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RESEARCH REPORT

Human dissection for anesthesiology resident training augments anatomical knowledge and clinical skills

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Abstract

Anatomy is an essential component of clinical anesthesiology. The use of simulated patients and alternative materials, including embalmed human bodies, have become increasingly common during resident physician training due to the deemphasis on anatomical education during undergraduate medical training. In this report, the need for a more extensive review of relevant anatomy for the practice of anesthesiology was addressed by the design, evaluation, and dissemination of a human dissection course for procedural training of anesthesiology residents. The course utilized “freedom art” embalmed human bodies that allowed trainees to perform ultrasound-based regional and neuraxial techniques followed by detailed dissections of critical anatomy. One hundred and four residents participated in workshops and small group discussions and were evaluated using pre- and post-course assessments. A variety of clinical techniques were performed on the bodies, including regional blocks and neuraxial catheter placement. Insertion of peripheral/neuraxial catheters was successful, with dissections demonstrating the expected placement. Assessment scores improved following the course (pre-course mean 52.7%, standard deviation (σ) 13.1%; post-course mean 72.2%, σ 11.6%; *t*-test $p < 0.0001$) and feedback highlighted the usefulness and clinical relevance of course content. The ability to correlate ultrasound imaging with subsequent dissections of the “blocked” area and visualization of dye staining was extremely relevant for spatial understanding of the anatomy relevant for the clinical practice of these techniques. This manuscript demonstrates successful implementation of a comprehensive course for anesthesiology resident physicians to address gaps in undergraduate anatomical education and suggests that broader adoption of dissection courses may be beneficial for training anesthesiologists.

KEYWORDS
anesthesiology, graduate medical education, gross anatomy, resident education

Garrett W. Burnett and Jeffrey T. Laitman contributed equally to this work.

INTRODUCTION

Anatomy is ingrained in the practice of anesthesiology. Virtually all clinical procedures performed daily by anesthesiologists are rooted in a proficient understanding of anatomical structures. Airway management, a core component of the anesthesiologist's skillset, requires a firm grasp of pharyngeal and laryngeal anatomy for the manipulation of tissues during intubation, supraglottic airway placement, or emergent surgical airway access (Apfelbaum et al., 2022). Anesthesiologists are also responsible for neuraxial procedures that require access to epidural or intrathecal spaces. Neuraxial procedures are often performed by feel, using the practitioner's knowledge of vertebral and spinal anatomy to guide access to the epidural and intrathecal spaces through overlying ligaments without potentially devastating complications that include permanent neurologic damage (Neal et al., 2015). Over the last two decades, the subspecialty of regional anesthesiology has grown, taking advantage of the understanding of motor and sensory nerve distributions to selectively anesthetize only portions of a patient's body for a targeted surgical procedure, such as brachial plexus blocks for upper extremity surgery (Pincus, 2019). Moreover, as essential practitioners of perioperative medicine, anesthesiologists must possess a facile understanding of all surgical anatomy, which influences pre-, intra-, and post-operative considerations for both routine and complex patients.

This requirement of anatomical proficiency is at odds with the current trend of deemphasis of anatomical subjects in undergraduate medical education (Rockarts et al., 2020; Balta et al., 2021). Over the last two decades, medical schools have moved toward integrated and patient-centered curricula, which focus on the repeated reintroduction of medical and clinical concepts within the framework of clinical correlations and holistic patient care (Hearn et al., 2019). This approach can be in conflict with traditional methods of gross anatomy education, which focus on hands-on human dissection for the in situ identification and spatial understanding of anatomical structures. Consequently, these traditional methods that have been employed for medical education for hundreds of years have grown out of favor at many institutions. A survey sent out to course directors at allopathic medical schools in the United States in 2018 demonstrated a 23% reduction in average course hours for gross anatomy when compared with a 2002 survey, although responses to the survey were limited (approximately 60% of allopathic programs responding) (Drake et al., 2002; McBride & Drake, 2018). This decrease is partially explained by the increase in integration of gross anatomy into organ system-based curricula, but nonetheless, these studies demonstrated a significant decrease in both total course hours and, arguably of more significance, hands-on laboratory hours in allopathic medical schools. While this reduction in hours was found to be only weakly associated with decreases in standardized licensing examination scores (Cuddy et al., 2013), its impact likely spreads beyond examination performance, as knowledge and technical skills learned in gross anatomy courses are highly relevant to the clinical practice of medicine and surgery (Cottam, 1999; Heisler, 2011).

