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The Feasibility of Ultrasound-Guided Knee Arthrocentesis Training Using Formalin-Embalmed Cadavers

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Background: The use of ultrasound guidance during knee arthrocentesis has proven to increase operator confidence and accuracy, particularly in novice healthcare providers. Realistic and practical means of teaching this procedure to medical trainees are needed. This study is intended to assess the feasibility and efficacy of using formalin-embalmed human cadavers in the instruction of ultrasound-guided knee arthrocentesis to medical trainees.

Methods: Twenty participants received a 30-minute didactic orientation detailing the principles of ultrasound-guided knee arthrocentesis, followed by a training practicum performed on human cadavers. The practicum included a 25-minute training period, followed by a 15-minute assessment period. Participants were objectively assessed on their ability to independently aspirate synovial fluid from the suprapatellar bursa using ultrasound guidance. Digital pretraining and posttraining questionnaires were administered to evaluate each participant's confidence in their ability to independently locate the site of optimal needle placement and successfully aspirate synovial fluid with the guidance of ultrasound imaging.

Results: An analysis via the Wilcoxon rank sum testing revealed that participant self-confidence increased significantly after training across all assessment items ($p < 0.0001$). Fifteen participants (75%) successfully aspirated 1 mL of synovial fluid on their first attempt, whereas 3 participants (15%) were successful on their second attempt. Two participants (10%) failed to perform a successful aspiration within the 15-minute time limit. The average time required to aspirate 1 mL of synovial fluid was 41 seconds.

Conclusions: Ultrasound images of the formalin-embalmed suprapatellar bursa are of sufficient quality to use in the instruction of arthrocentesis to medical trainees. Brief instruction using formalin-embalmed cadaver models significantly increases trainee confidence and prepares first-year medical students to successfully and independently perform ultrasound-guided knee arthrocentesis.

Current approaches in the instruction of arthrocentesis employ the use of synthetic models, soft-embalmed cadavers, or live patients[1-3]. Arthrocentesis training commonly takes place during residency and most often occurs using synthetic models rather than live patients or cadavers. Few patients are willing to consent to be a part of arthrocentesis training because of the propensity for patient discomfort[3]. Recent publications report low levels of confidence among novice providers regarding their

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ability to perform invasive procedures. Medical students and recent medical graduates self-reported proficiency in common clinical procedures including suturing and venipuncture but reported a lack of exposure to more invasive procedures including central venous access and arthrocentesis[4,5]. Although many medical education programs possess resources necessary for the instruction of invasive clinical procedures, medical students remain unprepared to perform arthrocentesis when entering residency[6].

Synthetic training models offer a safe and low-stress introduction to invasive procedures but pose limitations including prohibitive cost, inaccurate tactile representation of live tissue, and relative inaccuracy of anatomical relationships[2]. The use of human cadavers retains the benefits of simulated training while more accurately representing the kinesthetic quality of living tissue. Professionals trained to perform invasive procedures on cadaver models demonstrate greater self-efficacy and superior performance scores than those trained on synthetic models[7]. Formalin-embalmed cadavers are most commonly used for gross anatomy instruction in medical education because of tissue durability, simplicity of preparation, and low cost of maintenance[8]. Consequently, the formalin-embalmed cadavers are a compelling model for early-career introduction to invasive procedures.

Despite the benefits of using formalin-embalmed cadavers in procedural training, skepticism regarding their utility in ultrasound training persists. The main barrier to the use of the formalin-embalmed cadaver in ultrasound training is tissue desiccation, which diminishes sonographic image quality in many tissues[9,10]. Owing to the convenience and availability of the formalin-embalmed cadavers among medical education institutions, the authors seek to identify acoustic windows yielding clear ultrasound images for use in clinical procedural training.

This study aims to evaluate the feasibility and efficacy of using formalin-embalmed cadavers in the instruction of ultrasound-guided knee arthrocentesis. This objective was met by first acquiring and assessing ultrasound images for their ability to clearly visualize needle access to the formalin-embalmed suprapatellar bursa. The images acquired in this study demonstrate that the echogenicity of the formalin-embalmed cadaveric knee is sufficient for use in arthrocentesis training. Second, data presented in this study demonstrate the efficacy of using formalin-embalmed cadavers in the instruction of inexperienced medical trainees in ultrasound-guided knee arthrocentesis. The hand-eye coordination and probe/needle-handling skills developed by trainees in this study are generally applicable to all types of ultrasound-guided procedures and can be highly beneficial when introduced early in medical education.

