalates unfamiliar variants promptly.	Observed operative performance; operative case log; morbidity-and-mortality review.
Team communication	Briefs the operative team; updates the supervising surgeon; aligns radiology, pathology, anesthesia, nursing, and handoff communication; uses closed-loop language.	Team assessment; briefing and debriefing audit; multisource feedback.
Documentation and continuity	Documents structure, laterality, course, relationship to landmarks, management, and implications for future care.	Operative-note audit; postoperative handoff review; quality-improvement portfolio.
Reflective learning	Compares the case with literature; updates a personal or departmental variant library; contributes to teaching files or reporting when appropriate.	Portfolio reflection; teaching-file contribution; case-based presentation.

Note: The framework is intended to complement existing surgical milestones and patient-safety curricula, not replace them.

It should prioritize variants that change operative strategy, increase risk of catastrophic injury, require specific imaging review, or occur frequently enough to justify deliberate practice. Each variant should be linked to a clinical scenario, imaging example, operative decision point, communication requirement, and documentation expectation. Examples include bile duct and vascular variants in cholecystectomy, recurrent or non-recurrent laryngeal nerve variants in thyroid surgery, variant or aberrant pelvic vessels, aberrant renal vessels, replaced hepatic arteries, and nerve variants relevant to orthopedic, endocrine, vascular, or hernia surgery.

4.1.4 | Use Deliberate Contrast Across Modalities

Traditional donor dissection can reveal variation, but it does not guarantee systematic exposure. A safety curriculum should deliberately contrast canonical anatomy with common and high-risk alternatives through donors, imaging, intraoperative photographs, digital resources, and case libraries. Learners should compare, for instance, multiple cystic-artery configurations, recurrent laryngeal nerve pathways, hepatic arterial patterns, venous tributaries, and abdominal wall planes. The goal is pattern flexibility, not simply accumulation of facts.

4.1.5 | Design Technology Around Decisions, Not Display

Technology should be understood as an enabler rather than a solution. 3D printing, digital models, and virtual environments can multiply exposure to variants, but educational value depends on deliberate design. A model that merely displays a variant may increase interest without improving safety behavior. A stronger task asks the learner to plan a procedure, identify danger points, decide when anatomy is sufficiently clear, and communicate the plan to a team. This direction is consistent with 3D printing work in anatomy education and variant-specific hepatobiliary teaching (Li et al. 2017; Myles et al. 2025).

4.1.6 | Assessment Implications

Assessment should target behavior under uncertainty. A written examination that asks learners to list variants may be useful for foundational knowledge, but it cannot show whether a trainee can recognize and manage a variant safely in context. A stronger assessment blueprint combines knowledge assessment, image interpretation, simulation, direct operative observation, team-communication assessment, operative-note audit, and case-based reflection (Table 4). These methods align with competency-based education because they ask whether the learner can perform observable safety behaviors, not simply whether the learner can reproduce a catalog (Frank et al. 2010).

4.1.7 | Faculty Development and Systems Learning

Faculty development is essential. Many faculty surgeons already teach variation in the operating room, but the teaching may remain implicit. Programs should help faculty convert tacit expertise into observable teaching behaviors: asking residents to predict variants, pausing when anatomy is ambiguous, narrating disambiguation strategies, documenting variants clearly, and debriefing near misses. Clinical anatomists can support this faculty development by co-designing procedure-specific variant maps, donor or image-based comparison sessions, and point-of-care anatomy teaching aligned with operative decision points (Vieno-Corbett et al. 2025; Hirt and Shiozawa 2013; Pawlina and Drake 2017).

A discovered variant should not disappear when the operation ends. If a variant duct, artery, nerve, or venous pathway is identified, it may be relevant to postoperative imaging, future operations, reintervention, or patient counseling. Reporting standards and tools, such as AVQAT, reinforce the safety principle that anatomical observations should be described consistently and made available for learning (Wysiadecki et al. 2024; Kunc et al. 2026). A vague operative note that says "variant anatomy encountered" is not a safety document. A useful note states the structure, course, laterality, relationship to landmarks, management, and future-care implications.