Indeed, the decline in undergraduate gross anatomy education has been noted to impact graduate medical education (Standring, 2009). Resident physicians have been shown to be deficient in their general knowledge of anatomical structures (Cottam, 1999; Bergman et al., 2008), leading to an increase in graduate medical education curricula aimed at providing relevant anatomical education for various surgical subspecialties. While hands-on supervised learning with patients remains a mainstay of practical training in all medical specialties, the use of alternative teaching methods, including partial task trainers, standardized patients, embalmed human bodies, and high-fidelity simulators, has become increasingly popular (O'Regan, 2014; Wang et al., 2016; Sim et al., 2019). In surgical fields, embalmed human bodies have been described as the gold standard for the learning of technical skills as they allow the review of anatomy and the practice of surgical techniques in a safe environment where mistakes are tolerated (Gilbody et al., 2011). For example, embalmed human bodies have been used to practice the exposure of complex vascular anatomy that is not often seen in live patients (Mitchell et al., 2012). Embalmed human bodies have also been shown to be useful for training and research in a variety of other surgical subspecialties, including otolaryngology (Burns & Park, 1997; Zuckerman et al., 2009; Bhutta, 2016), neurosurgery (Gasco et al., 2013; Suri et al., 2014; Tripathi et al., 2015), and orthopedics (Groscurth et al., 2001; Trnka et al., 2001; DeFriez et al., 2011). Interestingly, some of these surgical courses have been conducted outside of the United States, suggesting the decline in anatomical education may extend beyond allopathic education in the United States.

The benefits of teaching with embalmed human bodies carry over to training in anesthesiology, where expert knowledge of vascular, neural, muscular, and osseous structures is essential. Indeed, embalmed human bodies have been shown to be effective research and teaching tools within anesthesiology, especially during procedural learning and for ultrasound-based techniques (Barrington et al., 2012; Kessler et al., 2014; Carline et al., 2016; Chuan et al., 2016; Ažman et al., 2017; Kovacs et al., 2018). Embalmed human bodies offer distinct advantages for hands-on practical learning and have been shown to be superior to manikins for teaching facemask ventilation, direct laryngoscopy, and fiber optically guided intubation of the trachea (Szucs et al., 2016; László et al., 2018). One course that incorporated embalmed human bodies workshops demonstrated a statistically significant improvement in resident multiple choice question (MCQ) and objective structured clinical examination (OSCE) scores (Garcia-Tomas et al., 2014).

Although the benefits of embalmed human body use have been demonstrated in the literature, there are obstacles to the incorporation of such materials into undergraduate and graduate medical education, including the availability and cost of materials and the availability of suitable space for such courses (Gilbody et al., 2011). There is also a lack of training on human dissection techniques and in teaching with embalmed human bodies that can impede such resources from being widely utilized in training programs. Moreover, traditionally embalmed human bodies are poor surrogates of living patients and are unusable for the practice of clinical techniques

(Groscurth et al., 2001), such as ultrasound-based regional blocks or the placement of epidural or regional catheters, due to inadequate mobility and echogenicity. Upon review of prior published curricula, no previous studies were found that fully addressed these challenges. In this report, the authors identified the need for more robust anatomical education of trainees within their department and aimed to develop a comprehensive human body dissection-based course designed to teach critical components of anatomy relevant for the clinical practice of anesthesiology. The goal of the course was to augment clinical knowledge and training by offering resident physicians the ability to practice ultrasound- and landmark-based techniques on human bodies embalmed with the "freedom art" technique that allows a greater degree of mobility and echogenicity, followed by full dissections of the targeted anatomy relevant for anesthesiology.

