Stathas et al. BMC Medical Education (2024) 24:931
https://doi.org/10.1186/s12909-024-05907-z

BMC Medical Education

RESEARCH

Open Access

Teaching medical students ultrasound-guided needle aspiration of synthetic cysts: effect of a formalin-embalmed cadaver simulation model

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Abstract

Background Standard training for ultrasound-guided cyst needle aspiration is currently performed on live patients during residency. This practice presents risk of iatrogenic injury to patients and provides a high-stress learning environment for medical trainees. Simulation training using synthetic cysts in a formalin-embalmed cadaver model may allow for realistic, practical, and effective training free from patient risk.

Methods Thirty first-year medical students viewed an orientation video, then attended a skills workshop to perform cyst needle aspiration in formalin-embalmed cadaver tissue under ultrasound guidance. Participants were randomly assigned to one of three ultrasound-trained instructor-types which included a medical student, clinical anatomist, or an ultrasound fellowship trained emergency medicine physician. After training, participants underwent a 5-min skills test to assess their ability to drain a synthetic cyst independently. Pre- and post-training self-confidence surveys were administered.

Results Ultrasound images of synthetic cysts in formalin-embalmed tissue were clear and realistic in appearance, and sonographic needle visualization was excellent. Participants took an average of 161.5 s and 1.9 attempts to complete the procedure. Two of the 30 participants could not complete the procedure within the time limit. Participants' self-reported confidence with respect to all aspects of the procedure significantly increased post-training. Mean confidence scores rose from 1.2 (95% CI 0.96 to 1.39) to 4.4 (95% CI 4.09 to 4.53) ($P < 0.0001$) Procedure time, number of attempts, performance scores, and self-confidence outcomes were not significantly affected by instructor type.

Conclusions The use of synthetic cysts in formalin-embalmed cadaveric tissue is feasible, realistic, and efficacious for the teaching of ultrasound-guided needle aspiration to novice medical trainees. This simulation training method can be delivered effectively by multiple instructor types and may allow medical trainees to increase their tactical skill and self-confidence prior to performing ultrasound-guided cyst needle aspiration on live patients.

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Keywords Education medical, Formalin embalmed cadaver, Simulation training, Students medical, Ultrasound guided procedure training, Ultrasound abscess drainage, Ultrasound training

Background

New residents and medical students have reported feelings of inadequate training and unpreparedness to perform invasive procedures on patients during residency [1]. When teaching medical trainees to perform any procedure, deliberately investing in skills that balance clinical utility, feasibility, and efficacy is crucial. Ultrasound (US) guidance is a highly applicable skill that decreases complication rates and increases success rates in new learners when used to guide procedures [2–6]. Its use spans multiple clinical disciplines, adds minimal risk to patients and is readily accessible to novice users.

At present, standard training for US-guided cyst drainage takes place during residency on live patients. Given the high level of spatial reasoning and hand–eye coordination required to simultaneously manipulate a transducer and needle to drain a cyst under US guidance, these procedures carry a high risk of iatrogenic injury when performed by untrained providers. These risks are likely to increase in the context of difficult anatomical regions. One of the most common US-guided aspiration errors noted amongst trainee residents is a failure to appropriately visualize and track the needle tip before penetrating deeper structures [7]. Previous studies have demonstrated that simulation training significantly reduces novice errors and improves patient outcomes [8–10]. Critical determinates of complication rates have also been found to be associated with the skill, knowledge, and confidence of a performing clinician [11]. Early opportunities for deliberate and realistic training with US-guided needle-based procedures for medical trainees may improve objective competence and subjective confidence in accessing and drainage cysts. Formalin-embalmed cadavers are available at many medical education institutions and can be used to create realistic, cost effective, and low stress training simulations for US-guided procedures [12, 13].

