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RELEVANT REVIEW

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Exploring the inclusion of anatomical variation in medical education

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Abstract

The role of anatomical variability in safe clinical practice is underappreciated. A lack of familiarity of anatomical variations is at the center of a multitude of medical and surgical errors. The recent rise in litigation due to such errors suggests that patient care may be compromised. This makes the knowledge of anatomical variation essential to medical education. Empirical studies were identified by searching several databases and repositories, and the Medical Education Research Quality Instrument (MERSQI) was used to assess study quality. Eight studies were eligible for this systematic review; three of which were conference abstracts. Thematic summary of these studies yielded six themes namely: (1) *importance of anatomical variation in medical education*; (2) *the ideal time to introduce anatomical variation in medical education*; (3) *important anatomical variations to include in medical education*; (4) *approaches to teaching anatomical variation*; (5) *assessing knowledge on anatomical variation*; (6) *barriers to including anatomical variation in medical education*. Including anatomical variations in medical education would improve clinical reasoning and surgical outcomes. Following the completion of this review, three recommendations were made: (1) increasing the emphasis of anatomical variation in medical education; (2) developing more resources for anatomical variation education; (3) investigating the implications of lack of knowledge of anatomical variation in medical education through further research.

KEYWORDS
anatomical variations, anatomy education, medical education, postgraduate medical education, systematic review, undergraduate medical education

INTRODUCTION

Surgical errors contribute a significant burden to health systems worldwide.[1] A large proportion of this burden is a result of patient-related complexities, which include "difficult or unusual anatomy" otherwise referred to as anatomical variations.[2] Anatomical variations are deviations from the typical arrangement of anatomical structures.[3] These variations are present within populations, and no two individuals have exactly the same anatomy.[4] Although the cause is still unclear, it is thought that humans are susceptible to a higher degree of anatomical variability more than most species.[5,6] Anatomical variation is likely the result of a combination of genetic and environmental factors interfering with the embryological development of anatomical structures.[6,7] However, such disruption is also the cause of pathological congenital abnormalities like structural cardiac defects and organ atresia. It is, therefore, important to distinguish an anatomical variation from other pathologic aberrations, as the former does not result in a demonstrable impairment in normal functioning.[7]

Anatomical variations do not typically warrant clinical attention.[8,9] Instead, because they may mimic sinister pathologies like malignancy,[10] anatomical variations are more likely to affect patients indirectly by obscuring diagnosis or obstructing management.[3] Radiology is increasingly central to daily clinical practice and has made it easier to accurately identify anatomical variations.[11] With approximately 62 million CT scans being obtained each year in the United States,[12] anatomical variations are being detected much more frequently.[4,9,13] Clinicians without an adequate appreciation of anatomical variability could be misled by incidentally detected variants. Consequently, further investigations and unnecessary medical procedures are pursued, which puts a strain on resources and, more importantly, affects patient care.[13]

Anatomical variations can negatively impact surgical outcomes, and a proportion of the avoidable deaths in the United States are due to inadequate anatomy knowledge.[2,7,14,15] A study of malpractice claims from four US-based insurance companies found that 25% of claims were attributed to anatomical variations,[16] despite a general underreporting of anatomy-related surgical complications.[17] Failure to identify variant anatomy in surgery not only affects patient safety but also incurs large litigation and malpractice claims.

There is a lack of interest in anatomical variation from an educational perspective and anatomists and physicians share the responsibility for this.[18,19] This is because variant anatomy is frequently encountered in dissection sessions and clinical practice, yet very little effort has been made to address the neglect of anatomical variations in medical education.[7,8,9,19,20,21] Further, modern medical curricula encourage students to focus on 'high yield' topics, which are often learnt from abbreviated resources that do not acknowledge the concept of anatomical variability or its clinical associations.[21,22] The predominance of learning resources like plastic models, which almost exclusively depict 'normal' or 'typical' anatomy, also continues to foster the notion of the ideal, non-variant anatomy, especially when educators fail to clarify to students that the range of 'normal' is wide.[19]

It is concerning that anatomical variation has little to no role in medical education today. Perhaps educators have failed to consider that future physicians will encounter even more anatomical variations than what previous generations found, due to increased access to evolving imaging techniques.[13,21] Currently, there is an appreciable gap in the literature regarding anatomical variation and medical education.[23] The main purpose of this systematic review is to examine the representation of anatomical variation in medical education literature and delineate relevant themes. The insights from this review are likely to influence the status of educational practices and contribute to the evaluation of current anatomy curricula.

MATERIALS AND METHODS

Study registration and reporting guidelines

The protocol for this review was prospectively registered with the International Prospective Register for Systematic Reviews (PROSPERO registration number CRD42020172808). The methodology was reported in line with the Preferred Reporting Items for Systematic Review and Meta-analyses (PRISMA) guideline[24] and the Synthesis Without Meta-analysis (SWiM) guideline.[25] The data did not include any personal or sensitive information, thus ethical approval was not required.

Search strategy

To identify the studies on anatomical variations, the following search terms were used: 'anatomy', 'variation', 'difference', 'aberrant', 'abnormal', 'anormal', 'anomaly,' and 'atypical'. These terms were selected from a recent review of the most common terminology used to describe anatomical variations.[26] To identify the medical education literature, the following search terms were used: 'education', 'training', 'learning,' and 'teaching'. The search strategies used for each database are outlined in Table S1.

