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ORIGINAL RESEARCH

Teaching Novices Ultrasound-Assisted Neuraxial Procedures Using Simulation-Based Courses: A Proof of Concept

Soleil S. Schutte, MD
Barys V. Ihnatsenka, MD
Christopher C. Samouce, PhD
Svetlana V. Chembrovich, MD
Federico Jimenez Ruiz, MD
Yury Zasimovich, MD
Isaac T. Luria, MD
K. Karisa Walker, MD, MEd
David E. Lizdas, BS
J. Rachael Ahn, PhD
Samsun Lampotang, PhD, FSSH, FAIMBE

INTRODUCTION

Accessing the intrathecal space for spinal anesthesia can be challenging in patients with elevated body mass index (BMI) due to barely palpable anatomical landmarks and deeper dural sacs. Trainees often struggle with redirecting the long, flexible spinal needles, making it difficult for instructors to guide them toward a successful dural puncture (DP). Multiple attempts can increase anxiety for both patients and proceduralists, further hindering the delivery of timely and effective feedback.

Ultrasonography (US) can help proceduralists visualize deep spinal anatomy, and this is particularly valuable in patients with elevated BMI or abnormal anatomy, such as scoliosis. In recent years, studies have shown that using US-assisted techniques improves the first pass success rate for neuraxial procedures and decreases complication rates and patient discomfort.[1–3] Learning US-assisted techniques involves correlating basic spinal anatomy to sonoanatomy and avoiding pitfalls in scanning and marking techniques. The initial learning curve can be steep, especially in patients with elevated BMI, as their sonoanatomy is often harder to acquire and visualize. Simulators provide a controlled, risk-free environment and enable systematic teaching of the sonoanatomy and scanning, marking, and needling skills without subjecting patients to prolonged procedures and discomfort.

The use of simulators to enhance procedural skills continues to evolve.[4–9] When integrated into a structured curriculum, they can be highly effective. One study demonstrated that deliberate practice using simulation-based learning can improve residents' clinical performance for spinal anesthesia.[10] We developed 2 courses to teach first-year residents the US-assisted technique for accessing the lumbar intrathecal space with spinal needles, an essential skill for spinal anesthesia. We hypothesized that this complex procedural skill could be effectively taught to novices using simulator-based courses. The conventional course (course C) followed a standard workshop format, using human models and lumbar simulators. In contrast, the experimental course (course E) took advantage of mixed-reality simulators with 3D visualization and applied principles of deliberate practice: well-defined learning objectives, focused repetition, objective performance metrics, and informative real-time feedback.[11] We compared the outcomes of the 2 courses.

MATERIALS AND METHODS:

The study was approved by the institutional review board (IRB), and the requirement for written informed consent was waived. A convenience sample of 24 learners was randomized into the 2 courses, courses C and E, to learn spinal anesthesia before starting their clinical anesthesiology training. The number of study participants was limited by the size of our anesthesia residency program, which admits up to 25 residents per year. Before the course, a survey was conducted to collect learners' demographic information, prior experience with neuraxial procedures and US, and their self-reported confidence levels in accessing the intrathecal space with a spinal needle.

The Simulators

The lumbar simulator used for course C consisted of a 3D-printed full-sized lower spine (T12–S1) based on Ultimate Human Anatomy V1 (MotionCow). The spine was encased in rejuvenable ballistic gel, and the depth of the spinous processes was 0.7–2.5 cm, simulating a normal BMI (Figure 1A). A 1.8-cm-thick ballistic gel pad could be added to simulate elevated BMI (Figure 1B). A simulated dura filled with water pressurized at 45 cmH_2O, simulating a normal opening pressure of the cerebrospinal fluid (CSF) in a sitting position,[12] was implanted in the spinal column. When the dura is punctured, water appears at the needle hub, simulating CSF.

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The mixed-reality lumbar simulator used in course E was developed by the Center for Safety, Simulation & Advanced Learning Technologies at the University of Florida. It is composed of the same physical lumbar simulator used in course C and displays a coregistered virtual model on a laptop screen, allowing for 360° and cross-sectional views of the anatomy using a handheld electromagnetically (EM)[13] tracked camera controller (Figure 1C and D). An EM-tracked 22-gauge introducer, which can accommodate up to a 24-gauge spinal needle, is used to display in real-time the positioning and trajectory of the spinal introducer relative to the spine on the laptop screen. The above EM-tracked components of the simulator are shown in Figure 1E. The system augments feedback with precise anatomy-needle visualization and supports the deliberate practice structure by making step adherence observable and coachable in real time.

Course E also utilized 2 mixed-reality thoracic simulators instead of human models to teach the US-assisted technique and the paramedian approach. The thoracic simulator consists of a 3D-printed mid-spine (T2–T9) segment encased within skin-colored ballistic gel. The depth of the spinous processes was 0.5–1.0 cm, simulating a normal BMI. With an 18-gauge EM-tracked Tuohy needle, it can simulate needle advance into the epidural space with the loss-of-resistance technique (Figure 2A). It can also simulate a wet tap and spinal cord injury if the needle is advanced too far (Figure 2B). A 4.5-cm-thick contoured ballistic gel pad can be added to simulate an extremely elevated BMI (Figure 2C). The other EM-tracked components and functions are like those of the mixed-reality lumbar simulator. The US images of the lumbar and thoracic simulators were compared side to side with those of human spines (Figure 3).

Study Design

Two courses were conducted simultaneously in separate rooms. Fellowship-trained regional anesthesiologists, who served as instructors for the courses, underwent precourse training to ensure consistency in teaching and adherence to the study protocol.