The primary aim of this study was to develop a practical, realistic, and inexpensive simulation method of teaching medical students US-guided needle aspiration of synthetic cysts in formalin-embalmed cadavers. This study explored changes in subjective self-confidence, and objective skills performance of participants following hands-on training with simulated cysts in formalin-embalmed cadavers. A comparison of the efficacy of instruction delivered by 3 distinct types of instructors including a medical student, a US-educator clinical anatomist, and an US-fellowship trained emergency medicine physician was also conducted. The authors examined the feasibility of this training method to allow new medical trainees to hone their skills and increase their self-confidence through realistic and repeated practice in US-guided cyst drainage in a low stress environment that is free from patient risk.

Methods

Setting and participant recruitment

This study was conducted in the gross anatomy laboratory at the Geisel School of Medicine at Dartmouth College. The Geisel class of 92 first-year medical students were contacted via email and invited to volunteer to participate in the study. 30 students were enrolled and signed a written consent form. Twenty-five participants reported no prior US experience and 29 participants had never used US to guide a needle. Approval of the study was granted by Dartmouth Committee for the Protection of Human Subjects (#00032735).

Equipment

Three Mindray MX7 ultrasound systems equipped with L12-3RC linear transducers (Mindray Global, Shenzhen China) were used to guide 18 g 2-inch hypodermic needles on 30 cc syringes during cyst needle aspiration.

Study design

This is a single-center non-randomized interventional study. Participants took a pre-training survey that used a 5-point Likert scale to gauge their self-confidence in performing various aspects of the procedure. It also gathered information about demographics and their experience level with US and with the procedure itself prior to training. Next, participants watched a 15-min training video covering the basics of imaging synthetic cysts and the steps required to access and drain them using a static (in-plane) approach under US-guidance prior to attending a training workshop. During the workshop, participants were allotted 20 min to practice the procedure. Each participant was paired with an instructor for one-on-one teaching at simulation station with three synthetic cysts in place. Each cyst could be accessed with a needle repeatedly before drainage, and students were given unlimited attempts to practice the procedure during this time.

Following the 20-min training period, each instructor rotated stations so they would not administer a skills test to a participant they had trained. Participants were given

5 min to pass a skills assessment during which they were required to image and fully drain a single cyst. Full drainage was defined as aspirations between 15–20 CCs of the fluid from a single cyst, as confirmed by the instructor. 3 cysts, on the opposite side of the cadaver from training, were available to the student for testing, should one rupture. Metrics regarding participant performance in the skills test were recorded by each instructor using a procedure assessment rubric (Appendix 1). An adapted version of a previously validated global ratings scale rubric [14] was also used to rate each participants performance using several pre-specified metrics (Appendix 1). Following skills testing, a post-training survey was administered. Questions on this survey mirrored the pre-training survey with the addition of an open-ended opportunity for participants to share their thoughts regarding the training program for the purpose of identifying any major weakness in the training methodology to advise future training program design.

Instructors

The participants were randomly assigned to one of three instructors, each with expertise in delivering US training. Instructors included a second-year medical student with 3 years' experience teaching US to residents, medical students, and prehospital providers; an US educator and clinical-anatomist faculty member with 9 years' experience teaching US skills to clinicians, medical students, and prehospital providers; and an US fellowship trained emergency medicine physician with 3 years' experience teaching US skills to clinicians, medical students, and prehospital providers. All instructors used a teaching rubric during training sessions to standardize the learning experience for each participant as much as possible. Instructors used verbal instruction, hand-over-hand guidance, and physical demonstration to teach participants to perform the procedure. Each participant was randomly assigned to their instructor and statistical analysis was performed to determine if the assigned instructor affected participant performance on the skills test.