An electronic search of Education Research Complete (ERC) (EBSCO Industries, Inc., Ipswich, MA), Educational Resource Information Centre (ERIC) (Institute of Education Sciences [IES], Washington, DC), Cumulative Index to Nursing and Allied Health Literature (CINAHL) Plus (EBSCO Industries, Inc., Ipswich, MA), Medical Literature Analysis and Retrieval System Online (MEDLINE) (US National Library of Medicine, National Institutes of Health, Bethesda, MD) and Excerpta Medica Database (EMBASE®) (Elsevier, Inc., New York, NY) was performed on 16th June 2021. A web-based search of open-access repositories including Google Scholar (Google, LLC., Mountain View, CA), Preprints (Multidisciplinary Digital Publishing Institute (MDPI), Basel, Switzerland), OpenGrey, Core (Knowledge Media Institute, Milton Keynes, United Kingdom), and ProQuest (ProQuest, LLC., Ann Arbor, MI) was carried out to retrieve published and unpublished materials pertinent to the review question. Additionally, a hand search of the reference lists and citations of the included studies was performed.

Inclusion criteria

All eligible studies were required to meet all the following criteria:

1. *The study must be original, empirical, and written in English language.*
2. *The study must describe human anatomy education for medical students or physicians-in-training.* The term 'physicians-in-training' collectively describes all physicians undergoing postgraduate/specialist medical training.
3. *The study must describe anatomical variations in the context of education.* This includes learning, teaching, or assessing knowledge of anatomical variations.

Exclusion criteria

1. Case reports
2. Non-empirical studies

3. Studies describing non-human anatomy
4. Studies including other groups of students or healthcare professionals
5. Studies describing anatomical variations in a non-educational context

Study selection and data extraction

Following the removal of duplicates, the titles and abstracts of all studies were screened against the eligibility criteria by one reviewer (I.C.N.). The full texts for the studies deemed potentially eligible were retrieved and independently examined by two reviewers (I.C.N. and H.A.I.). The eligible studies were then selected. The reference lists and citations of the included studies were screened, and any potentially eligible studies were independently screened in detail by two reviewers (I.C.N. and H.A.I.). Any disagreement between the two reviewers was discussed and resolved with the third reviewer (P.J.B.). The included studies were examined thoroughly to extract data on the following: study characteristics, study design and publication type, study population and participants, aims, study methods, results, and limitations.

Quality appraisal

The methodological quality appraisal for the included studies was carried out using the Medical Education Research Study Quality Instrument (MERSQI).[27] This scale is effective for assessing the methodological quality of both full-text articles and conference abstracts.[28,29] The MERSQI scale is made up of items clustered in six domains—study design, sampling, type of data, validity evidence for evaluation instrument scores, data analysis, and outcome. Each domain has a maximum score of 3. Five of the six domains have a minimum score of 1, and the *sampling* domain has a minimum score of 0.5. Thus, each study can score between 4.5 and 18. A MERSQI score >12 was considered high quality. If a study had a MERSQI score of <10, it was considered low quality. A MERSQI score between 10 and 12 indicated moderate quality.

Data synthesis

The extracted data were narratively synthesized using a modified three-stage process devised by Popay et al.[30] These stages were: (1) developing a preliminary synthesis of the findings of the included studies; (2) exploring relationships in the data within and between studies; (3) assessing the robustness of the synthesis.

Developing a preliminary synthesis

The purpose of the first stage was to provide a preliminary description of the main findings of the included studies, and this was achieved using tabulation for easy referencing of the extracted data.[30,31]

Exploring relationships in the data

Thematic summary—a deductive method of categorizing studies into relevant themes without the use of any specific methods of synthesis—was used to generate themes in this stage.[32-34] After reviewing the tabulated data thoroughly to construct themes, the full-text articles were re-read line-by-line to identify any themes that were not initially detected.[33] The included studies were then allocated to one or more themes, and the data from the studies in each theme were aggregated, synthesized, and narratively reported.[33]

Assessing the robustness of the synthesis

The robustness was assessed using the reporting guidelines (SWiM and PRISMA), the methodological quality appraisal (MERSQI) and the examination of the overall quality and trustworthiness of the systematic review.[30] A critical retrospective reflection of the entire review process was done to identify any limitations that constrained the validity of this systematic review.

RESULTS

Literature search

Searching the online databases yielded 16,675 titles and abstracts for initial screening. Fifty-three of those studies were screened in detail and three studies were deemed eligible. Of 2373 abstracts identified during the gray literature, citations and reference list searches, 5 studies were eligible for inclusion. In total, eight studies were included in the review. A flow diagram of the search strategy and study selection is included in Figure 1.

Quality appraisal

The quality appraisal is outlined in Table S2. The MERSQI scores for the included studies ranged from 8 to 13. Using the predetermined criteria, two studies[35,36] were considered high quality. There were two moderate quality studies.[37,38] The remaining studies were low quality.[39-42]

Narrative synthesis

The data from the included studies were extracted and summarized in Table 1. Most of the studies were conducted in the United States ($n = 3$). The remaining five studies were carried out in Australia ($n = 2$), the United Kingdom ($n = 2$), and Jordan ($n = 1$). The population of interest in six studies were medical students. There were five full-text articles and three conference abstracts. Regarding the study design, there was one randomized controlled study, one non-randomized controlled study and six cross-sectional