Course C started with a 40-minute multimedia presentation and demonstration on palpation-based DP and US-assisted techniques, followed by a 120-minute session during which 12 learners rotated through 3 stations: human models, lumbar simulators, and reading didactics with each learner spending 40 minutes at each station (Figure 4). At the human model station, groups of 4 learners practiced scanning and marking lumbar spines on each other. Each learner had 20 minutes to practice and 20 minutes to be a model while observing the US scanning. At the simulator station, groups of 4 learners practiced in pairs on 2 identical lumbar simulators. Each learner spent 20 minutes observing and 20 minutes performing palpation-based and US-assisted landmark assessments and DPs via midline and paramedian approaches. Two instructors, 1 at the human model station and 1 at the simulator station, provided real-time feedback as they would in clinical teaching.

The reading didactics for courses C and E were identical, covering lumbar anatomy and sonoanatomy and basic knowledge of spinal anesthesia.

Course E used the mixed-reality lumbar and thoracic spine simulators without human models. It was designed around the principles of deliberate practice: deconstructing the DP procedure into several steps, setting clear performance goals for each step, and providing accurate feedback through real-time 3D visualization.[11,14] Course E also started with a 40-minute multimedia presentation and demonstration on a mixed-reality lumbar simulator, covering the same content as course C. This was followed by 12 learners rotating through 3 stations: mixed-reality lumbar simulators, mixed-reality thoracic simulators, and reading didactics with each learner spending 40 minutes at each station (Figure 4). At the station equipped with 2 mixed-reality lumbar simulators, groups of 4 learners were instructed to perform a 3-step assessment before needle insertion: locating the anatomic landmarks by palpation or US, marking the landmarks on the skin, and then reassessing the marks using palpation or US to verify. Each learner spent 20 minutes observing and 20 minutes practicing assessment skills and DPs via both midline and paramedian approaches. The instructor at this station provided real-time feedback on needle position and guided needle redirection using the simulator's 3D visualization features.

At the mixed-reality thoracic simulator station, groups of 4 learners were instructed to approach the 2 thoracic simulators as if they were challenging lumbar spines where a midline approach was not feasible. This station provided a different but still relevant anatomy for residents to practice US scanning, marking, and needling skills rather than simulating any clinical application. As with the lumbar station, the instructor ensured that the learners performed the 3-step assessment before needle punctures and provided feedback using the 3D visualization function. The learning goal was to correctly mark the midline and bilateral interlaminar spaces using US and to intentionally perform at least two DPs on the simulators: first without (normal BMI) and then with the 4.5-cm ballistic gel pad (increased BMI).

After practice, all learners completed a postcourse survey followed by 3 tests. The first test evaluated their ability to identify anatomic landmarks using US. The learners were instructed to scan and mark the midline and interlaminar spaces at 4 lumbar levels (L2–S1) on human models. The models were young adults with normal BMI who had not been used during course C practice sessions. The marks were graded as correct or incorrect immediately after each test by proctors who are fellowship-trained regional anesthesiologists. Skin marks within 3 mm of the midline and 5 mm of the center of interlaminar spaces were deemed correct.

The second test allowed the learners 10 minutes to perform DPs using a 25-gauge spinal needle on a high-BMI lumbar simulator (Figure 1B). The spinous processes at T12 and L1 were difficult to palpate, and those at L2–L5 were not palpable. To eliminate visual cues of the midline, the simulator was partially

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covered with an opaque blue drape, exposing only a portion of the simulated skin. Participants were instructed to begin using palpation-based techniques but were permitted to switch to the US-assisted technique at any point. After a successful DP, regardless of the techniques used, they were encouraged to continue doing DPs until the 10 minutes had passed. At each interlaminar level, learners were allowed to perform up to 2 successful DPs, 1 via the midline and 1 via the paramedian approach. These tests were video-recorded and later analyzed by an anesthesiologist blinded to the learners' course assignments.

The third test was a 30-minute written assessment (Supplemental Online Material) containing 23 multiple-choice questions about lumbar anatomy and spinal anesthesia and 14 matching questions about lumbar sonoanatomy; the score was the percentage of correctly answered questions.

Data Analysis and Statistics

The primary outcomes included (1) the learner's ability to recognize lumbar sonoanatomy and identify anatomical landmarks using the US-assisted technique and (2) the percentage of learners who completed at least 1 DP regardless of the approach or technique used. The secondary outcomes included subjective confidence levels, rate of adherence to procedure steps, and total number of successful DPs.

The statistical analysis was performed with JMP Pro 17 (JMP Statistical Discovery). Categorical variables were compared by Fisher exact test. Numerical variables were expressed as mean ± standard error (SE) and compared by *t*-tests. A statistically significant level was set at $P < .05$.

RESULTS

Demographic Information

All interns in our anesthesiology residency program participated in this study. After randomization, each course consisted of 12 learners. The demographic information is summarized in Table 1. There was no significant difference in age, sex, experience in neuraxial procedures, or experience with US between the 2 groups.

US-Assisted Anatomical Landmark Identification

Course C and E learners correctly identified 74.4 ± 5.2% and 72.6 ± 8.1% of lumbar sonoanatomy during the written test, respectively (Student *t*-test, $P = .86$). The overall written test scores for all questions were also not significantly different between course C (73.0 ± 3.2) and course E (74.6 ± 6.3).