Methods

Setting and Population

This study was conducted at a United States College of Osteopathic Medicine, accredited through the Higher Learning Commission and Commission on Osteopathic College Accreditation. The study design was reviewed and approved by the Rocky Vista University Institutional Review Board #2018-0053. After approval, 20 first-year medical students with 2 respective hours of formal ultrasound training and no previous experience in ultrasound-guided procedures volunteered as participants. All participants offered Institutional Review Board-approved written consent before involvement.

Equipment

Six Z5 Portable Doppler Ultrasound systems equipped with 12-14 MHz linear transducers were used throughout the study (Mindray Medical International Ltd.). Each transducer was wrapped in a Tegaderm film (3M Deutschland GmbHm), sealing a layer of transducer gel (McKesson Medical-Surgical) against its footprint. Arthrocentesis was performed using 2-inch, 21-gauge BD PrecisionGlide needles with 10 mL disposable syringes (Becton Dickinson and Company). A smaller diameter needle was used in this project to prevent synovial fluid leakage from cadaveric knees that were accessed multiple times during training periods.

Cadaver Imaging and Selection

A total of 42 knees from 21 formalin-embalmed cadavers were imaged with ultrasound to assess the adequacy of the image quality for use in the instruction of arthrocentesis (Fig. 1-A). After feasibility imaging, each knee was evaluated for synovial fluid volume (Figs. 1-B and 1-C) using a single-plane technique, as described by Chiba et al.[11]. A single ultrasound image of each bursa was measured by 2 blinded operators. The yielded values were averaged to determine synovial fluid volume, as depicted in Figure 2. Knees measuring ≥100 mm^2 in suprapatellar bursa synovial fluid volume were deemed adequate for clear sonographic visualization and needle access, thus eligible for use in this study.

Didactic Instruction

Each participant attended a 30-minute oral presentation outlining the general principles of ultrasound-guided procedure in clinical practice, the study's aims and goals, and needle safety. The training summarized the sonographic anatomy of the knee and described detailed procedural steps involved in both the static (long axis) and dynamic (short axis) approaches to ultrasound-guided knee arthrocentesis[12]. Participants were then provided written procedures as described in the oral presentation to electively review before practical instruction.

Practical Instruction

Trainees received 25 minutes of individualized instruction time to complete an unrestricted number of knee arthrocentesis attempts on formalin-embalmed cadaveric models before advancing to a 15-minute skills assessment. Participants were randomly assigned 1 of 2 instructors, each of whom had been trained to perform knee arthrocentesis by a licensed orthopaedic surgeon. Measures were taken to standardize sequential delivery of instruction across all trials. Each participant was instructed to locate the optimal site for needle placement by palpating the margins of the patella and the quadriceps tendon, sonographically visualizing the suprapatellar bursa, and locating the largest and most accessible collection of synovial fluid within the bursa. Participants were then taught static (long axis) and dynamic (short axis) approaches to ultrasound-guided knee arthrocentesis through a combination of instructor demonstration, verbal coaching, and hand-over-hand guidance. Two training