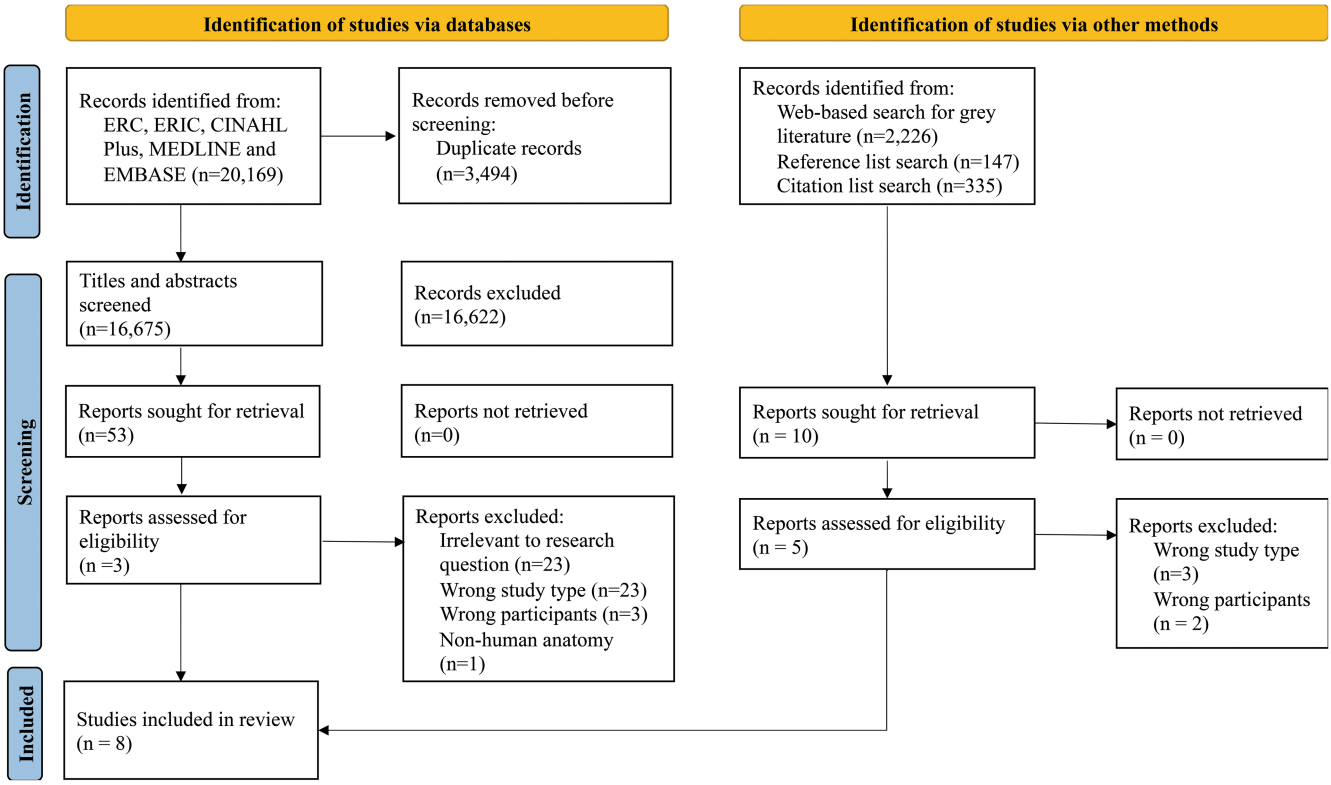

FIGURE 1 The PRISMA flow diagram of the search strategy and study selection.

studies. Six themes emerged after thematic summary, namely: (1) importance of anatomical variation in medical education; (2) the suitable time to introduce anatomical variation in medical education; (3) important anatomical variations to include in medical education; (4) approaches to teaching anatomical variation; (5) assessing knowledge on anatomical variation; (6) barriers to including anatomical variation in medical education.

Theme one: Importance of anatomical variation in medical education

Three cross-sectional studies[39,41,42] surveyed perceptions of various medical educators and the randomized study[36] compared outcomes of two cohorts of surgical trainees. There was a consensus that knowledge of anatomical variations is important and beneficial for clinical practice. In one study,[42] some educators were unclear of the benefit of learning about anatomical variation and felt it yielded no additional value to medical education. The randomized study[36] showed that incorporating anatomical variation in surgical simulations improved operative outcomes and technical skills.

Theme two: The ideal time to introduce anatomical variation in medical education

This theme addressed the perceptions regarding the most suitable time to introduce anatomical variation into the medical curriculum. Two studies[39,41] supported that concepts of anatomical variability are best introduced in medical school, with one study[39] highlighting that it is best to introduce these concepts in the pre-clinical years. Conversely, one study[42] reported that it was more beneficial to introduce anatomical variation in the middle of postgraduate medical training.

Theme three: Important anatomical variations to include in medical education

This theme was addressed in three studies.[39,41,42] One study[39] reported that circulatory and organ system variations were the most important variations to teach. Another study[41] reported that variations in anatomical relationships, especially the femoral triangle order and the brachial plexus composition, were the most important anatomical variations to know. All three studies agreed that the muscular system variations were the least important variations to include in the curriculum.

Theme four: Approaches to teaching anatomical variation

This theme focused on the various methods of teaching anatomical variation and was addressed by seven[35,36,38,39,40,41,42] of the eight included studies. Three studies[38,41,42] suggested that dissection was the best resource for teaching variation. In two studies,[39,40] both dissection and prosection were considered the best approaches. Other effective

methods of learning about anatomical variations such as augmented reality[35] and simulation[36] were reported. Four studies[35,38,40,42] outlined less effective approaches which included plastic models, textbooks, and lectures.

Theme five: Assessing knowledge on anatomical variation

Three studies[39,41,42] surveyed the faculty at institutions that assessed their students and trainees on anatomical variations. In one study,[37] three groups of trainees were assessed on their ability to recognize an anatomical variation. Hong et al.[35] investigated the impact of various teaching approaches on students' outcomes in an assessment. Paper-based[37] and computer-based[35] quizzes were utilized for assessment. In the randomized study,[36] trainees were assessed using a surgical simulation with variant anatomy models.

Theme six: Barriers to including anatomical variation in medical education

This theme addressed the challenges hindering the inclusion of anatomical variation in medical education. Only one study[39] highlighted this theme and reported that most of the faculty found that it was challenging to introduce the concepts of anatomical variability into the curriculum. However, no specific barriers were cited.