All learners achieved the learning goal of scanning and marking during their practice sessions. Out of the 8 test targets, 4 at midline and 4 at interlaminar spaces at L2–S1 levels, the number of correct marks made by learners in course C (5.8 ± 0.5) was not different from course E (6.8 ± 0.3) (Student *t*-test, $P = .09$). The results support the hypothesis that it is feasible to teach novices the US-assisted technique using simulator-based courses without using human models.

Assessment Consistency

During the instructional sessions, all learners were taught the 3-step assessment before needle insertion. However, only the learners in course E were consistently reminded to follow the steps during practice.

When using palpation-based techniques during the test, only 16.7% of the learners in course C made skin markings compared with 75% of learners in course E (Fisher exact test, $P < .01$). Before inserting the introducer, 8.3% of the learners in course C and 66.7% in course E reassessed the landmarks (Fisher exact test, $P < .01$). Learners in course C also spent significantly less time (32.2 ± 4.5 s) assessing the landmarks before their first needle insertion compared with those in course E (63.8 ± 4.5 s) (Student *t*-test, $P < .05$).

Among the learners who attempted US-assisted DPs, 85.7% in course C marked the skin, and none reassessed their markings with US. In contrast, 100% of learners in course E marked the skin, and 41.7% of them reassessed their markings with US ($P < .05$). The time spent on US-assisted assessment was not significantly different between the learners in course C (78 ± 17.2 s) and course E (82.3 ± 13.7 s). The results support that course E is more effective in enforcing a consistent, stepwise procedural approach among novice learners.

Success in DP

All learners achieved the practice session objective by completing at least 4 successful DPs on the lumbar simulator using palpation-based and US-assisted techniques via midline and paramedian approaches. During the 10-minute test, 10 learners in course C (83%) and 11 in course E (92%) completed at least 1 DP.

The total number of successful DPs performed by each learner is plotted in Figure 5. A noticeable difference between the 2 groups was the degree of variability in individual performance. Learners in course C showed greater variation in the number of successful DPs compared with those in course E. Statistical analysis confirmed that the number of DPs performed by course C learners did not follow a normal distribution (Shapiro-Wilk test, $P < .05$), whereas the data from course E learners were normally distributed. However, there was no significant difference in the average number of successful DPs between course C (2.8 ± 0.7) and course E (1.9 ± 0.3) (unequal variances *t*-test, $P = .25$). The median number of successful DPs was 2 in both groups.

Confidence Level

The learners rated their confidence level in performing DP on a Likert scale of 1–5, from least to most confident. The precourse rating was not different between course C (1.4 ± 0.3) and course E (1.3 ± 0.1). After the course, confidence levels increased significantly for both groups to 4.1 ± 0.2 in course C and 3.8 ± 0.2 in course E (paired Student *t*-test, $P < .001$).

DISCUSSION

This study demonstrated that it is feasible to teach novice learners the fundamental skills of DP for spinal anesthesia and US-assisted technique over a relatively short time frame using structured, simulator-based courses. Whereas full clinical competency cannot be expected from simulator-based training alone,

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these courses can lay a solid foundation for trainees and boost their confidence entering clinical training. Simulators are ideal for mastering procedural steps and basic needle manipulation skills, allowing the trainees to develop competence without subjecting patients to repeated needle attempts or prolonged procedure times.

To determine whether skills acquired through simulator training translate effectively to clinical performance, a follow-up study is needed. However, conducting such studies presents challenges, including variable intervals before patient encounters and a wide range of difficulty levels of patient anatomy. Nevertheless, our findings suggest that the US-assisted technique for neuraxial procedures can be effectively taught using simulators, comparable to training with human models.

Interestingly, although all learners in course E rated the 3D visualization as *very helpful* for their learning, they did not outperform the learners in course C in the DP test. Several factors may explain this result. First, the small sample size in this study limits its statistical power to detect differences between the 2 groups. As the number of learners is often limited in residency programs, future studies should ideally focus on interventions that yield detectable learning improvement in a small number of learners.

Second, procedural skill acquisition requires more than a cognitive understanding but also good hand–eye coordination and fine motor dexterity. Whereas 3D visualization may have improved learners' anatomical knowledge, the short practice session was likely insufficient for motor skill development. Repeated practice under the 3D visualization guidance may be necessary to achieve its full benefits. The 3D visualization may be more valuable in the later stages of training for self-directed practice and more targeted feedback.

Finally, the mixed-reality simulators may help mitigate unconscious learning of the simulator itself. The lumbar simulator has a normal, fixed anatomy, allowing learners to quickly memorize the entry sites and angles that would produce successful DPs, which can hinder the development of the essential skills for DP and artificially boost performance when the learners are tested on the same simulator. Adding a layer of ballistic gel to the simulator increased the simulated BMI and the difficulty level for needle maneuver, but it did not alter the bony structure. Consequently, once learners identify a successful puncture site, they could use it as a reference point for subsequent attempts. In contrast, the 3D visualization directed the learners' attention beyond the surface of the simulator and engaged them in deep anatomy navigation with each needle insertion. Theoretically, it should distract them from unconsciously memorizing the simulator itself. This theory was partially supported by our findings. Five out of the 6 top performers during the DP test, defined by achieving 4–6 DPs in 10 minutes, were from course C and did not use 3D visualization during the practice session. All of them skipped skin markings and used the first successful DP site as a reference to perform their second DP at the same level via a paramedian approach, evidenced by immediate second needle insertion without any assessments by palpation or US. This finding supported that their high performance was artificially augmented by memorizing the simulator. In contrast, the learners in course E, who used 3D visualization during their practice session, spent more time performing the assessment steps before needle insertions. Given the time-limited nature of the DP test and the absence of a requirement to perform the 3-step assessment, it is unlikely that their more methodical approach relied on memorizing the simulators.