Variant anatomy literacy should also be linked to institutional patient-safety systems. When an injury or near miss involves anatomical misidentification, the analysis should ask whether preoperative imaging was adequate, whether the team discussed variant risk, whether intraoperative cues were recognized, whether escalation occurred, and whether documentation supported continuity. This converts variation from an individual surprise into a learning opportunity for the system.

4.1.8 | Limitations and Future Research

This article has limitations. First, title-informed mapping is sensitive to terminology. Relevant papers may not include anatomical variation, patient safety, or training in the title even when the content is relevant. Second, titles can overstate novelty or conceal methodological weakness. Third, the map prioritizes English-language, indexed, and easily retrievable sources, which may underrepresent regional literature, surgical textbooks, local curricula, and non-English reports. Fourth, the article does not estimate variant prevalence, complication rates, publication trends, or educational effect sizes. These limitations mean that the article should not be interpreted as a definitive systematic review. Its value lies elsewhere: it identifies a set of clearly defined, actionable problems that surgical educators can translate into curricula, assessment frameworks, and safety practices. Future research should build a full systematic or bibliometric map, compare curricula across specialties, validate assessment tools, test simulation methods, and study whether structured variant anatomy training reduces misidentification, near misses, or operative complications. A further priority is to standardize reporting of anatomical variants in operative notes, imaging reports, and teaching files.

TABLE 4 | Assessment blueprint for variant anatomy literacy.

Assessment method	Example task	What faculty should look for
Image-based objective structured clinical examination	Review CT, ultrasound, angiography, cholangiography, or operative images before a planned operation and identify variant-related hazards.	Correct identification, explicit uncertainty, request for additional views, and credible contingency planning.
Simulation with variant anatomy	Manage a simulated hepatobiliary, thyroid, vascular, renal, pelvic, or hernia variant before irreversible action.	Pause behavior, landmark use, safe exposure, escalation, and avoidance of premature division.
Preoperative briefing audit	State variant risks, imaging uncertainties, and contingency plan during a team briefing.	Clear language, role alignment, contingency planning, and closed-loop confirmation.
Direct operative observation	Perform a relevant portion of a case where anatomy is unclear or variant.	Safe progression, consultation, technical control, respect for uncertainty, and escalation when needed.
Operative-note audit	Document a discovered variant after surgery.	Specific description of structure, course, laterality, operative relevance, management, and future-care implications.
Morbidity-and-mortality variant review	Analyze a near miss or complication involving anatomical misidentification.	Identification of cognitive, technical, communication, and system factors; feasible prevention strategy.

Note: The blueprint samples knowledge, judgment, communication, documentation and reflective learning. It is not intended to be a single summative examination.

5 | Conclusions

Variant anatomy literacy should be recognized as patient-safety competency in surgical training. The mapped literature frames anatomical variation not only as a morphological phenomenon but also as a problem of surgical error, curriculum design, terminology, reporting quality, simulation, systems communication, and competency assessment. A safety-oriented curriculum should move beyond memorization of rare variants. It should teach trainees to anticipate relevant variation, recognize when expected anatomy is absent, disambiguate safely, adapt the operative plan, communicate uncertainty, document findings, and learn from each case. In the operating room, the safest surgeon is not the one who has memorized the atlas the best; it is the one who can recognize when the patient in front of them is anatomically different and act accordingly.

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Ethics Statement

The authors have nothing to report.

Consent

The authors have nothing to report.

Data Availability Statement

Data sharing is not applicable to this article because no datasets were generated or analyzed during the current study. The search strategy and representative sources are reported in the Methods and References sections.

References

Accreditation Council for Graduate Medical Education. 2026a. ACGME Common Program Requirements (Residency). https://www.acgme.org/globalassets/pfassets/programrequirements/2025-reformatted-requirements/cprresidency_2025_reformatted.pdf.