METHODS

Educational approach

The authors designed and implemented a hands-on anatomy course offered to anesthesiology trainees that utilizes embalmed human bodies to teach anatomy relevant to clinical anesthesiology practice. Research pertaining to the course was approved by the Mount Sinai Hospital Institutional Review Board (IRB-21-00161).

Participants, educational setting, and staff

The course was held at the Icahn School of Medicine at Mount Sinai as a collaboration between the Department of Anesthesiology and the Center for Anatomy and Functional Morphology. The course was held four times (March 2020–2023) for a total of 20 days (5 days per year) and was offered to all anesthesiology resident trainees across all four years of training (PGY1 to PGY4). Each trainee participated for a single day (content was repeated each day for a new group of trainees), with five to eight participants each day on average. Trainees were given protected education time to attend the course without other clinical responsibilities. Staff for the course included three faculty members within the Department of Anesthesiology and two anesthesiology residents.

Educational materials and equipment

Twenty-four embalmed human bodies were obtained from the Center for Anatomy and Functional Morphology to be used across the four years. Body donors were obtained in accordance with the Center's rigorous Body Donation Program, for which donors specifically requested their remains be used for educational purposes within Medical Education. Donated human bodies were preserved using the "freedom art" embalming process, a method of preparing human bodies to retain mobility and echogenicity. Details of this embalming process can be provided upon request. Briefly, the human bodies are disinfected and then injected with Metaflow (Dodge, Billerica, MA, USA), an anticoagulant fluid, followed by the Freedom Art embalming solution (Dodge, Billerica, MA, USA). The remains are sprayed with a lanolin-based hydrant to promote elasticity and then refrigerated. The Center also provided all dissection tools and equipment, cleaning and preservation supplies, and lab and technical personnel.

Course syllabus and discussions

A syllabus was developed to guide trainees during the course. The syllabus contained dissection instructions adapted from Grant's Dissector (16th Edition, Lippincott Williams & Wilkins) to suit the anesthesiology focus of the course, along with descriptions of key structures to be identified during dissection. The syllabus was made available to course participants prior to the course for review. In addition, staff prepared slides of key anatomical structures and anesthesiology techniques that were reviewed at intervals during each day to guide subsequent procedures and dissections.

Educational program

Using the "freedom art" embalmed human bodies, trainees were able to use ultrasound to visualize anatomy, perform regional blocks, and then dissect the relevant structures to observe the effectiveness of these techniques, namely the distribution of local anesthetics or the placement of a catheter. During the course, participants were able to perform a series of regional anesthesiology blocks using ultrasounds, including interscalene, supraclavicular, costoclavicular, interpectoral, pectoserratus, serratus anterior, axillary, adductor canal, sciatic, popliteal fossa, erector spinae, and paravertebral blocks. Details of these clinical techniques can be found on the New York School of Regional Anesthesia's website (www.nysora.com). A mixture of methylene blue diluted in normal saline was used (5 mL methylene blue in 1000 mL normal saline) as an injectate to allow visualization of block spread after dissection, a method commonly used in dissection-based research investigating regional anesthesiology block mechanisms (McDonnell et al., 2007). Residents also practiced neuraxial techniques, such as the placement of lumbar and thoracic epidural catheters using both midline and paramedian techniques, and then dissected down to the spinal cord to observe proper placement of these catheters in the epidural space. A portion of each day was dedicated to the review of a "pro-section" of the head and neck focusing on airway anatomy that was completed and preserved prior to the first course in 2020.