This study is limited by the small number of learners. However, the study demonstrated that it is possible to teach novices the fundamental US-assisted technique for neuraxial procedures using simulator-based courses without human models. Incorporating 3D visualization and the principles of deliberate practice was more effective in shaping stepwise approaches for the procedure, but further research is needed to maximize the value of 3D visualization in simulation-based procedural training.

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The authors are at the University of Florida College of Medicine in Gainesville, FL. The following authors are in the Department of Anesthesiology: ***Soleil S. Schutte*** *is an Assistant Clinical Professor of Anesthesiology and Program Director of the Regional Anesthesia and Acute Pain Medicine Fellowship;* ***Barys V. Ihnatsenka*** *is an Associate Clinical Professor of Anesthesiology;* ***Svetlana V. Chembrovich*** *is an Assistant Clinical Professor of Anesthesiology;* ***Federico Jimenez Ruiz*** *is an Assistant Clinical Professor of Anesthesiology;* ***Yury Zasimovich*** *is an Associate Clinical Professor of Anesthesiology and Chief of the Acute Pain Medicine Division;* ***Isaac T. Luria*** *is an Assistant Clinical Professor of Anesthesiology;* ***K. Karisa Walker*** *is Associate Clinical Professor of Anesthesiology. The following authors are in the Department of Anesthesiology and the Center for Safety, Simulation & Advanced Learning Technologies:* ***Christopher C. Samouce*** *is an Assistant Scientist;* ***David E. Lizdas*** *is an Engineer.* ***J. Rachael Ahn*** *is a Research Scientist at Cognia.* ***Samsun Lampotang*** *is the Joachim S. Gravenstein Professor of Anesthesiology and Director of the Center for Safety, Simulation and Advanced Learning Technologies in the Department of Anesthesiology; the Center for Safety, Simulation & Advanced Learning Technologies.*

Corresponding author: *Soleil Schutte, MD; Department of Anesthesiology, University of Florida College of Medicine, 1600 Southwest Archer Road, P.O. Box 100254, Gainesville, FL 32610. Telephone: (352) 273-6575*

Email address: *Soleil Schutte: sschutte@anest.ufl.edu*

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Abstract

Background: Ultrasonography (US) provides valuable information for neuraxial procedures in patients with elevated body mass index (BMI). However, it is challenging to systematically teach US-assisted techniques to novices in clinical settings due to time constraints and patient factors. Simulator-based training may improve the learning experience while minimizing patient discomfort.

Methods: With institutional review board approval, 24 learners were randomized into 2 courses, conventional (C) and experimental (E). Course C used human models for the US-assisted technique and simulators to practice intrathecal access with a spinal needle, an approach commonly used in procedural workshops. Course E used simulators that featured a 3D visualization function and incorporated the principles of deliberate practice without using human models.

Results: Course C learners correctly identified an average of 74% of the sonoanatomy on a written test and marked an average of 5.8 out of 8 test targets during a lumbar sonography assessment, whereas course E learners scored 73% and marked 6.8. Ten learners in course C (83%) and 11 in course E (92%) successfully achieved dural punctures within 10 minutes on a high-BMI lumbar simulator. Additionally, 75% of course E learners followed the assessment steps before needle insertion compared with only 16.7% in course C.

Conclusions: The fundamental US-assisted technique for neuraxial procedures can be effectively taught using simulator-based courses without human models. Course E, which incorporated 3D visualization and the principles of deliberate practice, was more effective in shaping stepwise approaches for the procedure.

Keywords: simulation training, mixed-reality simulation, spinal anesthesia, ultrasonography, graduate medical education

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Figures

Figure 1. *Mixed-reality lumbar spine simulator. (A) The physical lumbar simulator consisted of a normal lower spine (T12–S1) encased within rejuvenable ballistic gel. (B) The physical lumbar simulator with an added ballistic gel pad to simulate elevated BMI. (C) The simulator was covered with a 2-mm-thick, skin-colored ballistic gel for the practice sessions. A 25-gauge spinal needle was inserted through the EM-tracked introducer at the L2–3 interspinous space with corresponding 3D-perspective visualizations of the spinal introducer shown in real time on the laptop screen of the simulator. Note the water drop at the needle hub simulating a successful dural puncture. (D) A cross-sectional view and a side view of the spine and introducer position are shown as examples of 3D visualization from different perspectives. (E) The tool tray of the mixed-reality simulator contains: (i) an EM-tracked Tuohy needle, (ii) an EM-tracked introducer needle, and (iii) a camera controller, a loss-of-resistance syringe, and a marking pen. Abbreviations: BMI, body mass index; EM, electromagnetically.*

