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Randomized Controlled Study of a Training Program for Knee and Shoulder Arthrocentesis on Procedural Simulators with Assessment on Cadavers

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Objective. The study objective was to assess the efficacy of simulators in improving the competence of students in performing a knee and shoulder arthrocentesis on cadavers and to determine the minimum number of simulator training procedures needed to achieve competence in arthrocentesis.

Methods. Two groups of 15 medical students were each trained to perform a single joint arthrocentesis ("knee group" and "shoulder group") on a simulator to serve as a control for the other. The two groups received the same theoretical training (anatomy, arthrocentesis techniques, ultrasound, and hybrid simulation). Each student punctured the two joints on a cadaver. A student was considered "competent on the cadaver" if they succeeded at two or more arthrocentesis procedures out of the three tests on the joint on which they were trained. The minimum threshold value to be competent was calculated by a receiver operating characteristic curve and the Youden index. An assessment of theoretical knowledge and confidence level in joint arthrocentesis was carried out at the start and end of the study.

Results. Twenty-two out of 29 students (75.8%) achieved competence in arthrocentesis at the joint for which they were trained. Of the students in the knee group, 79% were competent on the cadaver's knee versus 60% of the students in the shoulder group ($P = 0.43$). Of students in the shoulder group, 74% were competent on the cadaver's shoulder versus 57% of students in the knee group ($P = 0.45$). Four training punctures on a simulator are necessary to achieve competence on a cadaver. The students' confidence level in arthrocentesis increased significantly during the study, as did the students' theoretical knowledge.

Conclusion. Knee and shoulder arthrocentesis success rates were not statistically different between the two training groups. A minimum number of 4.0 training arthrocentesis on a simulator is needed to achieve competency on a cadaver.

INTRODUCTION

Musculoskeletal problems are one of the primary reasons for consultation in general medicine (1–3). The two principal indications for arthrocentesis are "diagnostic" puncture (to determine arthritis origin: septic, inflammatory, or mechanical) and "evacuating" puncture. If more practitioners, especially in general medicine and emergency departments, knew how to perform arthrocentesis and intra-articular injections, this would make it possible to shorten consultation times for rheumatologists and optimize patient care (4,5). In fact, mastering the procedural skills of arthrocentesis is essential. Not only does it guarantee the effectiveness of treatment, but it also prevents complications and lesions of periarticular structures, such as nerves, vessels, and tendons (6,7). However, medical students, and even residents, do not feel comfortable with arthrocentesis. Lafleur et al (8) noted, with 64 residents in 2019, a median confidence level in arthrocentesis of 4.8 out of 10. Procedural simulation is an innovative and efficient pedagogical method used to improve procedural skills through the "mastery learning" strategy. Simulation-based mastery learning is a rigorous method to achieve a predefined performance standard through simulation-based deliberated

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practice (well-defined learning objectives, repetitive practice, precise measurements of performance, and informative feedback concerning performance) until a "mastery level" is reached. Previous studies have compared different arthrocentesis training methods (theoretical courses, internet videos, supervised bedside training, procedural simulators, and cadavers). Unfortunately, objective competence evaluation is rarely done and is most often based on the students' confidence level before and after training. However, we know that it is an imperfect criterion (1,2,9–13). The aim of the study was to assess the efficacy of simulators in improving the competence of students in performing a knee and shoulder arthrocentesis on cadavers.

MATERIALS AND METHODS

Population. The study was approved by the Ethics Committee of the Caen University Hospital. It is a single center, prospective, open-label study with a cohort of 30 medical students. Eligible students were fourth- and fifth-year medical students. Fourth-year students have two full-time training periods of 8 weeks and one of 6 weeks in a clinical department interspersed with two periods of theoretical courses. Fifth-year students have the same number of training periods as fourth-year, but 14 weeks of theoretical courses. Fourth-year and fifth-year students have identical duties during their training periods.