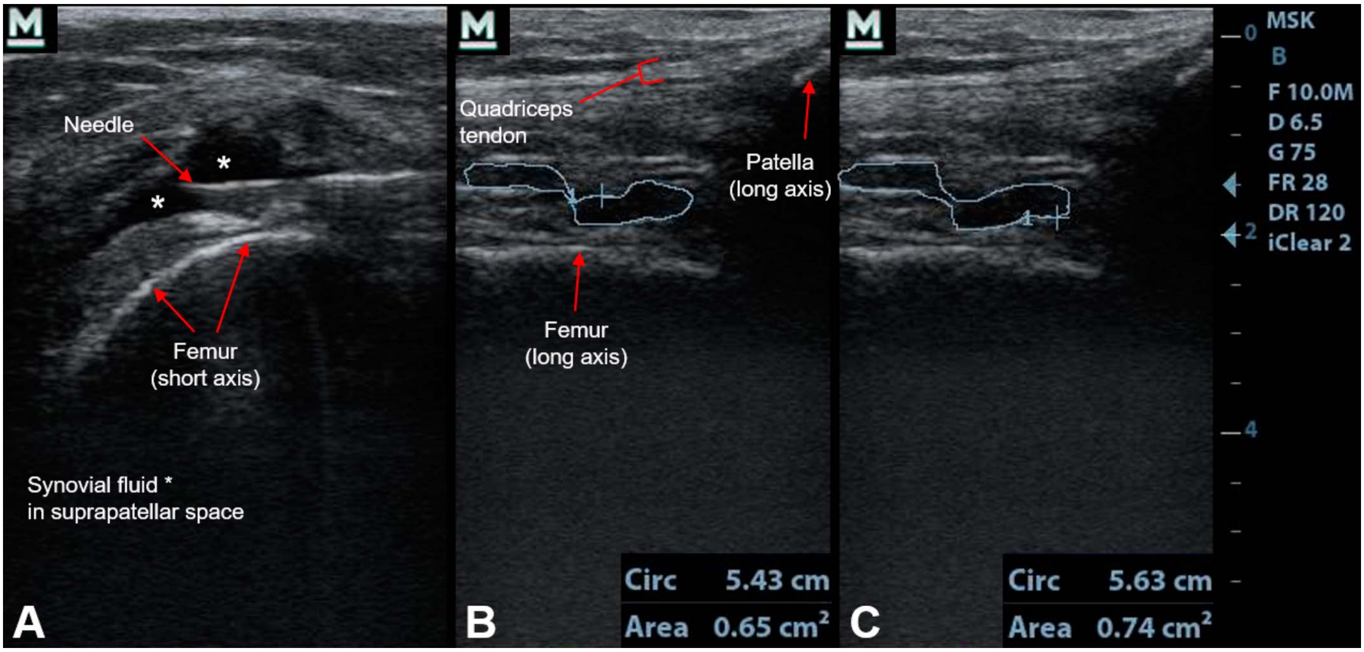

Fig. 1

Ultrasound imaging and synovial fluid volume measurement in formalin-embalmed cadavers. A series of ultrasound images depicting the suprapatellar region of formalin-embalmed cadaver knees. **Fig. 1-A** shows the suprapatellar bursa in a transverse plane during static (long axis) needle access, providing full visualization of the needle within the synovial capsule (red arrow). **Figs. 1-B and 1-C** illustrate a single plane technique used to measure synovial fluid volume in the longitudinal plane. Measurements were obtained by 2 blinded operators on a single ultrasound image (**Figs. 1-B and 1-C**) and averaged to determine synovial fluid volume

stations operated simultaneously, each providing participants 3 cadaveric knees for demonstration and practice. During both practical instruction and skills assessment, participants were instructed to aspirate 1 mL of synovial fluid into the syringe and then push the fluid back into the suprapatellar bursa without moving the needle tip. This ensured that any withdrawn synovial fluid was replaced directly from where it was taken to ensure that there was enough synovial fluid for the remaining participants to access.

Skills Assessment

Participants were assessed objectively on their ability to independently aspirate synovial fluid from the suprapatellar bursa using ultrasound guidance. Trainees used a static or dynamic approach according to personal preference. Each attempt was evaluated based on 3 criteria: time elapsed from initial needle stick to aspiration, volume of synovial fluid aspirated, and the number of needle sticks. Aspiration of