Accreditation Council for Graduate Medical Education. 2026b. Surgery Milestones, Version 2.1. https://www.acgme.org/globalassets/pdfs/milestones/surgerymilestones.pdf.

Alraddadi, A. 2021. "Literature Review of Anatomical Variations: Clinical Significance, Identification Approach, and Teaching Strategies." *Cureus* 13, no. 4: e14451. https://doi.org/10.7759/cureus.14451.

Arksey, H., and L. O'Malley. 2005. "Scoping Studies: Towards a Methodological Framework." *International Journal of Social Research Methodology* 8, no. 1: 19–32. https://doi.org/10.1080/1364557032000119616.

Brunt, L. M., D. J. Deziel, D. A. Telem, et al. 2020. "Safe Cholecystectomy Multi-Society Practice Guideline and State-Of-The-Art Consensus Conference on Prevention of Bile Duct Injury During Cholecystectomy." *Annals of Surgery* 272, no. 1: 3–23. https://doi.org/10.1097/SLA.0000000000003791.

Chiang, F.-Y., I.-C. Lu, H.-C. Chen, et al. 2010. "Anatomical Variations of Recurrent Laryngeal Nerve During Thyroid Surgery: How to Identify and Handle the Variations With Intraoperative Neuromonitoring." *Kaohsiung Journal of Medical Sciences* 26, no. 11: 575–583. https://doi.org/10.1016/S1607-551X(10)70089-9.

Estai, M., and S. Bunt. 2016. "Best Teaching Practices in Anatomy Education: A Critical Review." *Annals of Anatomy* 208: 151–157. https://doi.org/10.1016/j.aanat.2016.02.010.

Frank, J. R., L. S. Snell, O. ten Cate, et al. 2010. "Competency-Based Medical Education: Theory to Practice." *Medical Teacher* 32, no. 8: 638–645. https://doi.org/10.3109/0142159X.2010.501190.

Grant, M. J., and A. Booth. 2009. "A Typology of Reviews: An Analysis of 14 Review Types and Associated Methodologies." *Health Information and Libraries Journal* 26, no. 2: 91–108. https://doi.org/10.1111/j.1471-1842.2009.00848.x.

Haynes, A. B., T. G. Weiser, W. R. Berry, et al. 2009. "A Surgical Safety Checklist to Reduce Morbidity and Mortality in a Global Population." *New England Journal of Medicine* 360, no. 5: 491–499. https://doi.org/10.1056/NEJMsa0810119.

Hirt, B., and T. Shiozawa. 2013. "Clinical Anatomy as a Modern Concept for 21st Century Teaching, Postgraduate Education, and Research." *Kitasato Medical Journal* 43: 99–103.

Kachlik, D., I. Varga, V. Baca, and V. Musil. 2020. "Variant Anatomy and Its Terminology." *Medicina (Kaunas, Lithuania)* 56, no. 12: 713. https://doi.org/10.3390/medicina56120713.

Kimmorley, A. L., M. S. Reynolds, and L. S. Gregory. 2024. "Anatomical Variation Is the Norm: A Novel Curriculum Framework." *Anatomical Sciences Education* 17, no. 5: 1038–1054. https://doi.org/10.1002/ase.2428.

Kowalczyk, K. A., and A. Majewski. 2021. "Analysis of Surgical Errors Associated With Anatomical Variations Clinically Relevant in General Surgery: Review of the Literature." *Translational Research in Anatomy* 23: 100107. https://doi.org/10.1016/j.tria.2020.100107.

Kunc, V., D. Kachlik, and M. Benes. 2026. "Anatomical Variation Quality Assessment Tool (AVQAT): Structured Guide for Reporting and Assessing the Quality of Anatomical Case Reports." *Clinical Anatomy* 39: 645–649. https://doi.org/10.1002/ca.70141.

Levac, D., H. Colquhoun, and K. K. O'Brien. 2010. "Scoping Studies: Advancing the Methodology." *Implementation Science* 5: 69. https://doi.org/10.1186/1748-5908-5-69.