Students were excluded if they had previous experience in arthrocentesis and had already completed an internship in rheumatology. This was done to prevent different levels at baseline in procedural skills and knowledge in rheumatology. Sixty requests for participation in the study were received, of which 51 met the inclusion criteria. Students were recruited on a voluntary basis, in order of receipt of the first 30 requests, without any hierarchical link with the study investigator. All students participating in the study gave their written informed consent. We guaranteed the students anonymity in the processing of data.

Study design. All of the students were offered a theoretical course on shoulder and knee anatomy and pathologies (students were given a portable document format form after listening in person to be able to do self-review; Supplementary Material 1). They also attended a practical diagnostic ultrasound workshop on knees and shoulders (training on each other in pairs). They were provided with hybrid simulation videos (a simulated patient equipped with knee and shoulder procedural simulators) in order to learn the management of a patient (Supplementary Material 2).

Thirty students were randomized into two groups via a random draw conducted by a person with no conflict of interest with the study. Fifteen medical students (group A) were trained only for knee arthrocentesis on the procedural simulator LIMBS and THINGS ALT 70103 (Figure 1A). Fifteen medical students (group B) were trained only for shoulder arthrocentesis (glenohumeral joint) on the procedural simulator LIMBS and THINGS ALT 70202 (Figure 1B). In order to increase the environmental fidelity of the simulator training, we asked the students to train in gowns. Students from each group had the opportunity to train over 1 to 3 half-days, depending on their availability. The first simulation session began with a presentation of the simulators (knee simulator for group A and shoulder simulator for group B) and the available materials (20-ml syringes, 21 G * 2 ''/ 0.8 * 50-mm

(A) (B)

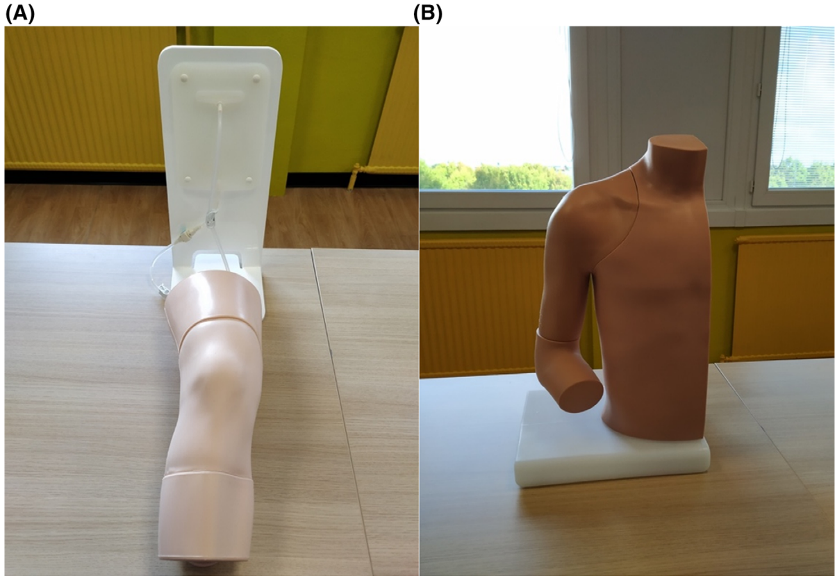

Figure 1. Knee simulator allows arthrocentesis and infiltrations of fluid (macroscopically similar to synovial fluid) using clinical and ultrasound landmarks via an ultrasound module **(A)**. Shoulder simulator allows arthrocentesis and infiltrations of fluid using clinical and ultrasound landmarks via an ultrasound module with access to the glenohumeral joint through an anterior or posterior route; acromio-clavicular joint, subacromio-deltoid bursa, and long biceps sheath **(B)**.

needles, sterile compresses, surgical masks, sterile gloves, sterile drapes, alcoholic betadine 5%, and collection containers). The knee puncture point was taut, located 1 cm above and laterally to the superior-external corner of the patella (14,15). The shoulder puncture point was taught, located 1 cm laterally and 0.5 cm below the anterolateral end of the coracoid process (6,7). For shoulder arthrocentesis, the need not to prick too low or too medially was emphasized to avoid the risk of failure and puncturing the brachial plexus and axillary vessels (6).