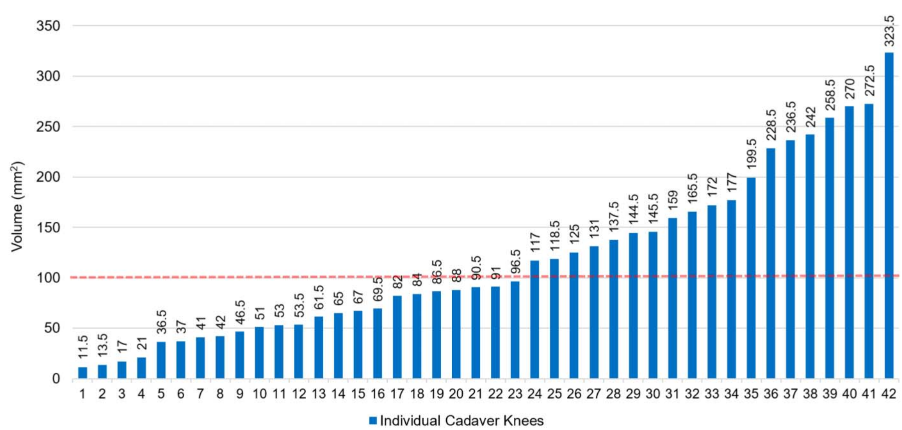

Fig. 2

Synovial fluid volume in formalin-embalmed cadaver knees. A distribution depicting the volume of synovial fluid found within the suprapatellar bursas of 42 cadaveric knees. The average synovial fluid volume across all knees calculated to be 118.8 mm^2. Nineteen knees (45%) contained a synovial fluid volume exceeding 100 mm^2 (red line), rendering them eligible for use in training and assessment.

TABLE I Self-Confidence Questionnaire Items*

Item Number	Questionnaire Item Text
1	I can recognize the appearance of the patella, femur, and suprapatellar space on an ultrasound image.
2	I can use an ultrasound machine to locate synovial fluid in the suprapatellar space of the knee.
3	I can use an ultrasound machine to find the optimal site for needle placement within the suprapatellar space of the knee.
4	I can use an ultrasound machine to guide a needle into the suprapatellar space of the knee without assistance.
5	I can aspirate synovial fluid from the suprapatellar space of the knee without help.
6	I am confident that I could use ultrasound to aspirate synovial fluid from the knee of a live patient if the procedure site was properly anesthetized for me.

*Assessment items from a self-confidence questionnaire administered posttraining. Participants quantified self-confidence using a 10-point Likert scale (0 = strongly disagree to 10 = strongly agree). Questions 1-3 correspond to panel A of Figure 2. Questions 3-6 correspond to panel B of Figure 2.

1 mL of synovial fluid within 2 minutes of a single needle stick qualified as a successful attempt and ended the assessment. Any attempt exceeding 2 minutes or requiring extraction of the needle from the skin was considered unsuccessful. Participants received 3 opportunities on successive knees to fulfill the proficiency criteria.

Subjective Assessment

Preceding didactic and practical instruction, study participants completed a digital questionnaire distributed via Google Forms (Google LLC), which indicated their previous experience operating ultrasound machines and performing ultrasound-guided procedures. The questionnaire used a sliding 10-point Likert scale (0 = strongly disagree to 10 = strongly agree) to quantify participants' confidence in their ability to independently perform 6 skill-based components of ultrasound-guided knee arthrocentesis (Table I). This same questionnaire, with the additional option to supply feedback, was administered after the skills assessment.

Statistical Analysis

A Wilcoxon rank sum test was used to analyze the statistical significance because the questionnaire items failed the Shapiro-Wilk test for normality. All statistical analyses were performed using SAS-STAT v.9.4 (SAS Institute Inc.). Significant differences were declared at $p \leq 0.05$.

Results

Cadaver Imaging and Selection

Ultrasound images of formalin-embalmed cadaver knees are shown in Figure 1, demonstrating the sonographic clarity obtainable. Panel A depicts the suprapatellar bursa in a transverse plane during static (long axis) needle access, providing full visualization of the needle within the synovial capsule. The image clearly delineates the suprapatellar space and its associated anatomical features including the quadriceps tendon and the distal shaft of the femur, patella, and synovial fluid. The volume of synovial fluid measured in the suprapatellar bursas of 42 cadaveric knees is illustrated in Figure 2. Knees containing a synovial fluid volume exceeding 100 mm^2 were deemed eligible for use in training and assessment. Of 42 knees, 19 (45%) met this criterion (red dotted line). The average synovial fluid volume across all measured knees was 119 mm^2.