Procedure simulation stations

Each simulation station (Fig. 1E–G) was equipped with an US machine and a linear transducer covered with a non-sterile plastic probe cover. The table at each station contained a prone formalin-embalmed cadaver with a 4 mm layer of opaque plastic sheeting covering the entire body donor and table. Holes were cut in the plastic that were just large enough to expose the procedure sites. An instrument tray containing a syringe equipped with a needle was placed over the cadaver's torso. Synthetic cysts were created using 7-inch latex balloons containing approximately 20 cc's of tap water and placing them approximately 1″ below the skin in the subcutaneous fat tissue. Three cysts were placed on each side of the body, spaced evenly along the buttock and posterior thigh.

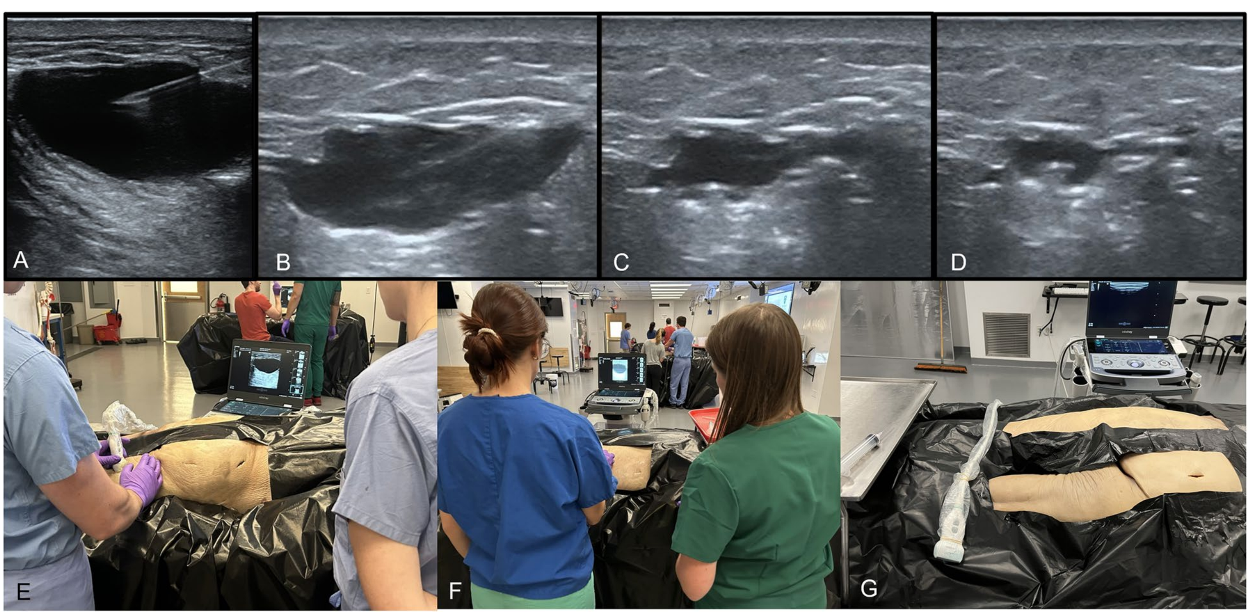

Fig. 1 Ultrasound Imaging of Synthetic cysts and Simulation Stations. **A**-**D** show a sequential series of ultrasound images demonstrating the sonographic appearance of synthetic cyst drainage in formalin-embalmed cadaver tissue. **E**–**G** depict components of simulation stations including a trainee, instructor, syringe and needle, ultrasound machine and linear probe, and a formalin-embalmed cadaver with synthetic cysts placed in the subcutaneous tissue. Informed consent to publish images in panels **E** and **F** was obtained from study participants

Three 1.5″ incisions were made along the lateral aspect of the buttock/thigh and blunt dissection was used to create a narrow tunnel through the subcutaneous tissue medially to allow a cyst to be placed under the skin a minimum of 2″ medial to the incision site. Care was used to displace as little of the fat as possible during tunneling and cyst placement to minimize air infiltration into the tissue and gross sonographic visualization of the cyst. Each cyst placement site was imaged with US to ensure proper cyst depth and adequate US image quality. The 3 cysts on one side of the body donor were utilized for teaching and the 3 on the opposite side were used for skills testing.