After each puncture, the trainer would provide feedback to improve the puncture technique. The student was considered to have mastery of a procedural skill if they succeeded at performing at least two-thirds of the punctures he had attempted. A volunteer medical student (not involved in the study) was recruited as a simulated patient to create hybrid simulation videos featuring an emergency consultation situation for monoarthritis of the knee and glenohumeral joints. Several points of interest were explained during these videos: interviewing the patient, looking for contraindications to arthrocentesis, explaining the procedure and the risks involved, collecting informed consent, preparing the material, and performing the technical gesture itself on the joint simulator.

After being trained on simulators, medical students were evaluated on cadavers in the anatomy laboratory of the Caen Medical School. One rater was dedicated to the evaluation of the knee puncture and the other to the evaluation of the shoulder puncture. Each student performed three knee and shoulder arthrocentesis procedures on a cadaver. Group A students, who trained only on a knee simulator, served as a control for shoulder arthrocentesis for group B students (who trained only on a shoulder simulator) and vice versa. Cadaver assessment was done openly, the assessor knowing which joint the student had trained on. We reconstructed joint effusions on cadavers by inserting intra-articular catheters under ultrasound guidance, allowing the joints to be filled with physiological saline coupled with blue dye. The cadaver joints were previously emptied of residual synovial fluid, then filled, aiming to achieve an effusion of the same volume as that present in the simulators (30 to 40 ml for the knee joint and 20 ml for the glenohumeral joint). Catheters were sutured onto the skin and connected to a plastic tubing with a stopcock, allowing the joint to be refilled several times after being punctured, ensuring the presence of the same amount of fluid between each gesture. Four "fresh" cadavers (tissue quality closer to living patients [16]) were prepared the day before the students' evaluations. Preparing four cadavers provided multiple support joints, reducing the number of puncture marks conventionally appearing on the skin (appearing classically after 15-20 arthrocentesis procedures) (17). This also limits the risk of effusion into the soft tissues (possible after several consecutive punctures at the same site). To reproduce knee effusion, a catheter was placed in the suprapatellar recess via the medial patellar approach (Figure 2A), leaving the superolateral area of the patella free for students to perform arthrocentesis. To reproduce glenohumeral effusion, a catheter was placed, under ultrasound guidance (SAMSUNG CART UGEO HM70A) by a posterior approach, in the glenohumeral joint at the depth of the infraspinatus (7) (Figure 2B). Students carried out shoulder arthrocentesis using an anterior approach. Cadavers were placed in a seated position (to come as close as possible to the arthrocentesis position on procedural simulators) (Figure 2C). The upper limb was externally rotated with the palm of the hand turned upward to free the tendon of the long biceps and facilitate access to the joint capsule (14).

The students were given a two-part questionnaire (rating of self-confidence in knee and shoulder arthrocentesis on a 5-point Likert scale and an assessment of theoretical knowledge in rheumatology) (Supplementary Material 3) at the start of the study, before the theoretical course, to map their basic knowledge. It was given to them again at the end of the study, just before the evaluation on cadavers. We could thereby analyze knowledge and self-confidence progression during the training period and observe the link between theoretical knowledge and the success rate of arthrocentesis on cadavers. Questions were on arthrocentesis indications and contraindications, knowledge of knee and shoulder arthrocentesis landmarks, materials needed for arthrocentesis, and knowledge of arthrocentesis complications. Questions were weighted using a keyword system to enable numerical evaluation of the results.

A student training evaluation questionnaire (Supplementary Material 4) was sent to the students 1 week after the assessment on cadavers to get their feedback on the training. The parameters studied were quality of the theoretical course, usefulness in clinical practice in the year following the introduction to ultrasound, quality of training on procedural simulators, quality of the assessment on cadavers, and whether doing arthrocentesis training was an added value for confidence. Students were also asked, after completing the training, how comfortable they felt performing knee or shoulder arthrocentesis on real patients.