Subjective Assessment

Participants reported no previous experience performing ultrasound-guided procedures of any kind. Self-confidence increased significantly across all assessment items after training ($p \leq 0.0001$) (Fig. 3-C). Participants were significantly more confident in their ability to identify sonographic anatomical landmarks and to use ultrasound to determine the optimal site for needle access (Table I, items 1-3). In this regard, confidence scores increased from an average of 2.9 to 9.2 (Fig. 3-A). The largest gains in participant confidence were observed in assessment items covering skill-related components of the arthrocentesis procedure, rather than the ultrasound imaging components. (Table I, items 4-6). Skill-related scores increased from an average of 1.6 to 8.45 (Fig. 3-B). A mixed linear model was used to assess the statistical relevance of subjective assessment outcomes according to the assigned instructor. As a covariate, assigned instructor showed no significant association to poststudy "confidence score." Statistically significant p-values for each questionnaire items are as follows: Q1: $p = 3.432 \times 10^{-6}$, Q2: $p = 3.118 \times 10^{-6}$, Q3: $p = 5.003 \times 10^{-6}$, Q4: $p = 7.159 \times 10^{-6}$, Q5: $p = 6.587 \times 10^{-6}$, and Q6: $p = 6.818 \times 10^{-6}$.

Skills Testing

Figure 4 illustrates the number of attempts and the length of time that participants needed to independently aspirate 1 mL of synovial fluid. Fifteen of the 20 participants (75%) successfully aspirated 1 mL of synovial fluid on their first attempt, whereas 3 participants (15%) succeeded on their second attempt. Two