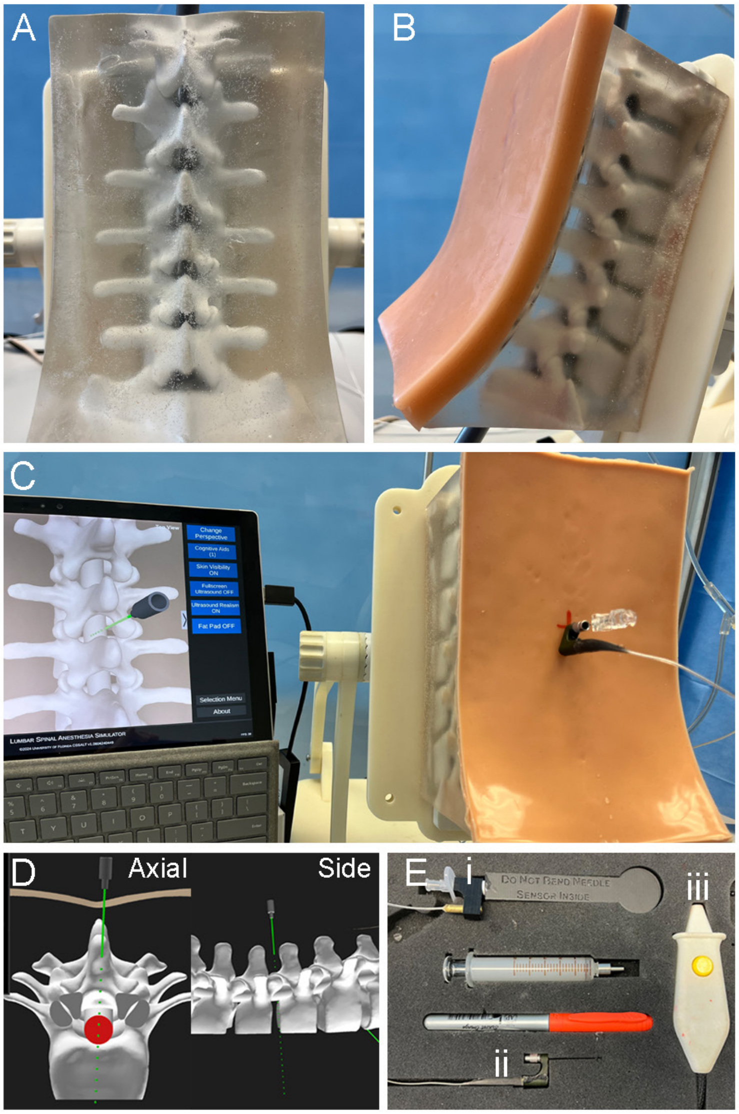

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Figure 2. *Mixed-reality thoracic spine simulator. (A) An 18-gauge EM-tracked Tuohy needle was inserted into the T4/5 interlaminar space on the simulator with a loss-of-resistance syringe attached. Corresponding 3D-perspective visualization of the Tuohy needle is shown in real time on the laptop screen of the simulator. (B) A simulation of a wet tap when the Tuohy needle is advanced too far into the interlaminar space. (C) The thoracic simulator with an added 4.5-cm-thick contoured gel pad to simulate extremely elevated BMI. Abbreviations: BMI, body mass index; EM, electromagnetically.*

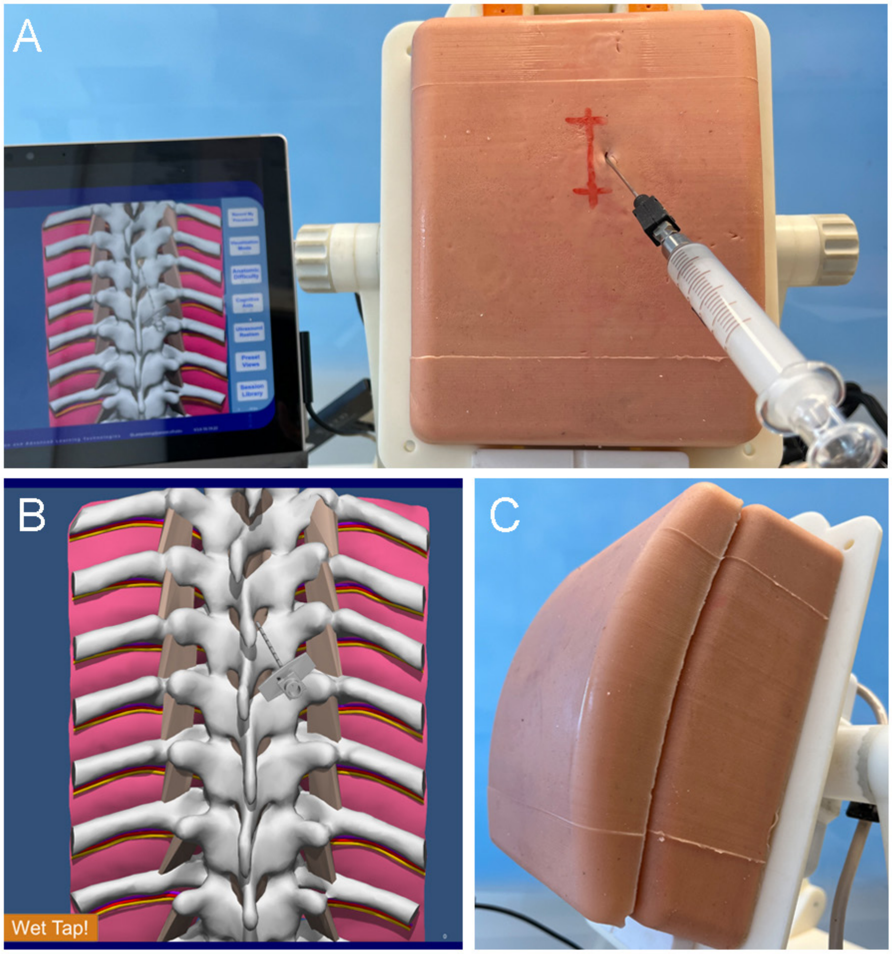

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Figure 3. *Ultrasound images of the lumbar and thoracic spine simulators and human spines at the same levels. (A) Transverse views of L3 spinous process. (B) Transverse views of the interspinous space L3/4. (C) Paramedian sagittal oblique views of the L3/4 interlaminar space. (D) Paramedian sagittal oblique views of the T5/6 interlaminar space. The orientation marker was aimed cephalad in panels C and D. Images were acquired using a SonoSite Edge C5-1 curvilinear probe (FUJIFILM Sonosite). Abbreviations: AC: anterior complex; AP, articular process; L, lamina; PC, posterior complex; SP, spinous process.*