Assessment

Participants completed anonymous pre- and post-course multiple-choice assessments testing basic and advanced anatomic and anesthetic knowledge pertaining to the regional, neuraxial, and airway topics covered in the course. Assessments were administered immediately prior to the start of the course each morning and again immediately following the conclusion of the educational program in the afternoon. The assessments consisted of seventeen multiple-choice questions, two of which utilized ultrasound images. The distributions of mean assessment scores before and after participation in the course were assessed using Kolmogorov-Smirnov tests. No violation of normality was observed. The data were analyzed by a paired *t*-test. Residents who participated in the course in prior years were excluded from analyses of assessment scores for subsequent years (approximately 3 to 5 residents each year). Objective knowledge-based assessments were chosen over evaluation of clinical proficiency due to the inherent difficulties in assessing course-related improvements in clinical skills and due to the major confounder of independent perioperative exposure to the techniques reviewed in the course. Participants also completed anonymous surveys assessing comfort with human dissection, perceived usefulness of the course, subjective learning benefits, and related topics. Survey data included free text responses and Likert scale assessments.

RESULTS

The course, which was held four times over the past four years, was well received by resident trainees and faculty. A total of 104 residents participated across all levels of training (postgraduate year (PGY)1: 8; PGY2: 41; PGY3: 27; PGY4: 28). Voluntary yearly participation in the course has risen from approximately 30% of the authors' residency program in 2020 to almost 50% in 2023. Most participants (>80%) had not been exposed to human dissection since their first-year medical school anatomy course. However, most felt that it was helpful to use human bodies to review anatomy (Strongly Agree: 91.2%; Agree: 8.8%), that they were comfortable with the dissections (Strongly Agree: 46.4%; Agree: 30.4%; Neutral: 19.2%; Disagree: 2.4%, Strongly Disagree: 1.6%), and that there was adequate guidance during dissections (Strongly Agree: 87.2%; Agree: 9.6%; Neutral: 3.2%).

Ultrasound images obtained on embalmed human bodies were comparable to live patients (Figure 1), including the identification of expected muscle and neural tissue, with the notable exception of vascular structures, which were sometimes difficult to identify due to a lack of flow or compressibility. Participants were able to visualize needle insertion and injection of fluid as they would on live patients using ultrasound. Postblock dissections demonstrated the spread of injectate in expected distributions and correct peripheral catheter placement. Methylene blue staining was observed in the popliteal fossa surrounding the bifurcation of the sciatic nerve into tibial and common peroneal components, along with the placement of a peripheral catheter in this area (Figure 2A). In addition, methylene blue and a correctly placed peripheral catheter were observed in the interscalene region where the C5–C7 roots travel between the anterior and middle scalene muscles (Figure 2B). Blue staining was also observed over the phrenic nerve, highlighting the expected complication of hemi-diaphragmatic paresis with interscalene nerve blocks. Neuraxial catheters were identified in the epidural space as expected (Figure 3), including for both midline and paramedian insertions of thoracic and lumbar epidurals. Methylene blue staining confirmed the epidural injection of fluid through these catheters. The airway pro-section was well-received, with 96% of participants reporting an improvement to their understanding of airway anatomy.