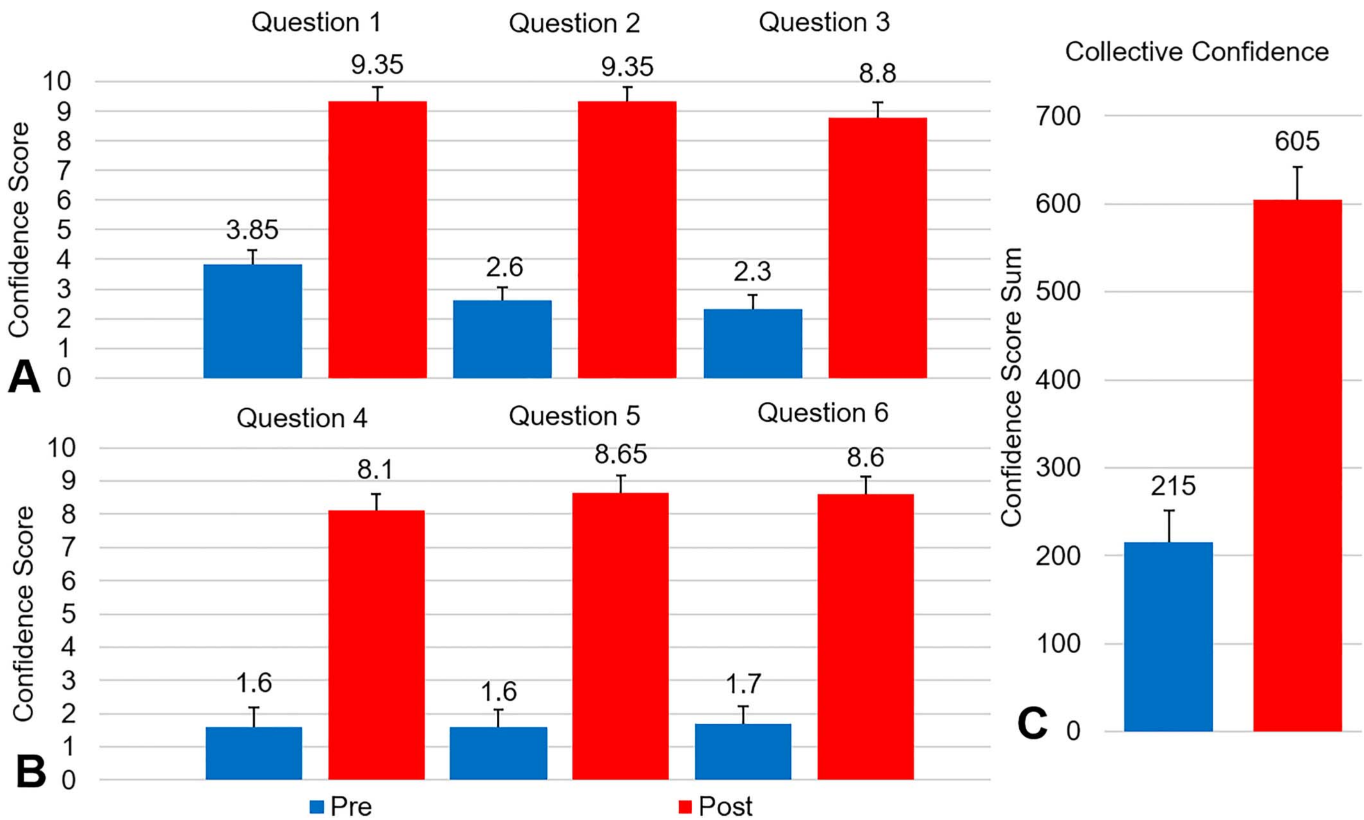

Fig. 3
Participant self-confidence pretraining versus posttraining. Quantitative responses to subjective self-confidence questionnaire items (Table I) pretraining and posttraining with standard mean error bars. Questionnaire items 1-3 (**Fig. 3-A**) assessed participant confidence related to ultrasound imaging of the knee, whereas questionnaire items 4-6 (**Fig. 3-B**) assess participant confidence in performing knee arthrocentesis. **Fig. 3-C** depicts the collective change in participant confidence when all assessment items are aggregated together. An analysis via the Wilcoxon signed rank test found that changes in participant confidence after training was significant across all individual and collective assessments ($p < 0.0001$) ($n = 20$).

participants (10%) who failed to meet the proficiency criteria within the 15-minute time limit and were excluded from the results in Figure 4. A mixed linear model was used to assess the statistical relevance of skills assessment outcomes according to each assigned instructor. As a covariate, the instructor assigned to each participant showed no significant association to participant skill assessment performance.

Participant Comments

Participants were invited to submit feedback regarding their experience in the cadaver workshop. Responses were overwhelmingly positive. One participant remarked, “This experience was extremely beneficial. I walked into this having no education on where the suprapatellar space was via ultrasound, and after 30 minutes I feel very confident that I could perform this procedure on a live patient. The ability to feel the real patella, tendon, and see the fluid within the pocket on a donor body was an amazing learning experience. I feel like I was able to truly experience it prior to performing it on a patient in rotations.”

Several participants commented on the anticipated clinical benefit of having received training on cadaveric models. Comments included, “I thought it was interesting to notice the difference in (suprapatellar) spaces between each (cadaveric) patient, and also to be able to successfully find the space and place the needle. It also taught me how to hold a syringe and withdraw the plunger better. Adjustments I had to make in training would have been nerve-wracking to perform on a live patient,” and “The smaller/skinnier knees were more difficult (to aspirate) because the sides of the ultrasound probe would be dangling in space sometimes and create odd images on the screen, but such is life with a real patient. Overall, it was a great experience.” Another participant commented, “I felt like the training was thorough and I felt like I learned a skill in a low-stress environment that will actually correlate to how I will do the same procedure in practice. I wouldn’t change anything. I learned to aspirate a knee in just under 30 minutes so I don’t think it can get any better.” Participants identified the use of a larger gauge needle as a limitation of the study; the larger gauge increased the difficulty of aspirating the viscous synovial fluid from the joint space. A larger diameter needle was used in this project to minimize synovial fluid leakage from the cadaveric knees that were subjected to repeated needle sticks after withdrawal of the needle.