Principal endpoints. The primary endpoint was the rate of successful arthrocentesis on cadaver, defined as two or more successful punctions out of three attempts on the joint for which they were trained by simulator, with more than 3 ml of synovial fluid obtained at the shoulder arthrocentesis and more than 5 ml at the knee. This success rate of two-thirds was chosen following an analysis of the literature (15,18) and was validated by four hospital practitioners from the Rheumatology Department of our university hospital, including the head of the department. A grid for evaluating the general quality of arthrocentesis was designed to consider parameters other than success or failure of arthrocentesis (Supplementary Material 5). We designed the grid using the most relevant elements found in the literature (13,19,20). During the evaluation on cadavers, students performed arthrocentesis according to the method taught during training on simulators. The examiner silently filled in the grid during the assessment.

Figure 2. Catheter placed in the suprapatellar recess via a medial patellar approach **(A)**. Catheter placed using posterior approach in the GH joint at the depth of the infraspinatus **(B)**. Cadaver placed in a seated position to reproduce arthrocentesis position on simulator **(C)**. GH, gleno humeral joint.

The time allocated for arthrocentesis on cadavers was 6 minutes for the first (including skin disinfection time) and 2 minutes for each of the other two arthrocentesis procedures. Evaluation was carried out by two raters of a comparable skill level for this exam—although at different stages in the medical curriculum—a rheumatology resident (competent in ultrasound teaching and technical procedures) and a senior rheumatology staff member.

The secondary endpoint was to determine the optimum number of procedures required on a simulator to achieve mastery of the punction on cadaver on the joint for which they were trained by simulator. To this end, we developed a "cadaver competence algorithm" in which the student was considered "competent on cadaver" if success (a rate of success of at least two-thirds on arthrocentesis) was achieved on the joint for which they were trained by simulator, regardless of the result (success or failure) on the other joint. Conversely, a student was considered "not competent on cadavers" if failure (a rate of success of at least two-thirds on arthrocentesis) resulted on the joint for which they were trained by simulator, regardless of the result (success or failure) on the other joint.

We used a receiver operating characteristic (ROC) curve to determine the J statistics and established this as the cut-off point for the minimum number of arthrocentesis procedures to perform before being considered competent on a cadaver.

Other endpoints. The two-part questionnaires (self-confidence in knee and shoulder arthrocentesis and assessment of theoretical knowledge in rheumatology) that were carried out at the start and end of the study, as well as the student training evaluation questionnaire, were analyzed for each student group.

Statistical analysis. The number of subjects required to detect significant differences in success between the two groups was not calculated prior to the study. We used a type 1 error rate of 0.05. The Fisher exact test was used to study the association between two qualitative variables when conditions for applying the chi-square test were not met. A non-parametric Wilcoxon-Mann–Whitney test was used to analyze variables whose distribution did not follow a normal distribution (time, for example). Differences in scores to the self-administered questionnaires before and after the procedure on simulator were tested by Wilcoxon signed-rank test. We used the ROC curve (Supplementary Material 6) to provide a measure of the performance across all possible classification thresholds. The student population was dichotomized into two groups (competent and not competent), according to the results of the procedure on the cadavers (binary outcome). The number of arthrocentesis procedures to be carried out on a simulator in order to be classified as "competent" constituted the quantitative variable. We then used the Youden index to compute the minimum threshold value of arthrocentesis on the simulator in order not to fail the procedure on the cadaver. The choice of the ROC curve was due to our interest in depicting performance, rather than learning. Moreover, ROC is irrespective of underlying group size. Other examples of the use of the ROC curve in similar settings can be found in the literature. In his dissertation, "The Use of Receiver Operating Characteristic Curve Analysis for Academic Progress and Degree Completion Academic Progress and Degree Completion," J. W. Schutts (21) uses the ROC curve to evaluate predicted satisfactory academic progress and degree completion as Raju and Schumacker (22) and Lucio et al (23). The use of the J statistics has already been used in non-diagnostic settings. It is easy to calculate and favors maximizing correct classification and difference from chance.