DISCUSSION

This is the first systematic review that addresses how anatomical variations are represented and discussed in medical education literature. Although the significance of anatomical variability is not novel, the role it plays in medical education has not been explored. This is evidenced by the literature search which generated almost 20,000 studies and yielded only 8 eligible studies, including 3 conference abstracts. Considering the paucity of research on this topic, some interesting themes still emerged. By exploring these themes below, this review highlights important factors educators should account for when deciding how to incorporate anatomical variations into the curricula for training future physicians.

Importance of anatomical variation in medical education

All four studies that addressed this theme supported the notion that it is important to teach anatomical variations. However, only two of these studies identified reasons for this perceived importance. In the first of these studies, Buongiorno et al.[39] found that knowledge of variant anatomy is important for improving clinical reasoning. Since patients are anatomically unique,[20] knowledge of anatomical variation can be leveraged and adapted to suit the individual clinical needs of each patient. Additionally, clinicians will be safer practitioners,[37] as they are less likely to be misled in their clinical reasoning by incidentally discovered variants.[44] The knowledge of anatomical variations is the foundation of robust diagnostic acumen. This is underscored in the qualitative study by Cheung et al.,[45] in which a participant asserted "… you have to know what's the normal and you also have to know the normal variations so that you have a chance to be able to spot an abnormality and you won't misdiagnose a normal variant as an abnormality."

Secondly, Piromchai et al.[36] asserted that knowledge of anatomical variation is important for improving surgical outcomes. They demonstrated that incorporating anatomical variations into surgical simulations improved technical operative skills, with surgical trainees being less likely to damage surrounding anatomical structures when they encountered anatomical variations.[36] Attention should be given to this observation since limited knowledge of anatomical variation is a rising cause of malpractice and litigation claims in surgery.[2,46] Despite this clear clinical rationale for the importance of anatomical variation, published core syllabi or curricula for anatomy, such as the United States Medical Licensing Examination (USMLE) content outline[47] or the Anatomical Society's Core Syllabus for anatomy,[48] do not include variant anatomy as an essential criterion. Whether this is a symptom of reduced curricular time for anatomy in medical education or a deliberate omission is not clear from the literature. It is worth noting that these anatomical curricula are not prescriptive to medical schools but are merely used as a loose guide for anatomical education.

The ideal time to introduce anatomical variation in medical education

Royer[13] has argued that medical educators struggle with identifying the appropriate time to introduce anatomical variation. While there were mixed stances from the findings in this review, most of the literature favored introducing anatomical variation in education as early as possible, particularly in the pre-clinical years of medical school.[39,41] The concept of medical education being divided into undergraduate/basic and postgraduate/specialist forms may influence this position. Since postgraduate training programs are more specialized, it is more difficult to standardize the curriculum at this point, especially as the education the trainees receive is geared toward their respective specialties. A standardized curriculum across all medical schools, as is the case in the United States, makes it the logical part of medical training to introduce anatomical variation.[49] The pre-clinical years are also preferred because this is traditionally when anatomy is taught, and anatomy is not typically revisited in the clinical years.[44] Furthermore, introducing anatomical variation around the time when students are learning pathophysiology would facilitate easier integration and appreciation of their clinical relevance.[50]

TABLE 1 Summary table of the data extracted from the included studies

First author (year) (country)	Study design (publication type)	Aims	Participants
Al-Mnayyis et al.[37] (Jordan)	Cross-sectional study (full-text article)	To evaluate the ability of residents to identify the right azygos lobe	227 physicians (173 interns, 28 radiology residents and 26 surgery residents) participated. (response rate = 59.9%)
Buongiorno et al.[39] (USA)	Cross-sectional study (conference abstract)	To explore the integration of anatomical variations in the curriculum of allopathic medical schools in the USA To highlight the attitudes of the anatomy faculty regarding including anatomical variations in clinical training	Anatomy teaching faculty from 44 allopathic medical schools in the USA were surveyed (response rate = 31.7%)
Hong et al.[35] (USA)	Non-randomized controlled study (conference abstract)	To assess the usefulness of augmented reality (AR) for learning about anatomical variations	125 medical students participated
Piromchai et al.[36] (Australia)	Randomized controlled study (full-text article)	To investigate the importance of exposing surgical residents to anatomical variations	11 otolaryngology residents participated