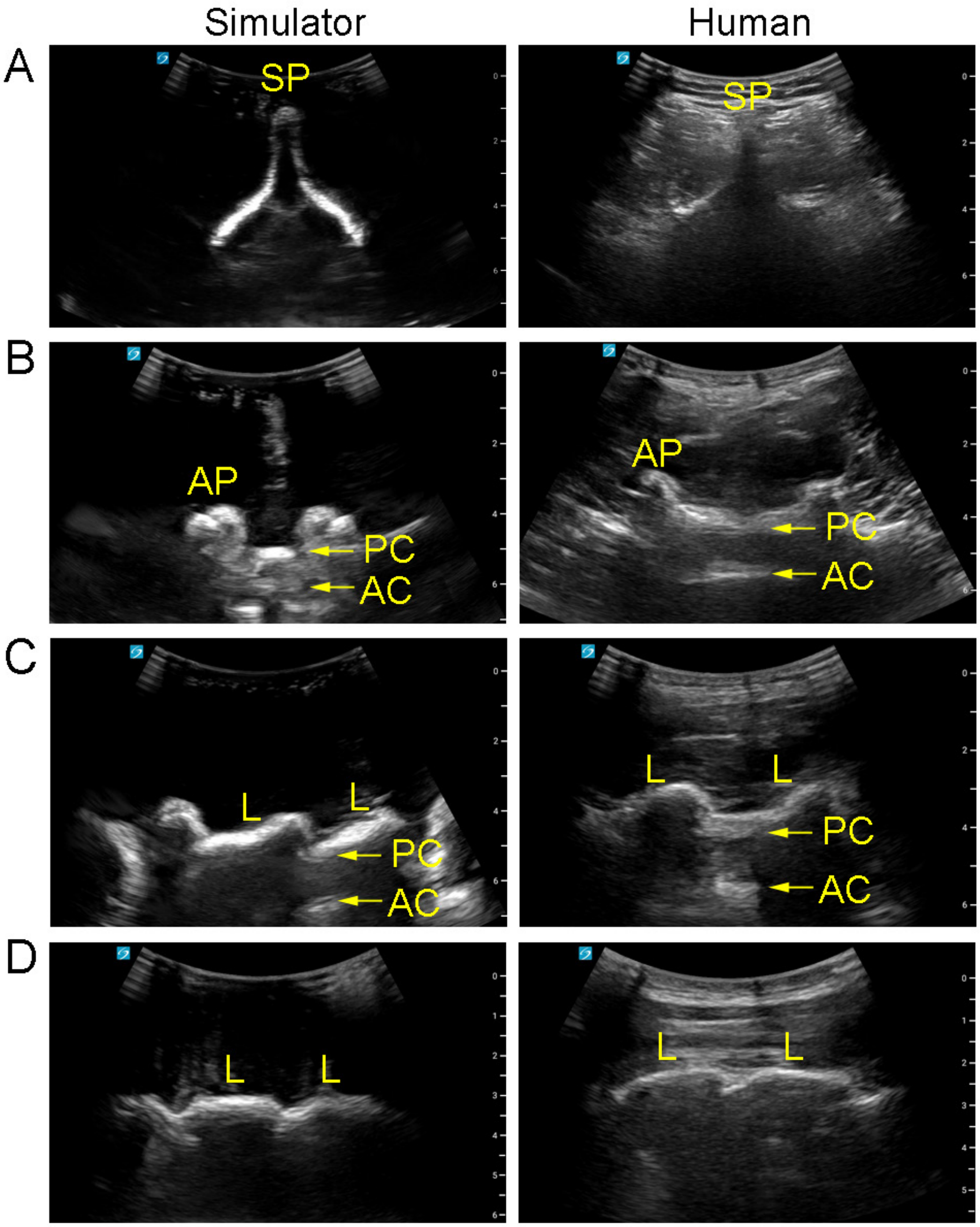

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Figure 4. *Flowchart of the study design.*

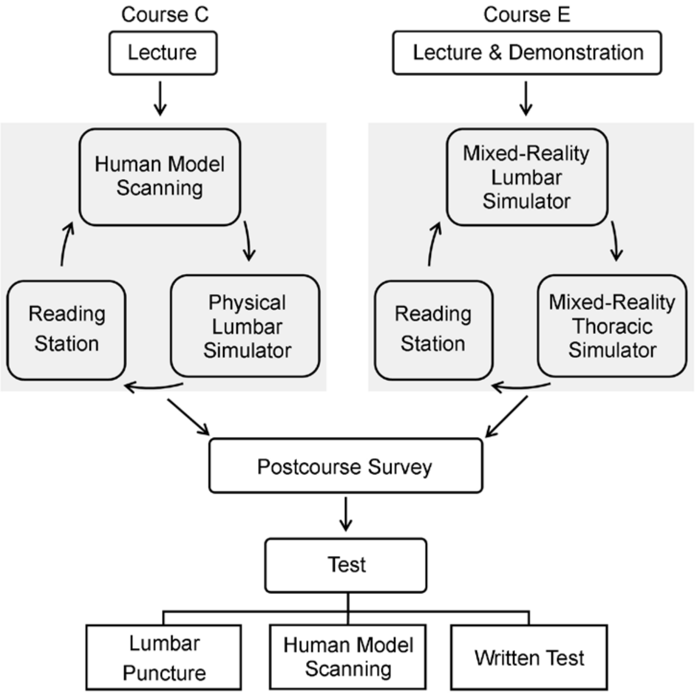

Figure 5. *Comparison of the total number of successful dural punctures performed by each learner in courses C and E. Each black dot represents the total number of successful dural punctures performed by a learner. Blue circles and bars represent the mean and standard error (n = 12 for each course).*