RESULTS

The study was conducted from February 2020 through March 2020. Of the 60 requests to participate received, 51 were eligible. The first 30 requests received in chronological order were accepted, respecting a balanced ratio of fourth- and fifth-year medical students. Twenty-nine students completed all of the following steps of the study: theoretical course, start-of-study questionnaire on arthrocentesis self-confidence and theoretical knowledge in rheumatology, introduction to ultrasound, procedural simulator training, end-of-study questionnaire on arthrocentesis self-confidence and theoretical knowledge, cadaver arthrocentesis assessment, and student training evaluation questionnaire. The only participant lost to follow-up was from the knee group. He did not attend the initial theoretical course and was therefore excluded from the study (Figure 3).

Demographic and baseline characteristics of the participants. Group A and group B were comparable (Table 1). None of the students had previous experience in rheumatology and arthrocentesis. About two-thirds were women in each group, explained by the larger number of women in medical studies at our university. The distribution between fourth- and fifth-year students was comparable in the two groups.

Efficacy endpoints. Twenty-two out of 29 students (75.8%) achieved competence on a cadaver (success on the simulator's training joint; 11 students from group A and 11 students from group B). There was no statistically significant difference between groups in "success" on cadaver knee and shoulder arthrocentesis: 79% of students from group A (knee group) succeeded at knee arthrocentesis on a cadaver versus 60% of students from group B (shoulder group) ($P = 0.49$). Seventy-four percent of students from group B (shoulder group) succeeded at shoulder arthrocentesis on a cadaver versus 57% of students from group A (knee group) ($P = 0.43$) (Table 1).

Other parameters of the evaluation grid (Supplementary Material 5) on cadavers were satisfactory. Basic asepsis rules were respected, in the same way between groups A and B. A surgical mask was worn in 93% and 100% of cases, respectively ($P = 0.48$); hand disinfection protocol was followed in 93% and 80% of cases, respectively ($P = 0.6$), and skin disinfection protocol with betadine and wearing of sterile gloves was done in 100% of cases, respectively (Table 1).

The minimum number of arthrocentesis training sessions on a simulator required to achieve competence on cadavers was estimated at four arthrocentesis training sessions (Supplementary Material 6).

Evaluation on cadavers was appreciated by students, giving it an overall score of 3.4/4 on the 4-point Likert scale (Supplementary Material 4).

Arthrocentesis training on a procedural simulator. Students had the opportunity to train on their respective simulator over 1 to 3 half-days depending on their availability. All group A students achieved, on the procedural knee simulator, an average success rate of greater than or equal to two-thirds of the arthrocentesis procedures performed (corresponding to the threshold of success on cadavers required for the evaluation). Of group B students, 14 of 15 reached this threshold on the shoulder procedural simulator, with only one student having successfully completed less than two-thirds on arthrocentesis training (Table 1).

Students were satisfied with training on the LIMBS and THINGS ALT 70103 and 70202 procedural simulators, rating them on a 4-point Likert scale 3.6/4 for clinical landmark quality, 3.7/4 for sensation during arthrocentesis, and 3.2/4 for realism (Supplementary Material 4). Some students, however, said they were disturbed by the needle marks left by the previous students' training at the puncture site, especially on the shoulder simulator.

Self-confidence in arthrocentesis and assessment of theoretical knowledge in rheumatology. Students reported a very low confidence level in knee and shoulder arthrocentesis at the beginning of the study, with a mean score of 1.03/5 and 0.76/5, respectively, on the 5-point Likert scale. After their "blended-learning" training, the mean self-confidence in performing knee and shoulder procedures increased significantly, from 1.03/5 pre- to 3/5 points post-workshop ($P < 0.01$) and from 0.76/5 to 2.8/5 ($P < 0.01$), respectively. Theoretical knowledge in rheumatology improved significantly over the entire questionnaire between the start and the end of the study (Table 2).