Methods	Results	Limitations
Residents were asked to identify the right azygos lobe in both an anatomy figure of the lung and an axial CT image	No intern or surgery resident correctly identified the anatomical variation in both the figure and CT image 16 (57.1%) radiology residents correctly identified the anatomical variation in both the figure and CT image. The right azygos lobe was most misidentified as the bronchus (25%) and lung apex or superior vena cava (17%) in the CT scan and figure, respectively	Only one institution Low response rate Only descriptive statistical analyses
The survey used had four parts: (1) Likert scale questions to rate the importance of 50 anatomical variations categorized into musculoskeletal, circulatory, nervous, and organ systems (2) Ranking questions to determine how anatomical variations were taught at each institution (3) Likert scale questions to examine faculty perceptions on integrating anatomical variations into medical education (4) Free-text comments to identify major curricular formats at each institution and the career demographics of the respondents	The respondents agreed that it was important for medical students to appreciate the omnipresence of anatomic variability (mean score: 4.64 ± 0.57) They also agreed that clinical reasoning was improved by learning about anatomical variations (mean score: 4.25 ± 0.74) All categories of anatomical variations were rated as important. However, circulatory and organ system variations were deemed more essential for clinical training than nervous and musculoskeletal variations Cadaveric dissection or prosection was rated as the most effective method of introducing anatomical variations into the curriculum (mean score: 4.27 ± 0.84) 88.6% of the respondents agreed or strongly agreed that the optimal time to introduce the concepts of anatomical variability is the pre-clinical years 77% of the respondents agreed or strongly agreed that introducing these concepts is difficult 38.6% of the faculty surveyed do not assess the knowledge of anatomical variations	Low response rate Only descriptive statistical analyses
An AR model of the aberrant right subclavian artery (ARSA) and an animation depicting the embryological origins of ARSA were created The students were divided into two groups. The 'no AR' group learnt about ARSA using traditional resources (text, images, and 3D SketchFab model) alone. The 'with AR' group used the traditional resources and the AR hologram. To learn the embryology of ARSA, the students were divided into two groups—the 'animation only' and 'text only' group Pre- and post-test quizzes and a survey were used to compare the efficacy of the resources	The two groups of students performed similarly on the pre-test quiz While there was an overall improvement in post-test scores across both groups, the 'animation only' group scored better than the 'text only' group (82.2% vs. 76.7%; $p > 0.05$) The 'with AR' group scored better than the 'no AR' group (83.2% vs. 76.3%; $p > 0.05$) For the embryology, 90% of the students found the animation more helpful than text The students reported the 3D model to be helpful for learning about ARSA (mean score of 4.4/5) The students ranked the efficacy of the resources. From most to least helpful: AR (most helpful) > animation >3D model > text (least helpful) ($p < 0.01$)	Only one institution Missing information regarding the groups
The residents were instructed to independently perform a standard cochlear implant after a series of workshops The residents were randomized to either a single training model (SM) group ($n = 5$) or multiple training models (MM) group ($n = 6$) Both groups received four weekly training sessions where they performed various parts of the surgery on a temporal bone simulator (two procedures per session) During the first three weeks, the SM group trained with the same temporal bone six times while the MM group trained with six different models one time. On the fourth week, each resident operated on two temporal bones—one 'normal' and one 'challenging'. The challenging bone had an anatomical variation The final procedures were recorded and assessed independently with a validated assessment tool by two consultant surgeons. The validated tool comprised of a global rating scale and a task-based checklist	Although the overall global rating scale indices between the two groups were not significant, the MM group showed significantly better use of the otological drill on the challenging bone ($p = 0.04$) The overall task-based checklist indices between the two groups were not significant, however, the MM group were significantly better at preserving the facial nerve on the challenging bone and visualizing the round window niche on the normal bone Additionally, the MM group caused fewer injuries to the incus and facial nerve, and they were significantly more likely to reach the round window membrane	Small sample size Only one institution Varied operative experience between the residents

(Continues)

TABLE 1 (Continued)

First author (year) (country)	Study design (publication type)	Aims	Participants
Goldberg and Royer[41] (USA)	Cross-sectional study (conference abstract)	To determine the inclusion of anatomical variations in the curriculum	Anatomy teaching faculty from 29 allopathic medical schools in the USA were surveyed (response rate = 24.4%)
Raikos and Smith[42] (Australia)	Cross-sectional study (full-text article)	To identify the current trends in teaching and assessing anatomical variations in the curricula of various surgical and radiological training programs in Canada and Australia	31 physicians were surveyed (response rate = 25.4%)

Methods	Results	Limitations
Faculty were asked to complete a survey which had four parts: (1) Likert scale questions rating the importance of 74 anatomical variations categorized into skeletal, muscular, arterial, venous, nervous, organ, miscellaneous, relationship variations (2) Forced-choice questions asking how the variations are taught and assessed (3) Likert scale questions evaluating faculty perceptions of the importance of anatomical variations in medical education and training (4) Forced-choice and open-ended questions evaluating faculty and institution demographics	The overall benefit of learning about anatomical variations had a mean score of 4.2 ± 0.8 58.2% of the respondents ranked dissection as the primary method of exposing students to anatomical variations The respondents agreed that the most important variations are relationship variations (mean score 4.2 ± 0.36) and the least important are muscular variations (mean score 2.7 ± 0.37) They also agreed that the two most important relationship variations are the femoral triangle order and brachial plexus composition 85% and 93% of the respondents taught femoral triangle and brachial plexus variations, respectively Only 52% of the respondents had formal assessment on anatomical variations The faculty surveyed rated medical school as the better time for learning about variations compared to residency or in clinical practice after residency (mean score 4.1 ± 1.0 vs. 2.2 ± 1.15 vs. 1.4 ± 0.78)	Low response rate Only descriptive statistical analyses
Physicians were asked to complete a survey that comprised of 41 questions divided into 6 parts: (1) General data (2) Anatomy training (3) Anatomy assessment (4) Anatomical variations training (5) Anatomical variations assessment (6) Opinion on anatomical variations and training	45.2% and 32.3% of the respondents recognized that learning about the anatomical variations in their specialty is important and very important, respectively Although 80.7% of the respondents reported that their training curricula considered frequently encountered variations relevant to the context of the specialty, 85.7% were uncertain whether there were plans to include learning objectives on anatomical variations in the curriculum Only 29% of the respondents reported that lists of important variations were suggested to their residents Although 71% of the respondents agreed that the best resource for learning anatomical variations is dissection courses, most respondents reported that their trainees learnt through the consultant or supervising physicians (100%) and suggested books of the specialty (87.1%). Specialized books on anatomical variations and websites were the least used resources 58% of the respondents agreed that more teaching on anatomical variations might be beneficial. 22.6% reported that it would add no further value to training and 19.4% were unsure of the benefit More than 75% of the respondents agreed that trainees would benefit the most if additional teaching on anatomical variations was introduced in the middle of their training (years 3 and 4) The most common variations taught were arterial, venous, and organ system variations, and the least common variations taught were skeletal, muscular, and neural variations 67.7% of the respondents assess knowledge of anatomical variation in their curriculum. Of these respondents, 100% assessed knowledge of variations during training. 85.7% assessed this during final examinations and only 4.8% assessing variations in entry examinations for the specialty The most frequent categories of variations assessed were arterial, nervous, and skeletal systems. Venous, organ and then muscular system variations were the least common variations assessed	Low response rate Only descriptive statistical analyses Responses not stratified by specialty