Li, K. H. C., C. Kui, E. K. M. Lee, et al. 2017. "The Role of 3D Printing in Anatomy Education and Surgical Training: A Narrative Review." *MedEdPublish* 6: 92. https://doi.org/10.15694/mep.2017.000092.

Lingard, L., G. Regehr, B. Orser, et al. 2008. "Evaluation of a Preoperative Checklist and Team Briefing Among Surgeons, Nurses, and Anesthesiologists to Reduce Failures in Communication." *Archives of Surgery* 143, no. 1: 12–17. https://doi.org/10.1001/archsurg.2007.21.

Myles, C., L. Gorman, and J. F. X. Jones. 2025. "3D Printing Variation: Teaching and Assessing Hepatobiliary Variants in Human Anatomy." *Anatomical Sciences Education* 18, no. 9: 885–896. https://doi.org/10.1002/ase.70073.

Nzenwa, I. C., H. A. Iqbal, and P. J. Bazira. 2023. "Exploring the Inclusion of Anatomical Variation in Medical Education." *Anatomical Sciences Education* 16, no. 3: 531–546. https://doi.org/10.1002/ase.2254.

Page, M. J., J. E. McKenzie, P. M. Bossuyt, et al. 2021. "The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews." *BMJ* 372: n71. https://doi.org/10.1136/bmj.n71.

Pawlina, W., and R. L. Drake. 2017. "Bridges Are Waiting to Be Built: Delivering Point-Of-Care Anatomy for Everyday Practice." *Anatomical Sciences Education* 10, no. 4: 305–306. https://doi.org/10.1002/ase.1714.

Raikos, A., and J. D. Smith. 2015. "Anatomical Variations: How Do Surgical and Radiology Training Programs Teach and Assess Them in Their Training Curricula?" *Clinical Anatomy* 28, no. 6: 717–724. https://doi.org/10.1002/ca.22560.

Smith, B. K., K. Yamazaki, A. Tekian, et al. 2024. "Accreditation Council for Graduate Medical Education Milestone Training Ratings and Surgeons' Early Outcomes." *JAMA Surgery* 159, no. 5: 546–552. https://doi.org/10.1001/jamasurg.2024.0040.

Sugand, K., P. Abrahams, and A. Khurana. 2010. "The Anatomy of Anatomy: A Review for Its Modernization." *Anatomical Sciences Education* 3, no. 2: 83–93. https://doi.org/10.1002/ase.139.

Tricco, A. C., E. Lillie, W. Zarin, et al. 2018. "PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation." *Annals of Internal Medicine* 169, no. 7: 467–473. https://doi.org/10.7326/M18-0850.

Turney, B. W. 2007. "Anatomy in a Modern Medical Curriculum." *Annals of the Royal College of Surgeons of England* 89, no. 2: 104–107. https://doi.org/10.1308/003588407X168244.

Vieno-Corbett, K., N. Campbell, A. Pecyna, and K. A. Rogers. 2025. "A Scoping Review of Teaching Approaches and Learning Objectives for Anatomical Variation in Gross Anatomy Courses Across Degree Programs." *Anatomical Sciences Education* 18, no. 9: 937–947. https://doi.org/10.1002/ase.70072.

World Health Organization. 2026a. *WHO Guidelines for Safe Surgery 2009: Safe Surgery Saves Lives*. World Health Organization. https://www.ncbi.nlm.nih.gov/books/NBK143243/.

World Health Organization. 2026b. *WHO Patient Safety Curriculum Guide: Multi-Professional Edition*. World Health Organization. https://iris.who.int/handle/10665/44641.

Wysiadecki, G., I. Varga, I. Klejbor, et al. 2024. "Reporting Anatomical Variations: Should Unified Standards and Protocol (Checklist) for Anatomical Studies and Case Reports Be Established?" *Translational Research in Anatomy* 35: 100284. https://doi.org/10.1016/j.tria.2024.100284.