Statistical analysis

Demographic, pre-test and post-test confidence assessment along with objective performance score variables we compiled in a spreadsheet. Time to complete the procedure variable was converted to seconds. Descriptive statistics were calculated for categorical variables (categories and Likert scores) as frequencies while continuous variables (attempts and time to complete the procedure) were calculated as means with their respective standard errors. Associations were assessed using different tests depending on the type of variables evaluated. Although we present confidence (Likert scores) as means these were assessed using non-parametric Wilcoxon signed-rank tests due to non-normality issues. Other associations were evaluated using Generalized Linear Models where residual distributions were optimized through -2 Residual Log-Likelihood model fit assessments (smallest) on preliminary models. For discrete count data the negative binomial distribution provided the best fit while for continuous data the Gaussian distribution provided the best fit. Success of the procedure was assessed using a contingency table with an Exact test. All statistical analysis was performed on SAS/STAT v.9.4 (SAS Institute Inc., Cary, NC). Significance was declared at $P \leq 0.05$ and estimates are presented with their respective 95% confidence interval.

Results

Ultrasound images of synthetic cysts in formalin-embalmed tissue

Figure 1A-D showcase the sonographic clarity and realistic nature of ultrasound images acquired during the drainage of synthetic cysts in formalin-embalmed cadaver tissue. The subcutaneous tissue, synthetic cysts, and needle were all clearly visible during US guidance.

Subjective surveys

Figure 2 depicts the results of participants' pre- and post-training self- confidence survey responses (Appendix 2). Analysis via Wilcoxon-signed rank test revealed a significant increase in reported self-confidence with the various steps of the procedure post-training across all survey items ($P < 0.0001$). Overall mean Likert scores rose from 1.18 (95% CI 0.96 to 1.39) to 4.31 (95% CI 4.09 to 4.53) following training ($P < 0.0001$). The open-ended feedback from participants regarding the training program collected using the post-training survey did not reveal any recuring themes in participant-identified problems with the design of the training program.

Skills testing

Figure 3A displays mean scores of participant performance during skills testing using a global ratings scale rubric (Appendix 1). Panel B of Fig. 3 shows the collective performance of participants on specific skills test performance metrics on the skills assessment rubric (Appendix 1). Participants took an average of 161.5 ± 12.4 s to independently image and fully drain a cyst during the skills assessment. Full drainage was defined as aspiration of approximately 15-20 cc of fluid by volume into the syringe as confirmed by the instructor administering the assessment. This was achieved by participants in a mean number of 1.9 ± 0.2 attempts. An attempt was defined as an individual needle stick needed to correctly place the needle within the cyst (large needle angle re-directs within the tissue were not permitted in order to preserve the integrity and reusability of the cadaver tissue for subsequent participants). Two of the thirty students did not pass the skills test by failing to complete the procedure within the 5-min time limit. One participant failed because they could not break the pressure seal to withdraw the plunger to aspirate, although their needle guidance technique was ideal. The second failure was caused by poor imaging technique and using an overly flat angle of approach while advancing the needle.

Participant performance by instructor type

A series of statistical tests were performed to assess for associations in skills performance and confidence of participants, based on instructor-type. The results of these analyses are depicted in Table 1. No differences were identified in participant procedure time, number of attempts, procedure performance metrics, or subjective self-confidence outcomes regardless of the assigned instructor type. Exact P-values for all non-significant values are reported in Table 1.