(Continues)

TABLE 1 (Continued)

First author (year) (country)	Study design (publication type)	Aims	Participants
Chapman et al.[40] (United Kingdom)	Cross-sectional study (full-text article)	To evaluate student perceptions of teaching methods and the ability of the methods to achieve learning objectives	170 students were surveyed (response rate = 70.8%)
Kerby et al.[38] (United Kingdom)	Cross-sectional study (full-text article)	To investigate the student perceptions of teaching methods and the ability of the methods to achieve the anatomy course aims.	302 students were surveyed (response rate = 52.1%)

According to Raikos and Smith,[42] the middle of postgraduate/specialist training is optimal for introducing anatomical variation. Perhaps this is because trainee physicians at this stage are more active in the elements of patient care that explicitly require the knowledge of anatomical variation.[51] Hence, trainees can better integrate this knowledge with the foundations built at the start of their training. While this may be the case, the findings of this review lean more strongly toward introducing anatomical variation in the pre-clinical phase of undergraduate/basic medical education. A compromise approach, where anatomical variation is introduced in the pre-clinical years and revisited in appropriate depth and breadth during postgraduate training, is the optimum.

Important anatomical variations to include in medical education

As previously highlighted, there is variation in every anatomical structure. It is, therefore, not practical, or of clinical relevance, to attempt to teach all known anatomical variations. However, this review has shown that certain anatomical variations are of greater importance in medical education than others.

Goldberg and Royer[41] argued that it is most important to understand the variations in the relationship between anatomical structures, especially the order of the contents of the femoral triangle and the composition of the brachial plexus. Some anatomical variations such as the complete transposition of the femoral artery and vein have been associated with very technically challenging and unexpectedly demanding operations, with relatively high incidences of intraoperative complications.[52] Inadequate knowledge of such variations has been significant in iatrogenic vascular injuries during varicose vein surgery[53] and major complications during femoral nerve blocks.[54] This suggests that the importance of an anatomical variation can be defined by the adverse impact of its misidentification in clinical settings.

Anatomical variations of the brachial plexus,[18,55] circulatory, and organ systems[26,39,42] are encountered so frequently that it is imperative to teach these variations based on their prevalence in the population. This is corroborated by Raikos and Smith[42] who found that circulatory and organ system variations were the most taught anatomical variations in postgraduate surgical and radiology training programs. Ultimately, the most important anatomical variations to include in medical education should be those that are most prevalent as well as those that are of the most clinical importance.

Approaches to teaching anatomical variation

Having addressed the time and content of anatomical variation teaching, it was necessary to identify the most suitable teaching approaches. Most of the studies agreed that teaching with cadaveric specimens, especially through dissection, was the most effective way of imparting knowledge on anatomical variation. This is echoed by some authors[56,57] who claimed that a wide range of clinically significant variations become apparent in the anatomy laboratory, especially those discovered incidentally during dissections.[58] This was also supported by Eizenberg[59] who asserted that after many years of experience, they were yet to encounter a completely dissected

Methods	Results	Limitations
The ability of six teaching methods—dissection, prosection, lectures, software, living and radiological anatomy (LA/RA), and models—to achieve nine learning objectives, including 'to appreciate anatomical variations', was evaluated The link between a teaching method and a learning objective was scored from 1 ('poor link') to 5 ('excellent link')	Both dissection and prosections were significantly preferred for appreciating anatomical variations (median score of 5) For appreciating anatomical variations, lectures, software, and LA/RA received a median score of 3 ($p < 0.05$). The students perceived models as the least suitable resource for anatomical variations, with a median score of 2 ($p < 0.05$)	Only one institution
The ability of six teaching methods—dissection, prosection and demonstration, didactic teaching only, models, technology (computer-assisted learning (CAL), slides, and videos) and living and radiological anatomy (LA/RA)—to achieve twelve course aims, including 'to appreciate anatomical/biological variations', was evaluated The 'fitness of purpose' between the teaching method and course aim was scored from 1 ('no fit') to 5 ('excellent fit') The student perceptions were compared to the perceptions of experts (anatomists) adapted from Patel and Moxham[43]	The students ranked the teaching methods in order of achieving the aim of appreciating variations. From highest to lowest ability: dissection > prosection and demonstration > LA/RA > technology > didactic teaching only > models There was no excellent fit teaching method for appreciating variations Both the anatomists and students agreed that dissection, prosection and LA/RA were a good fit for appreciating variations The anatomists perceived CAL and LA/RA as a moderate fit for appreciating variations while the students perceived didactic teaching and CAL as a moderate fit Both students and anatomists agreed that models were a poor fit for appreciating variations, with anatomists also rating didactic learning as a poor fit method	Low response rate Incorrectly filled or incomplete data fields (error rate = 1.49%) Students' perception of efficacy possibly influenced by teaching and assessment styles at each institution

cadaver with <30 visible anatomical variations. However, it is difficult to justify the use of a slow-paced and resource-dependent method like dissection, especially when such learning can be accessed less painstakingly.[20] Still, Kumar and Singh[50] suggest that verifying theoretically taught anatomical variations through experimental dissection is superior to alternatives like audio-visuals of cadaveric dissection.