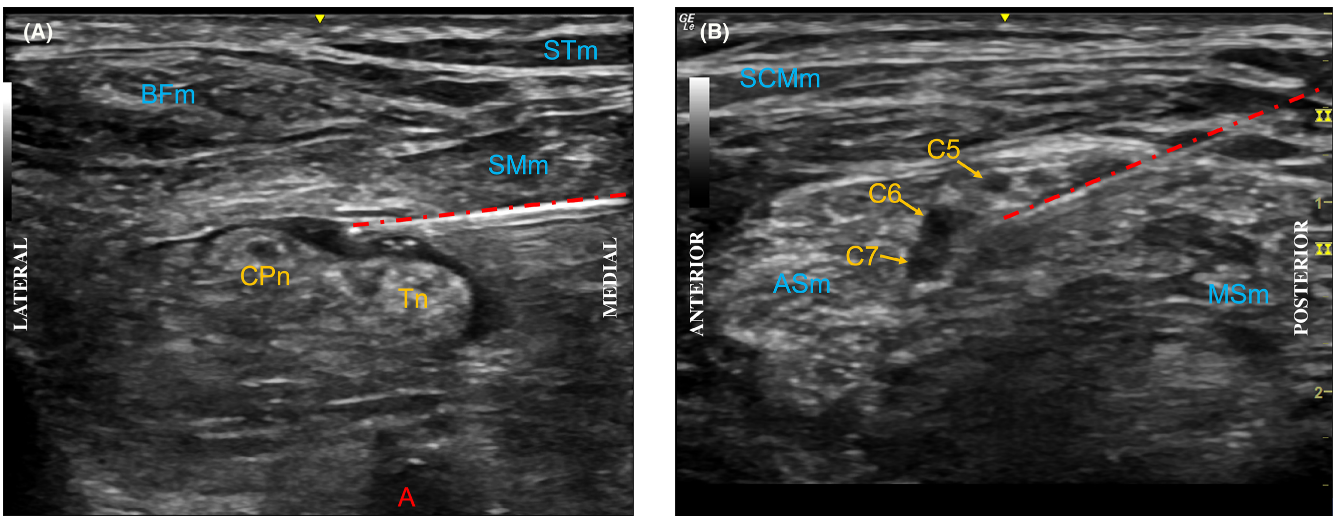

FIGURE 1 Ultrasound images obtained from embalmed human bodies. (A) transverse view of popliteal fossa, ultrasound probe directed anteriorly, common peroneal and tibial nerves visualized. BFm, biceps femoris muscle; CPn, common peroneal nerve; SMm, semimembranosus muscle; STm, semitendinosus muscle; Tn, tibial nerve; A, popliteal artery (needle approach from medial side due to body positioning); (B) interscalene block with brachial plexus roots C5, C6, and C7 visualized in a transverse view of the neck, ultrasound probe directed medially. ASm, anterior scalene muscle; MSm, middle scalene muscle; SCMm, sternocleidomastoid muscle. Red dashed lines: needle trajectory.

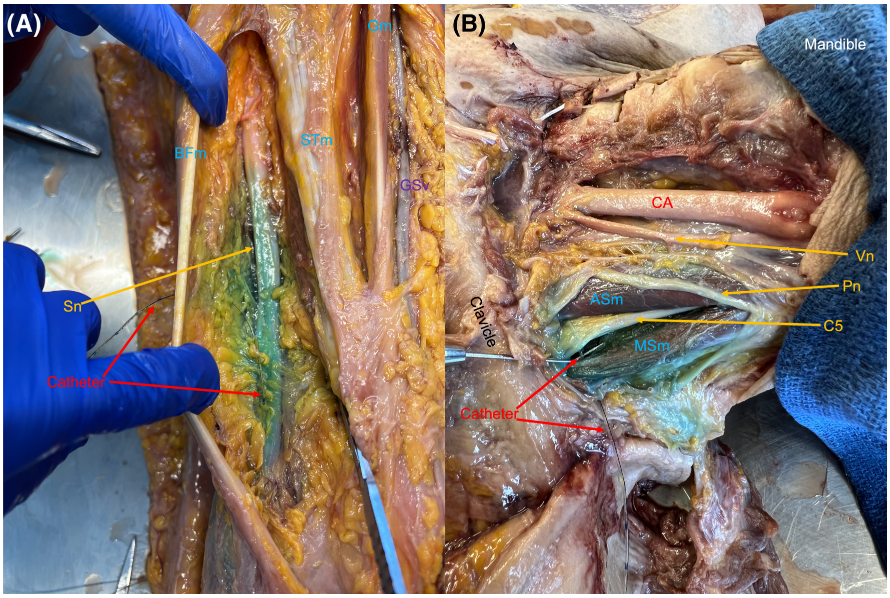

FIGURE 2 Human body dissections. (A) dissection of the popliteal fossa region with a catheter and blue injectate visualized. A catheter inserted from the posterolateral thigh directed medially toward the bifurcation of the sciatic nerve. Sn, sciatic nerve; BFm, biceps femoris muscle (retracted); STm, semitendinosus muscle; Gm, gracilis muscle; GSv, great saphenous vein; (B) dissection of the interscalene region with an interscalene catheter and blue injectate visualized. A catheter inserted along the needle trajectory depicted in Figure 1B (posterolateral insertion directed medially toward C5–C7 roots). CA, carotid artery; Vn, vagus nerve; Pn, phrenic nerve; C5, C5 nerve root; ASm, anterior scalene muscle; MSm, middle scalene muscle.