Discussion

Participant skills

Simulation training has been shown to consistently improve success rates and decrease complications in US-guided needle-based procedures in medical trainees

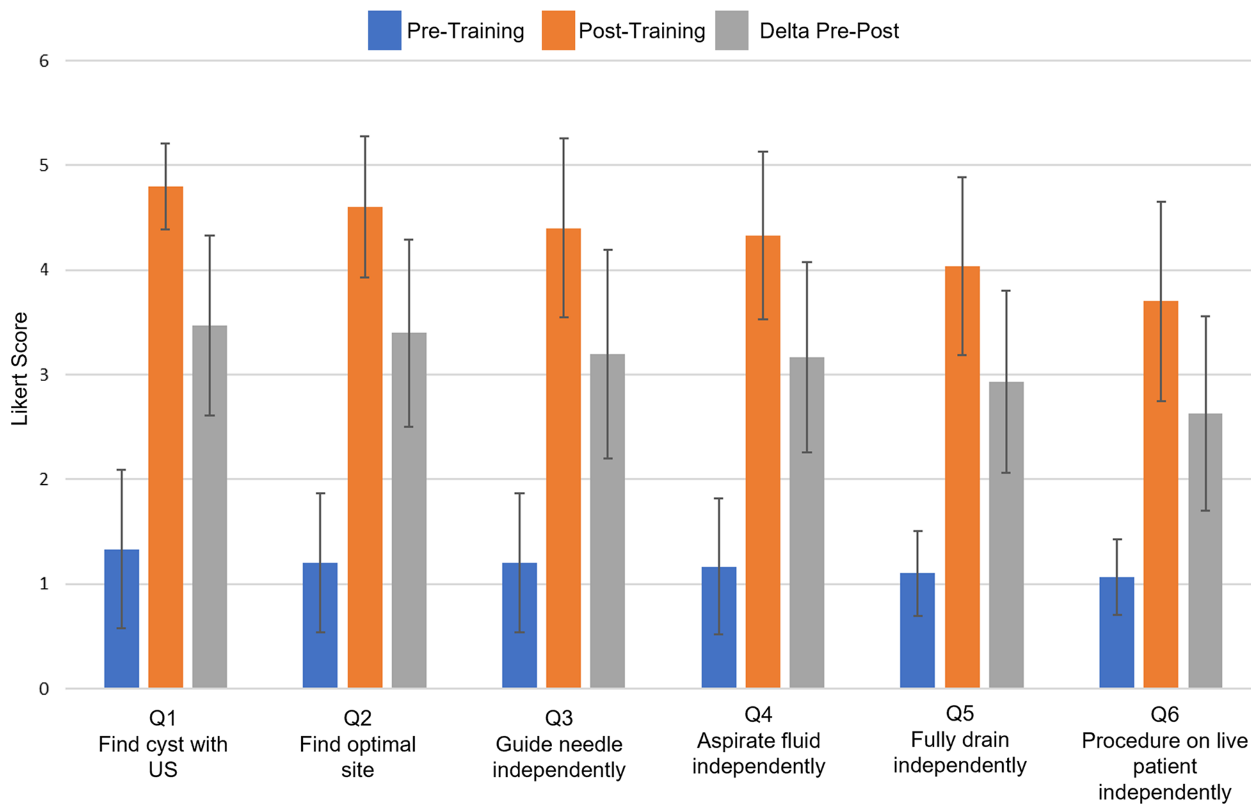

Fig. 2 Participant self-reported confidence before and after training. pre- and post-training responses to a subjective self-confidence survey related to performing various aspects of an ultrasound-guided cyst needle aspiration procedure. Participants used a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree) to indicate their confidence in performing each task. Significance was assessed via Wilcoxon signed-rank test revealed that all Likert scores increased significantly following training ($P < 0.0001$)

A. **Procedure Perfromace Variable**	**N**	**Mean**	**Std Dev**	**Min**	**Max**
Respect for tissue	30	4.46	0.899	2	5
Time and motion	30	3.1	1.213	1	5
Instrument handling	30	3.06	1.172	1	5
Flow of procedure	30	3.4	1.162	1	5
Knowledge of procedure	30	3.63	0.927	2	5
Overall performance	30	3.2	1.242	1	5