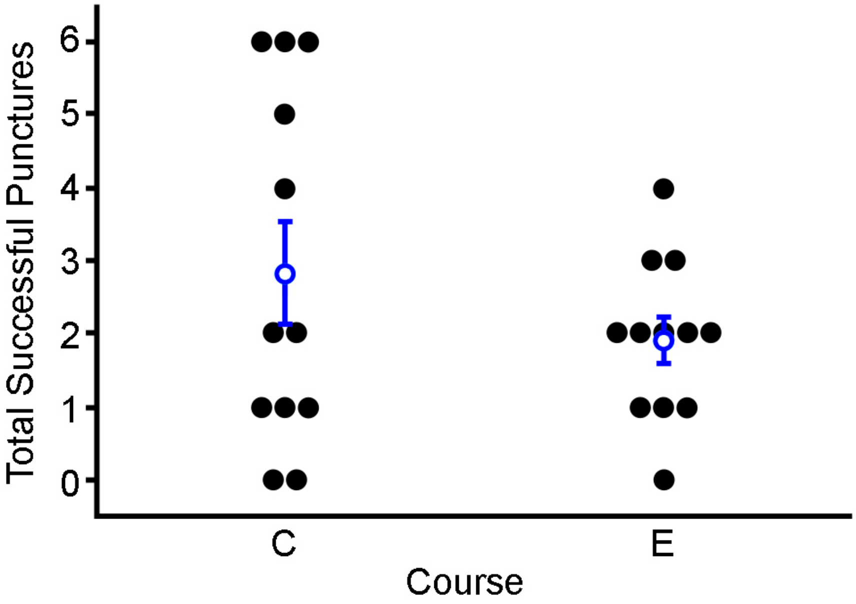

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Table

Table 1. *Learners' Demographic Information*

		Course C	Course E	*P* value
Age (years)		30.0 ± 1.4	29.6 ± 1.5	.84
Sex	Female	3	5	.67
	Male	9	7	
Experience in performing neuraxial procedures	0	7	8	.58
	<20	4	4	
	>50	1	0	
Experience in using ultrasound for procedures	Barely used it before	2	5	1.0
	Used it a few times	10	7	

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Supplemental Online Material

ID:_________

1. After entering the skin, a spinal needle will penetrate the following subsequent tissue layers to reach CSF via midline:
   - A. Subcutaneous fat, interspinous ligament, supraspinous ligament, ligmentum flavum, dura
   - B. Subcutaneous fat, supraspinous ligament, interspinous ligament, ligmentum flavum, dura
   - C. Subcutaneous fat, ligmentum flavum, supraspinous ligament, interspinous ligament, dura
   - D. Subcutaneous fat, ligmentum flavum, dura, supraspinous ligament, interspinous ligament

2. At what level does the conus medullaris most commonly end in adults?
   A. T12/L1 B. L1/L2 C. L2/L3 D. L3/4
3. At what level does the dura sac most commonly end in adults?
   A. L5/S1 B. S1/S2 C. S2/S3 D. S3/S4

4. What is the average anterior-posterior dimension of the lumber sac in normal young adults?
   A. 7-9 mm B. 13-15mm C. 10-12 mm D. 16-18mm
5. What is the average anterior-posterior dimension of the supraspinous + interspinous ligaments?
   A. 26-30 mm B. 31-35 mm C. 36-40 mm D. 21-25 mm
6. The ligamentum flavum is the thickest at _____ spine.
   A. Cervical B. Thoracic C. Lumbar D. Sacral
7. The ligamentum flavum becomes thinner as people age.
   A. True B. False
8. What is the average anterior-posterior dimension of lumbar ligamentum flavum at midline in a young healthy adult?
   A. 4-5 mm B. 6-7 mm C. <1 mm D. 2-3 mm
9. A 62-year-old otherwise healthy patient presents for knee replacement. He took nonsteroidal anti-inflammatory drugs (NSAIDs) 2 hours ago. The operation will take 45 minutes and the patient is interested in spinal anesthesia. Which of the following anesthesia plan is the best option?
   - A. Spinal anesthesia with bupivacaine
   - B. Spinal anesthesia with lidocaine
   - C. Spinal anesthesia with chloroprocaine
   - D. General anesthesia because spinal anesthesia is not appropriate for this patient.

10. The "pop" felt just before entering the epidural space represents passage through which ligament?
    - A. Posterior longitudinal ligament
    - B. Ligamentum flavum
    - C. Supraspinous ligament
    - D. Interspinous ligament.