For theoretical knowledge in rheumatology, there was no difference between the two groups for any parameter, whether

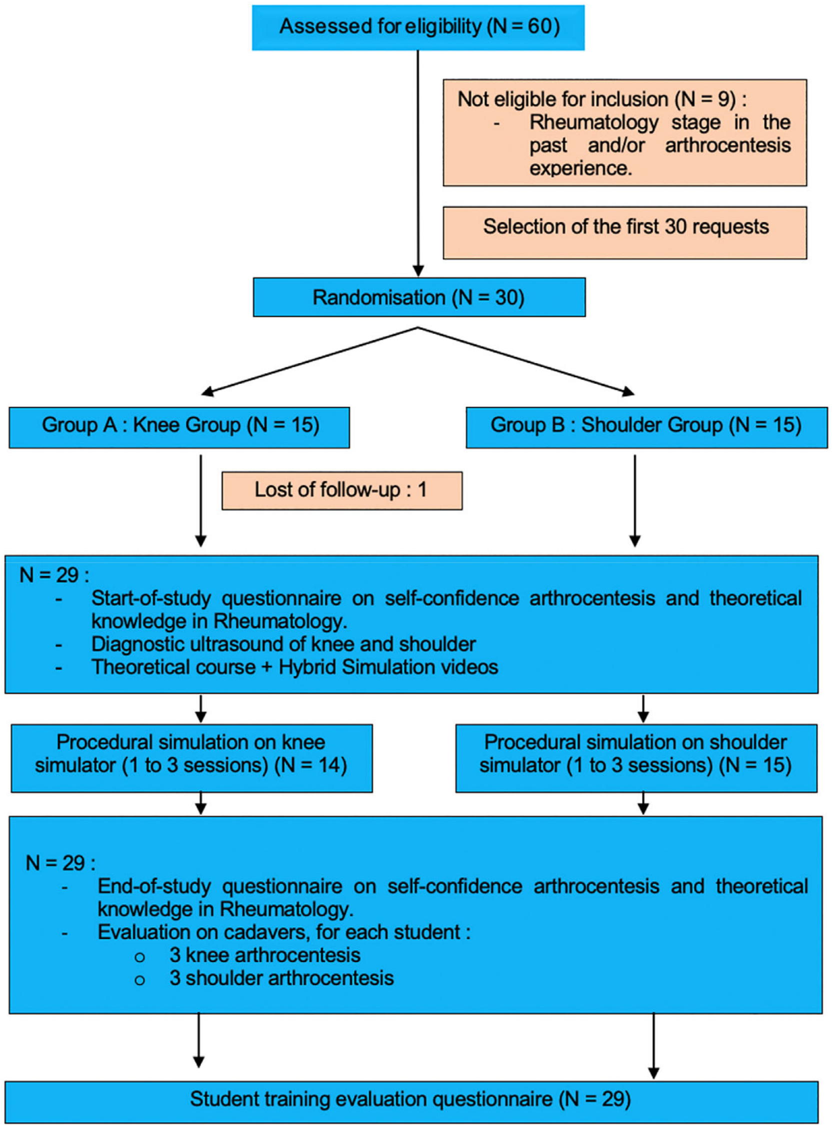

Figure 3. Flow chart of the study.

at the beginning or at the end of the study (Supplementary Material 7). However, regarding self confidence in performing knee and shoulder arthrocentesis, we noted that students were much more confident in performing arthrocentesis at the joint for which they were trained. The comparison of confidence levels in arthrocentesis of the knee and shoulder at the end of the study between the two groups was statistically significant ($P < 0.001$), whereas this was not the case at the start of the study (Table 3).

DISCUSSION

Knee and shoulder arthrocentesis success rates were not statistically different between the two training groups. A minimum number of 4.0 arthrocentesis training sessions on a simulator is needed to achieve competency on a cadaver.