While it is unsurprising that dissection has remained at the center of anatomical variation education, teaching practices should evolve to maximize learning.[20] Authors such as Zucconi et al.[60] have modified the traditional dissection courses to encourage students to efficiently build their knowledge on anatomical variation. They have also proposed a systematic investigation of the anatomy, embryology, and clinical manifestation of variant anatomy identified during dissection (Zucconi et al.[60]). Such a systematic approach fosters curiosity[56,62] and, because this is an active learning process, the students are more likely to retain this appreciation for anatomical variability. Another modification is a cadaver reassignment system, which works by reallocating students to different cadavers after some time, such that each student has worked on more than one cadaver by the end of the module.[61] This approach fostered the appreciation of anatomical variation and directed the main goal of the course from rote-memorization of the details of a single specimen to the development of a more robust mental map of various specimens.[61] This approach could also reinforce the concept of patient individuality.

The use of pre-dissected cadaveric specimens or prosection is also sufficient for teaching anatomical variation. This is especially because it is easier to preserve anatomical variations in prosected specimens, although it requires more time and skilled personnel to prepare.[15] Students or trainees who dissect with a modern atlas, which often excludes anatomical variations, are less likely to recognize or preserve the variation.[57] Another advantage is that students learning from prosection can be exposed to a greater number of anatomical variations across several specimens compared to those who perform dissections.[57] Cadaveric specimens can provide a diversity and wide range of anatomical variations, but they are heavily dependent on available time, faculty, and facilities. In addition, these resources are not readily accessible due to logistical barriers, laboratory restrictions, and health concerns from prolonged exposure to cadaver-related infections and preservation materials like formalin.[63]

The evolution of technology has spurred the use of technology-enhanced learning (TEL) in anatomy education, using radiological resources and 3D models. Chapman et al.[40] and Kerby et al.[38] suggested that the efficacy of both resources is comparable. Imaging provides in vivo visualization of anatomical variations, especially as modalities like CT, MRI, and ultrasonography have made it possible to view detailed 2D images and 3D reconstructions of internal anatomy.[15,64] 3D modeling of anatomical variations is another innovative feature. Augmented reality (AR) is one of the more recently developed tools that incorporates 3D modeling. AR utilizes elements of virtual reality to integrate computer-generated objects into the real, physical world and augment the user's perception of reality.[15,65] The illusion of the anatomical structures in AR is very useful for visualizing potentially complex anatomy like vascular variations.[66] Although, while TEL can overcome many of the limitations of cadaveric specimen, there is no clear evidence

that TEL on its own is superior to cadaveric dissection for teaching anatomical variation.

This review, therefore, shows that a variety of approaches and resources can be employed in teaching anatomical variation. In contrast, the review also highlighted two approaches that were less effective for teaching anatomical variation. The first approach was the use of plastic models. Both Chapman et al.[40] and Kerby et al.[38] reported that plastic models were ranked as the worst method of learning anatomical variation. This is likely because even though they are highly durable and easy to procure, plastic models are typically modeled to the idea of perfect anatomy. They are often color-coordinated, impeccably shaped in a way no human body is, and do not account for anatomical variation.[56,67] These models can thus be misleading and potentially dangerous for clinical practice, as they perpetuate a very superficial orientation of the body without any appreciation of anatomical variability.[68] A more suitable alternative to plastic models is plastinated specimen. Plastination mitigates the wear and tear that is associated with poor handling or overuse of prosected specimens for long periods of time, while maintaining the natural anatomical variation.[56] Furthermore, plastinated specimens are more readily accessible as they can be used outside the anatomy laboratory.[69]

Secondly, lecture-based teaching was cited as a deficient method of teaching anatomical variation.[38] While this approach has been largely criticized for being ineffective and failing to engage students actively,[15,70] it is more likely that lectures are rated poorly because anatomical variations are simply not reflected or discussed in them. Therefore, the notion that it is the lecture itself that is ineffective for teaching anatomical variation should be challenged, as the responsibility lies with the educator who has chosen to exclude the subject while delivering the lectures.

Assessing knowledge on anatomical variation

As with teaching, anatomical variations are poorly reflected in medical school assessments.[20] Goldberg and Royer[41] found that only about half of the anatomy faculty surveyed formally assessed their medical students on anatomical variation. Conversely, in postgraduate training,[42] found that all program directors assessed their trainees on their knowledge of anatomical variations. Since assessments are generally constructively aligned with teaching and learning outcomes, this is not entirely unexpected. Assessment drives learning. Consideration should be given toward assessing variant anatomy, especially those variations with defined clinical relevance, in preclinical assessments and licensing examinations.[50]

This review highlights some approaches that can be used to effectively assess the understanding of anatomical variation in both medical school and postgraduate medical training. These include the traditional paper-based assessment,[37] computer-based assessment,[35] and surgical simulations.[36] Moore et al.[71] also found that 3D models depicting variant anatomy are very useful for examinations since the models could be used to assess both the knowledge of anatomical variation and the appreciation of spatial relationship. This is especially valuable for institutions whose limited cadaveric resources make other forms of assessments like traditional spotter tests impractical to execute.

Barriers to including anatomical variation in medical education

While Buongiorno et al.[39] argued that it was challenging to introduce anatomical variations into the medical school curriculum, no explicit reasons for this were cited. However, there are three possible barriers deduced from this review, namely: (1) the debatable importance of anatomical variations; (2) a fear of overwhelming students and trainees; (3) a decline in anatomy education.