11. When performing a single-shot spinal anesthetic, the level of block for motor, sensory, and sympathetic blocks differs often by at least two dermatomes. Which of the following sequences is correct from the highest to the lowest level of block?
    - A. Sensory, sympathetic, motor
    - B. Sympathetic, sensory, motor
    - C. Sympathetic, motor, sensory
    - D. Sensory, motor, sympathetic

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Supplemental Online Material *continued*

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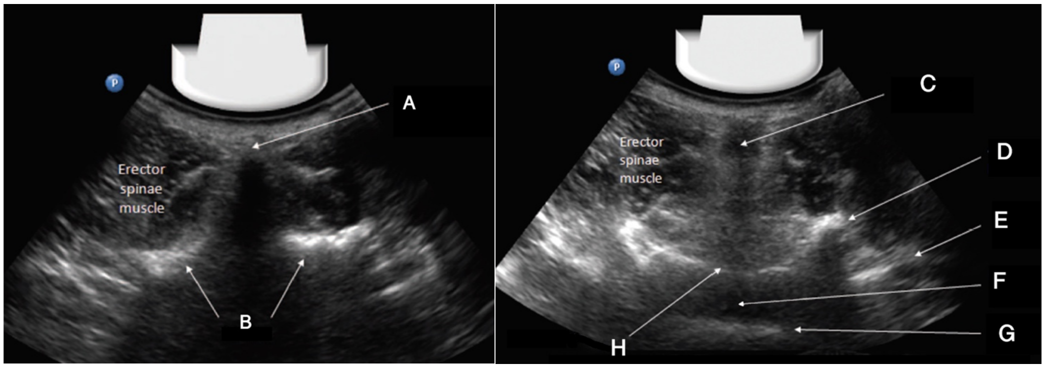
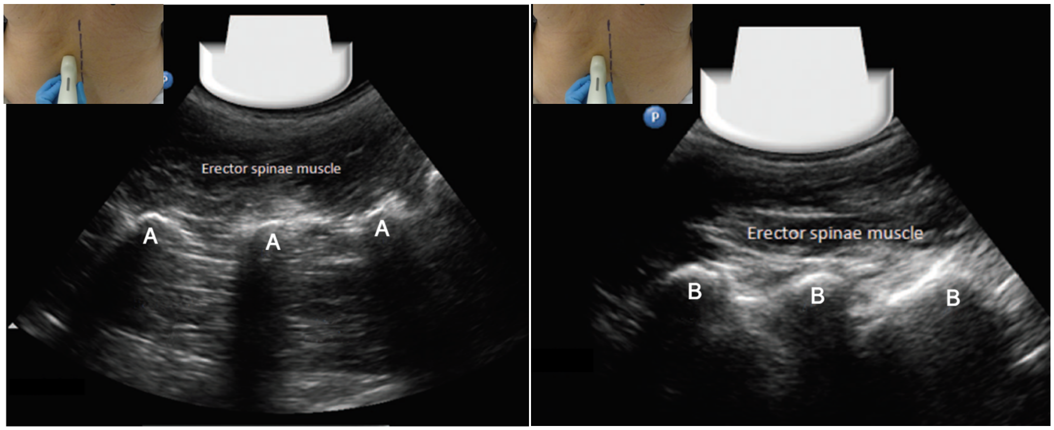
12. in the two transverse scan views, match the letters to the corresponding structures listed below:

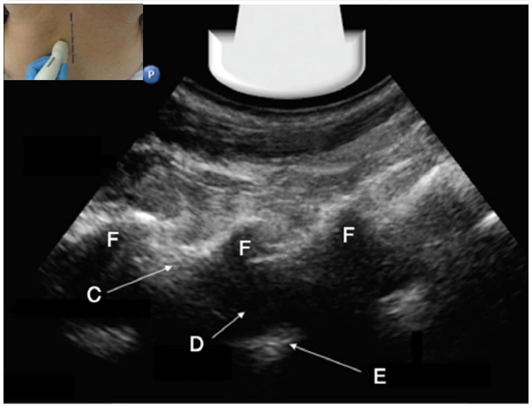


___ Transverse process
___ Lamina
___ Intrathecal space
___ Articular process

___ Spinous process
___ Interspinous ligament
___ Anterior complex
___ Posterior complex

13. In the following paramedian and paramedian oblique views, match the letters to the corresponding structures listed below:





___ Transverse process

___ Intrathecal Space

___ Lamina

___ Anterior complex

___ Articular process

___ Posterior Complex

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14. Which of the following would have the GREATEST effect on the level of sensory blockade after a subarachnoid injection of hyperbaric 0.75% bupivacaine?
    A. Patient age
    B. Addition of epinephrine to the local anesthetic solution
    C. Patient weight
    D. Patient position

15. The common element thought to be present in cases of cauda equina syndrome after continuous spinal anesthesia is
    A. Use of microcatheter
    B. Maldistribution of local anesthetic
    C. Administration of lidocaine
    D. Addition of epinephrine

16. Severe hypotension associated with high spinal anesthesia is caused primarily by
    A. Decreased cardiac output secondary to decreased preload
    B. Decreased systemic vascular resistance
    C. Decreased cardiac output secondary to bradycardia
    D. Decreased cardiac output secondary to decreased myocardial contractility

17. Select the FALSE statement regarding spinal anatomy and spinal anesthesia.
    A. The addition of phenylephrine to lidocaine will prolong spinal anesthesia
    B. A high thoracic sensory block will result in total sympathetic blockade
    C. The largest vertebral interspace is L5-S1
    D. The dural sac extends to the S4-S5 interspace

18. A 75-year-old man is scheduled to undergo elective orchiectomy for prostate cancer. The patient has selected spinal anesthesia. What is the minimum dermatomal level that must be achieved to carry out this operation?
    A. T4 B. T10 C. L3 D. S1