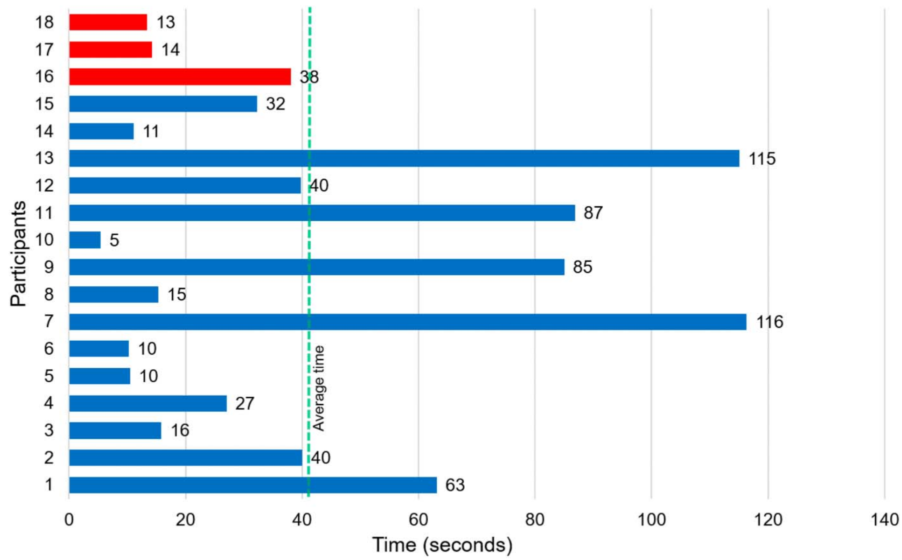

Fig. 4

Time to successful aspiration of 1 mL of synovial fluid. A bar graph depicting the length of time required for each participant to independently aspirate 1 mL of synovial fluid during skills assessment. Aspirations performed successfully on the first attempt are represented by blue bars. Successful trials requiring 2 attempts are represented by red bars. Two participants who were unable to complete the assessment within the time limit have been excluded. Average time required to aspirate 1 mL of synovial fluid across all successful participants was 41 seconds (green dotted line).

Discussion

Cadaver Imaging

The scientific and medical communities have previously neglected to use formalin-embalmed cadavers in ultrasound-guided procedure training because of joint rigidity and diminished tissue water content. These factors are known to inhibit the ease of manipulation and diminish sonographic image quality in specific tissues[9,10]. Ultrasound images obtained in this study clearly depict the suprapatellar space, synovial fluid, patella, femur, quadriceps tendon, and needle (Fig. 1) even with the use of mid-range quality ultrasound machines. These images demonstrate the efficacy of formalin-embalmed cadavers as a model in the instruction of ultrasound guided knee arthrocentesis.

Subjective Assessment

Outcomes in subjective assessment demonstrate that the use of formalin-embalmed cadavers in the instruction of ultrasound-guided knee arthrocentesis significantly improves trainee confidence (Fig. 3). After brief instruction, medical trainees are significantly more confident in identifying knee anatomy on ultrasound images and in determining proper needle placement to safely avoid the quadriceps tendon when accessing the synovial capsule. Participants were also more confident in their ability to simultaneously manipulate a needle and an ultrasound probe. When medical trainees learn to use ultrasound to guide a needle to perform arthrocentesis, they are also learning the essential hand-eye coordination and probe/needle handling skills that are necessary for success in many other types of ultrasound-guided procedures.

Skills Testing

After training using formalin-embalmed cadavers, first-year medical students completely untrained in ultrasound-guided procedures were able to perform arthrocentesis at a level very similar to residents being trained in similar environments. Participants were able to independently aspirate 1 mL of synovial fluid from the suprapatellar bursa in an average time of 41 seconds on the first stick (Fig. 4). Emergency medicine residents training to perform ultrasound-guided arthrocentesis in the hip, ankle, and wrist in a similar simulated testing environment using fresh cadavers were able to, on average, aspirate 1 mL of fluid in a single attempt in 38 seconds[13].

Limitations and Future Directions

This study lacks a control group comparing other modalities of instruction in ultrasound-guided arthrocentesis. However, the objective of this study was not to compare the efficacy between multiple methods of knee arthrocentesis training but to assess the feasibility of a novel method that uses readily available educational resources, which include formalin-embalmed cadavers and entry-level ultrasound units. Further investigation is required to compare the efficacy of synthetic models, live patients, and cadavers preserved using various embalming methods. It would also be relevant to assess learning curves and skill retention by evaluating trainee performance of arthrocentesis on live patients during clinical rotations and residency.