Residents reported a subjective improvement in their understanding of the anatomical basis for peripheral nerve blocks (PNBs) and neuraxial nerve blocks (NNBs) following the course (PNBs—pre-course mean Likert score: 3.0, σ 0.92, post-course mean: 4.2, σ 0.67, unpaired *t*-test $p<0.0001$; NNBs—pre-course mean Likert score: 3.6, σ 0.89, post-course mean: 4.5, σ 0.58, unpaired *t*-test $p<0.0001$; Figure S1). Residents also reported that the ability to use ultrasound on the freedom-embalmed human bodies was highly educational (Strongly Agree: 99.2%; Agree 0.8%). During each year of the course, residents demonstrated an improvement in pre- and post-course assessment scores (Table S1) and this trend remained true when stratifying by level of training (Figure 4). Narrative comments positively emphasized the course's organization and clinical relevance. "Excellent course. It greatly enhanced my understanding of neuraxial and peripheral nerve blocks as well as airway anatomy. It was pretty interesting to perform ultrasound guided nerve blocks with methylene blue and then to confirm visually upon [human] dissection. I would definitely recommend to all anesthesia residents!" Another participant later reported that his experience learning the paramedian approach to thoracic epidural placement during the course directly facilitated his first successful preoperative placement in a patient.

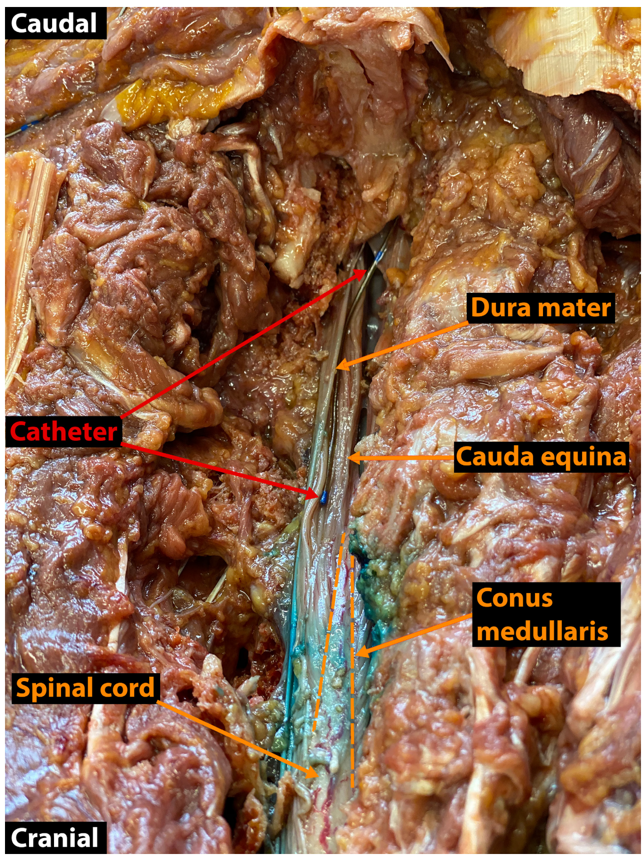

FIGURE 3 Dissection of spinal cord with catheter and injectate visualized. Catheter was epidural prior to the opening of dura mater. Left side of the spine (right side of image) partially obscured by remnants of the neural arch.