Debatable importance of anatomical variations

It is difficult to introduce a concept into the curriculum when its importance is not unanimously appreciated. Raikos and Smith[42] found that half of the clinicians surveyed did not see the benefit of teaching anatomical variation. Interestingly, the clinicians surveyed were exclusively surgeons and radiologists.[42] This is evidence that even in anatomy-focused specialties, the relevance of anatomical variation in medical education continues to be debated. Moreover, many educators feel that because anatomical variations exist in a smaller portion of the population, they are interesting but not essential to learn.[18,20,21] In a perspective piece, Bergman[18] noted that the first book of anatomical variations they wrote was reviewed by an otolaryngologist who declared that the book was worthless for anyone except "smart Alec residents." However, medical education must prepare students and trainees to competently manage diverse clinical scenarios, especially as anatomical variations that are minutiae to one clinician can be essential information to another.[37,42]

Fear of overwhelming students and trainees

Because the disciplines of medicine, especially anatomy, are voluminous and demanding,[44,72] many educators draw on the cognitive load theory to enhance the cognitive efforts of students and trainees.[73] Working memory is constrained by cognitive load and limiting this load is crucial for optimizing learning.[74-76] Anatomical variations without clinical context can be abstract[72] and boring to learn.[13] Additionally, there is no consensus on how much knowledge of anatomical variation is required. Medical educators likely feel that teaching anatomical variation would increase cognitive load, as students are not only under stress to digest an uncertain amount of new information but also have to learn content that they may perceive as abstract. This is evident as Cheung et al.[45] reported that anatomy was perceived to be challenging to learn because of the volume and abstractness of the content, with one

participant describing abstract information as "…really hard to consolidate…".

The decline in anatomy education

Currently, anatomy pedagogy is one of the most controversial aspects of medical education.[77,78] While Bergman et al.[79] suggests that there is no empirical evidence for this, several authors[44,80,81,82,83] are concerned that the quality of anatomy education is falling beyond levels that are safe for clinical practice. Recent years have seen a major decline in the number of medical schools that utilize dissection due to a decreased availability of cadavers.[15,56] Having established that cadaveric dissection is an important resource for appreciating anatomical variability, the shortage of cadavers coupled with the unmet need for alternative resources makes it challenging for medical educators to expose students and trainees to anatomical variation.

Furthermore, faculty are burdened with teaching anatomy with a shortened schedule to accommodate other disciplines in the modern medical curricula.[44,72] In the United Kingdom, the average time spent teaching anatomy over five or six years in medical school is only 149 h.[84] This means there is increased pressure to significantly reduce the volume of content and focus on the most clinically relevant anatomy in order to maximize the allotted time.[84] Since medical school faculty can only teach what they feel is most important to know, anatomical variation is likely to be excluded from the curriculum.

Limitations of the study

The heterogeneity of the eligible studies was a significant limitation. A meta-analysis could not be pursued due to the wide variability in the study design, target parameters, methodology, and methodological quality. Furthermore, the validity of this review may have been constrained by the inclusion of low-quality studies.[85] The included studies were also poorly geographically distributed, and consequently, this review may not be representative of teaching practices worldwide. As most of the included studies were survey-based, the results may have been skewed by response bias.[86] Finally, while the inclusion of gray literature increased the comprehensiveness of this review, the lack of scientific rigor and a standardized method of retrieving such studies could reduce the validity.[87]

Implications for anatomy education

This review highlights the importance of including anatomical variation in medical education and emphasizes the following key messages:

(i) Anatomical variation is clinically relevant and important to include in medical education.
(ii) The optimal time/place for inclusion of anatomical variation is during pre-clinical education with reintroduction in postgraduate/specialist training.
(iii) The most important anatomical variations to include are those that are most prevalent and those with the most significant clinical impact.
(iv) A variety of approaches can be utilized to teach/learn anatomical variations with cadaver-based approaches being most beneficial.
(v) Assessment of anatomical variations is useful to drive learning.

The review also highlighted the following barriers to the introduction of anatomical variation into medical education:

(i) Debatable importance of anatomical variations
(ii) Fear of overwhelming students and trainees
(iii) Decline in anatomy education

Following the completion of this review, recommendations for future practice were made as follows. Firstly, an increased emphasis on anatomical variation could be a significant catalyst of change. Although some medical educators have questioned whether this would impact students' understanding of variation,[88] this action could foster interest and increase the perception of importance. While it may be more practical and effective to prioritize appreciating the concept of anatomical variation over learning specific variations, there are certain anatomical variations worth teaching. Anatomy educators should consult with clinicians to ensure that the most clinically relevant anatomical variations are included in the curriculum.

Secondly, more resources should be developed for anatomical variation education. Moore et al.[71] previously recommended the creation of a database of known anatomical variations. However, in addition to writing one of the few existing textbooks on anatomical variations, Bergman also curated a comprehensive open-access encyclopedia of anatomical variations.[79,89,90] These resources should be continually updated, as they are excellent points of reference for both students and educators. Furthermore, they could be used to create and revise other anatomy textbooks, atlases, and TEL resources.

Finally, an increased commitment toward further research on anatomical variation in medical education is warranted. This review could contribute to the execution of high-quality, multicenter observational and interventional studies. Pilot studies and larger scale cross-sectional studies like that of Buongiorno et al.[39] and Goldberg et al.[41] can be conducted to investigate how anatomical variations can be included in the medical curriculum and address significant challenges involved in the process. Interventional studies with representative study participants can investigate the efficacy of innovative teaching approaches and resources for anatomical variation education. Most importantly, the findings of these studies should be disseminated at national and international conferences to encourage discourse and raise awareness of the role of anatomical variation in medical education.

CONCLUSION

The crux of medical education is to produce excellent physicians, who can competently and safely treat patients, and this must be reflected in the curriculum. Although this systematic review underscores that anatomical variation is important for medical education, there is evidence that students and trainees are poorly equipped to deal with the concepts of anatomical variability and its translation into clinical practice. Consequently, this leads to misdiagnosis and malpractice. Those actively involved in medical education are responsible for ensuring that students and trainees are adequately exposed to anatomical variation. The inclusion of anatomical variations in the medical curriculum would clarify misconceptions of the normality of the human body and provide valuable insight necessary for understanding patient individuality. It could also foster interest and curiosity such that when clinicians stumble on an anatomical variation, it would be perceived as a positive learning opportunity; not another unnecessary detail to remember.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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