B. **Skills Test Varible**	
Mean procedure time	161.5
Mean number of attempts	1.9
Number of skills test failures	2

Fig. 3 Post-training skills assessment and outcome measures. **A** reports participant performance in 5 measured skills and knowledge variables and overall performance as objectively ranked (1 to 5) by an instructor using metrics in the procedural skills rubric (Appendix 1). **B** reports mean skills assessment outcomes as objectively reported by instructors (Appendix 1). Procedure time ended at drainage of 15–20 ccs of fluid as confirmed by an instructor. The number of attempts was defined as individual needle sticks necessary to complete the procedure

Table 1 Displays a comparison of the performance between participant groups that were taught by each of the three instructor-types by specific performance variable. Specific statistical tests used and associated *P*-values of each metric are reported

Variable	Test type	*P*-value
Success of the procedure	Contingency table (exact test)	1
Time to complete (seconds)	Linear model (Gaussian)	0.413
Number of attempts	Linear model (negative binomial)	0.890
Respect for tissue	Linear model (negative binomial)	0.607
Time and motion	Linear model (negative binomial)	0.517
Instrument Handling	Linear model (negative binomial)	0.520
Flow of procedure	Linear model (negative binomial)	0.816
Knowledge of procedure	Linear model (negative binomial)	0.760
Overall performance	Linear model (negative binomial	0.639
Pre training overall confidence (Sum)	Linear model (Gaussian)	0.166
Post training overall confidence (Sum)	Linear model (Gaussian)	0.390

Effects of Instructor-Type on Objective Participant Performance Measures

[7, 10, 15]. Through deliberate and repeated practice on cadavers and task trainers, medical trainees can learn to perform critical bedside procedural skills in a risk-free environment [12, 13, 16]. Participants in this study were able to successfully use US-guidance to fully drain a synthetic cyst, independently, in less than 5 min (mean: 161.5 ± 12.4 s), with a mean of 1.9 ± 0.2 attempts. With only a 20-min time period of one-on-one training, first-year medical students were able to establish proficiency and practice building the tactile skills necessary to simultaneously manipulate a transducer and needle. Allowing medical trainees to build muscle memory and tactile skills through this novel simulation training methodology using synthetic cysts in cadavers, before performing the procedure on live patients, may ultimately increase patient safety and satisfaction by decreasing complication rates, patient discomfort, and the number of attempts required to complete a procedure. This notion is supported by previous studies demonstrating associations between increased simulation-based and supervised training experiences and decreased complication rates, improved clinical outcomes, and fewer malpractice claims in trainee procedures [10, 17–19].

Self-reported confidence

Medical students consistently report feeling unprepared to perform basic medical procedures without assistance [20–23]. Confidence in learned skills remains an important predictor of trainee burnout and academic satisfaction for medical students [24, 25]. Our data shows that the practice of draining synthetic cysts in cadavers significantly improves participants' confidence in their ability to perform all aspects of this procedure under US-guidance. Notably, participant confidence to perform the procedure on a live patient without help rose from 1.06 (95% CI 0.80 to 1.33) to 3.70 (95% CI 3.44 to 3.96) following training ($P < 0.0001$). Our data indicates that even short training opportunities for repeated realistic practice using synthetic cysts and formalin embalmed cadavers significantly improves medical student confidence in their procedural abilities.

Instructor types

This study also investigated the presence of confounding effects that instructor-type may have had on participant performance. Three instructor-types with prior US teaching experience were included in this study: namely, a second-year medical student with 3 years' experience, a US and clinical-anatomy educator with 9 years' experience, and an emergency medicine physician with 3 years' experience. Procedural duration and number of attempts required did not significantly differ between the instructor groups. Table 1 demonstrates that there were no statistical differences between groups in any other measured skills or confidence-related variables as well. This suggests that regardless of background, instructors with prior US teaching experience may be able to effectively deliver this training. Furthermore, numerous studies have established that peer-peer teaching of both bedside US and clinical skills can be effective [26–33]. In one study, participants rated the teaching competency of their peer US instructors as equivalent to their faculty instructors [24]. Another study found that clinical anatomy faculty can quickly learn and effectively teach trainees bedside

US at a level statistically indistinguishable from clinician educators [34]. Given the reported need for more US instructors across undergraduate and graduate medical education [35–38], the use of ultrasound-trained peers and anatomy faculty instruction may help address the demand for US educators. The non-contributory role of instructor type further underscores the accessibility of such US-guided cadaveric training programs for medical schools.