DISCUSSION

The trend of deemphasizing anatomical dissection within undergraduate medical education has presented a new challenge to graduate medical programs. Prior reports have demonstrated the utility of

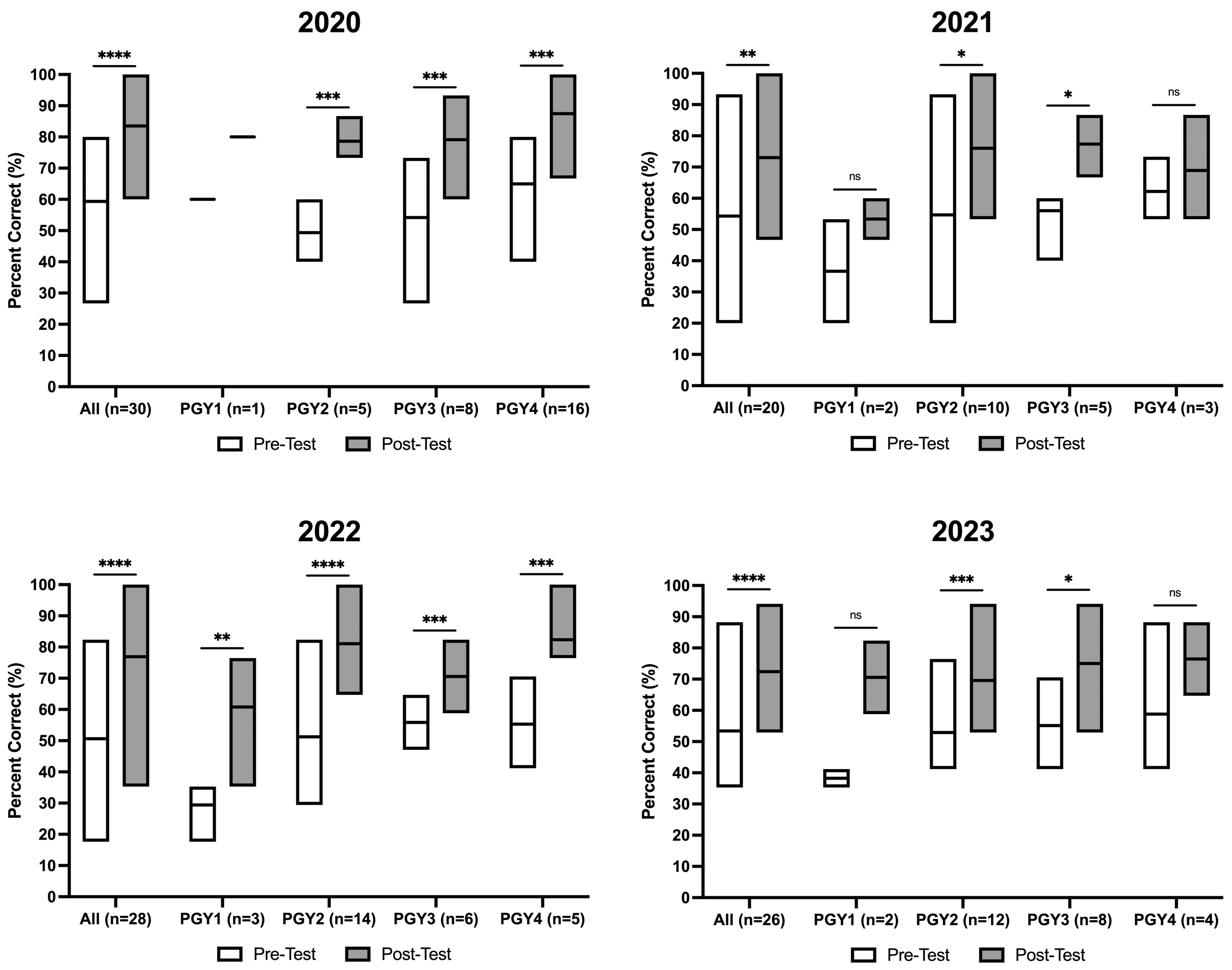

FIGURE 4 Mean assessment scores before and after the course. Max, min, and mean scores indicated by bars. p-values determined by a paired t-test. $^*p \le 0.05$; $^{**}p \le 0.01$, $^{***}p \le 0.001$, $^{****}p \le 0.0001$; ns, not significant.

human dissection for the education of graduate trainees in a variety of surgical subspecialties. This study adds to this literature by describing the creation and implementation of a comprehensive course for anesthesiology residents to improve their understanding of the anatomic basis of commonly performed regional, neuraxial, and airway techniques during clinical practice. The course offered resident physicians the ability to visualize ultrasound- or landmark-based anatomy combined with a focused dissection of the same targeted structures. Assessment scores improved following the course for all levels of training, and participants reported a subjective increase in their understanding of the basis of peripheral and neuraxial techniques. Overall, the course was well received by residents and demonstrated significant value to the residency training program.