General Conclusion

Teaching medical trainees to perform ultrasound-guided arthrocentesis using formalin-embalmed cadavers fully uses resources commonly available in many medical education programs. Formalin-embalmed cadavers accurately simulate the kinesthetic dynamics of performing arthrocentesis on a live person while avoiding the potential for patient harm or discomfort during training. Performing arthrocentesis on cadaveric joints allows trainees to experience the sensation of a needle entering a joint space while introducing the challenge of aligning a probe and needle on irregular anatomical surfaces. Training attempts performed across multiple cadaveric bodies encourage the adaptation of technique to account for the natural anatomical variation that will be evidenced within the patient population. This experience would be extremely difficult to replicate using synthetic models.

This study demonstrates that first-year medical students can learn to independently perform a difficult and invasive procedure under ultrasound guidance after brief training using formalin-embalmed cadavers. The use of formalin-embalmed cadavers in the training of ultrasound-guided procedures will encourage the utilization of existing resources in the expansion of the scope of medical education in a way that is economical, effective, and highly clinically relevant. ■

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References

1. Santen SA, Hemphill RR, McDonald MF, Jo CO. Patients' willingness to allow residents to learn to practice medical procedures. Acad Med. 2004;79(2):144-7.
2. Berman JR, Ben-Artzi A, Fisher MC, Bass AR, Pillinger MH. A comparison of arthrocentesis teaching tools: cadavers, synthetic joint models, and the relative utility of different educational modalities in improving trainees' comfort with procedures. J Clin Rheumatol. 2012;18(4):175-9.
3. Brodsky J, Patton E, Fischer H. Arthrocentesis training using a knee simulation model. Osteoarthritis and Cartilage. 2013;21:S151.
4. Elnicki DM, Shumway JM, Halbritter KA, Morris DK. Interpretive and procedural skills of the internal medicine clerkship: performance and supervision. South Med J. 1996;89(6):603-8.
5. Promes SB, Chudgar SM, Grochowski CO, Shayne P, Isenhour J, Glickman SW, Cairns CB. Gaps in procedural experience and competency in medical school graduates. Acad Emerg Med. 2009;16(suppl 2):S58-62.
6. Chrisman SPD, Lowry S, Herring SA, Kroshus E, Hoopes TR, Higgins SK, Rivara FP. Concussion incidence, duration, and return to school and sport in 5- to 14-year-old American football athletes. J Pediatr. 2019;207:176.e1.
7. Michels NR, Vanhomwegen E. An educational study to investigate the efficacy of three training methods for infiltration techniques on self-efficacy and skills of trainees in general practice. BMC Fam Pract. 2019;20(1):133.
8. Hayashi S, Naito M, Kawata S, Qu N, Hatayama N, Hirai S, Itoh M. History and future of human cadaver preservation for surgical training: from formalin to saturated salt solution method. Anat Sci Int. 2016;91(1):1-7.
9. Benkhadra M, Faust A, Ladoire S, Trost O, Trouilloud P, Girard C, Anderhuber F, Feigl G. Comparison of fresh and Thiel's embalmed cadavers according to the suitability for ultrasound-guided regional anesthesia of the cervical region. Surg Radiol Anat. 2009;31(7):531-5.
10. McLeod G, Eisma R, Schwab A, Corner G, Soames R, Cochran S. An evaluation of Thiel-embalmed cadavers for ultrasound-based regional anaesthesia training and research. Ultrasound. 2010;18(3):125-9.
11. Chiba D, Tsuda E, Maeda S, Sasaki E, Takahashi I, Nakaji S, Ishibashi Y. Evaluation of a quantitative measurement of suprapatellar effusion by ultrasonography and its association with symptoms of radiographic knee osteoarthritis: a cross-sectional observational study. Arthritis Res Ther. 2016;18(1):181.
12. Wiler JL, Costantino TG, Filippone L, Satz W. Comparison of ultrasound-guided and standard landmark techniques for knee arthrocentesis. J Emerg Med. 2010;39(1):76-82.
13. Berona K, Abdi A, Menchine M, Mailhot T, Kang T, Seif D, Chilstrom M. Success of ultrasound-guided versus landmark-guided arthrocentesis of hip, ankle, and wrist in a cadaver model. Am J Emerg Med. 2017;35(2):240-4.