Limitations

Hands-on procedure-based training of this nature is logistically difficult to offer to large groups of learners. This study's applicability may also be limited to regions where cadaveric-based medical education is restricted. Furthermore, the authors acknowledge that this study's evidence level is confined to Kirkpatrick level 1, focusing on participants' confidence rather than clinical performance or patient outcomes This study explores both the feasibility of using formalin-embalmed cadavers and synthetic cysts to create a useful simulation training model that looks realistic on ultrasound imaging, and the efficacy of these novel training tools in teaching students US-guided needle aspiration skills. Nearly all US-guided cyst needle aspiration procedural training sessions are conducted with small groups of residents which are normally much smaller than 30. It would be valuable to include a power analysis in future studies of this nature. This study also contained no pre-training skills test, to determine the baseline ability of participants to perform the procedure. However, given the lack of US and procedural experience reported by participants on the pre-training survey, it is reasonable to assume performance on such a pre training skills assessment would have been poor. In the interest of the safety of the participants, the US equipment, and the body donor tissue, the authors felt it would not be prudent to allow untrained medical students to attempt to perform a procedure without preparation. Although this study was focused on introducing procedural skills early in medical education in order to promote tactile skills, muscle memory, and self-confidence in manipulating a transducer and needle simultaneously, it would be beneficial for future studies to examine the actual retention of skills related to performing this procedure as the participants advance through their medical education.

Conclusions

This project demonstrates the feasibility and efficacy of a novel training program to teach medical students how to perform US-guided needle aspiration of synthetic cysts in formalin-embalmed cadavers. US images of the synthetic cysts were noticeably clear and realistic, and needle visibility during the procedure was excellent. All training materials used were cheap and are readily available at most medical education institutions. Of the thirty participants, twenty-eight achieved a successful outcome, and participants reported significant increases in their confidence with respect to every assessed component of the procedure. When standardized training rubrics are used, our data suggests that both medical students and clinical anatomy faculty with US training can effectively teach medical trainees US-guided cyst needle aspiration. Using cheap and readily available materials, this project developed a realistic model for teaching clinically relevant US skills to medical trainees in a safe learning environment, without risk to patients. Allowing trainees to practice manipulating a transducer and needle simultaneously may contribute to decreased patient discomfort and complications when trainees eventually perform US-guided cyst drainage on live patients. Additionally, the tactile skills developed with this type of US-guided procedure training are broadly translatable to other types of US-guided procedures, which all require the same basic hand–eye coordination and dexterity development.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12909-024-05907-z.

Supplementary Material 1

Supplementary Material 2

Acknowledgements

The authors would like to thank those who donate their bodies to the medical sciences without whom educational projects like this would not be possible.

Authors' contributions

SS- study design, data collection, primary authorship. VB- study design, data collection, manuscript authorship. MK- study design, data collection, manuscript authorship. IZ- statical analysis, data interpretation, manuscript authorship. AT- data collection, manuscript authorship. NM- study design, data collection, corresponding authorship.

Funding

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

IRB approval to conduct this exempt study was provided by the Dartmouth Committee for the Protection of Human Subjects (#00032735). Permission to use body donors in this project was provided by the Geisel Anatomical Gifts Program.

Consent for publication
Informed consent to publish was obtained from the participants.

Competing interests
The authors declare no competing interests.

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Received: 28 November 2023 Accepted: 14 August 2024
Published online: 27 August 2024

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