Subjective feedback obtained after the course from the voluntary participants has been extremely positive. Free text comments from participants highlighted the educational program as a unique experience not otherwise replicated during training. Trainees noted that the ability to use ultrasound on embalmed human bodies and then dissect the relevant structures made the course highly applicable for clinical practice. Residents were strongly supportive of the implementation of the course as part of the department's training curriculum, as evidenced by the increasing rate of voluntary participation by residents. Residents have suggested that the curriculum be made a standard component of training rather than an opt-in course. While the authors are exploring this option, significant challenges remain, including availability of materials, the allotment of protected nonclinical time, and determining when training would be optimal—early to facilitate a basic understanding of these techniques versus late to reinforce clinical experience. Although the course is currently an optional component of training, the authors' department has recognized the value of hands-on human dissection for clinical training and has committed to offering protected education days to residents who wish to participate in the course.

To achieve clinical relevance, the course utilized "freedom art" embalmed human bodies, which were found to be excellent approximations of clinical anatomy, especially when compared with traditional formalin-fixed human bodies that do not allow the use of ultrasound and are not ideal for fine dissection of life-like structures (Wolff et al., 2008; Sawhney et al., 2017). Thiel's preservation method has also been described as a way to prepare human bodies that have a high degree of mobility and on which ultrasound images can be obtained (Thiel, 1992; Wolff et al., 2008). However, the embalming method carries significant disadvantages, including high cost and long preparation times (6 months) (Benkhadra et al., 2009; McLeod et al., 2021). In contrast, the "freedom art" embalming technique allows the comparatively quick and cheap preservation of human bodies while maintaining the flexibility and echogenicity required for an anesthesia-based curriculum. Very few prior studies reference this embalming technique, and it has not been thoroughly explored for use in medical education. One study developed a scoring system to compare various soft-preservation embalming techniques, including the "freedom art" method, but only used pork specimens and did not include the echogenicity of the techniques (Wang et al., 2023). Thus, this report is the first to document the practical utility of the technique for medical education purposes.

Despite the objective and subjective benefits of the course, it is difficult to accurately measure the effects of participation in this course on patient care. While knowledge of anatomy and proficiency with regional and neuraxial techniques can be assessed, how this correlates with improved patient outcomes is complex. Quantitative metrics, such as pain ratings or the quantity of opioid medications administered postoperatively, can be used to estimate block effectiveness. However, such data are heavily influenced by uncontrollable patient- or care-based factors, including inherent pain tolerance and variations in nursing assessment that may not be consistent between patients. OSCE, or objective structured assessment of technical skill (OSATS) styled examinations are a possible method of evaluating the benefit of the course (Niitsu et al., 2013), especially compared to nonparticipants and stratified across training levels. However, the variability of perioperative exposure of trainees to these techniques, even early in training, is a major confounder for such comparisons.

CONCLUSIONS

Overall, the addition of human dissection to anesthesiology residency training was extremely beneficial. The ability to use ultrasound on "freedom art" embalmed human bodies augmented the clinical relevance of the course, allowing residents to practice clinical techniques that could be easily correlated with the targeted gross anatomy after dissection. The role of human dissection in anesthesiology training has continued to expand within the authors' department, including the implementation of a dissection course for anesthesiology fellows in various subspecialty training programs, such as liver transplantation, regional, head and neck, and cardiac anesthesiology. In addition, the authors are exploring the expansion of the curriculum for trainees and faculty from other institutions.

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CONFLICT OF INTEREST STATEMENT

None to report.

DATA AVAILABILITY STATEMENT

Data is available upon request.

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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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