There are several possible explanations for the lack of demonstrated effectiveness of a simulator training compared with a standard way of teaching. In the first place, the standard way of teaching was perhaps already quite intensive, thanks to the visualization of videos demonstrating the gesture. Another explanation is that training in a simulator with instructor feedback, even though at a joint different from the one that the student is then being assessed on, can improve the competence of the student. For example, even though the students do not identify the anatomical landmarks of the knee when practicing on a shoulder simulator, the simulated training can help them practice arthrocentesis preparation, getting used to the feel of landmarks and punctures, overcoming fears, which can then improve their knee arthrocentesis in a cadaver, as reported by students. This had a potential impact on the control group, possibly improving the results of this group. The small sample size of our population also possibly explains the

Table 1. Comparison between the two groups for several parameters: study population at baseline and data on procedural training on simulators and evaluation on cadavers (equipment used during the evaluation and performance at knee and shoulder arthrocentesis)

Characteristics	Group A (knee group) n = 14	Group B (shoulder group) n = 15	*P* value
Study population			
4th year medical students, n (%)	6 (42.9)	9 (60)	0.581
5th year medical students, n (%)	8 (57.1)	6 (40)	
Men, n (%)	4 (28.6)	5 (33.3)	0.78
Women, n (%)	10 (71.4)	10 (66.7)	
Rheumatology stage in the past, n (%)	0 (0)	0 (0)	—
Prior experience in arthrocentesis, n (%)	0 (0)	0 (0)	—
Procedural simulators			
Average number of arthrocentesis training sessions on their respective simulators	8.1	7.7	0.59
Number of students who reached ≥2/3 arthrocentesis success, n (%)	14 (100)	14 (93.3)	—
Evaluation on cadavers			
Equipment used			
Surgical mask, n (%)	13 (93)	15 (100)	0.48
Hand disinfection protocol, n (%)	13 (93)	12 (80)	0.6
Skin disinfection protocol, n (%)	14 (100)	15 (100)	—
Sterile gloves, n (%)	14 (100)	15 (100)	—
Arthrocentesis on cadaver			
Success of knee arthrocentesis (≥2/3 arthrocentesis success), n (%)	11 (79)	9 (60)	0.49
Success of shoulder arthrocentesis (≥2/3 arthrocentesis success), n (%)	8 (57.1)	11 (74)	0.43
Student training evaluation questionnaire			
Ready to realize a knee arthrocentesis on a real patient, n (%)	13 (93)	12 (80)	0.6
Ready to realize a shoulder arthrocentesis on a real patient, n (%)	5 (36)	14 (93.3)	0.002

Results of the survey after training on the ability to feel ready to puncture a knee or a shoulder on a real patient, by training group, are presented (see Supplementary Material 4).

lack of positive findings. As there was little or no data in the scientific literature and it was an exploratory pilot study, we had not previously calculated the number of subjects needed. Our purpose was to provide preliminary data for further studies. Finally, the lack of effectiveness of the training could also be due to the limits of realism of the simulators, which do not reproduce the variability of the morphology of real patients.

Twenty-two of the 29 students successfully completed arthrocentesis on the joint on which they were trained on a simulator, including 11 of 14 of group A students and 11 of 15 of group B students. Fourteen out of 22 students successfully performed arthrocentesis on both joints, seven in each group.

The increased confidence level of all the students in performing arthrocentesis was significant over the course of the study, with 2 points gained for knee and shoulder arthrocentesis and with a significant difference in confidence levels at the end of the study between the two groups depending on the joint on which they were trained. These results are similar to those reported by Wilcox et al during their training of 63 residents in arthrocentesis, intra-articular injection, and clinical examination of the knee and shoulder (9). Theoretical knowledge in rheumatology improved significantly over the entire questionnaire between the start and the end of the study in the two groups in a similar manner.

The lower success rates on cadavers compared with simulators can be explained by the properties of the simulator joints, particularly standard morphology and absence of osteoarthritic changes (24). Despite this, 76% of students confirmed that

Table 2. Progression in students' arthrocentesis self-confidence and theoretical knowledge in rheumatology from the start to the end of the study (total doesn't take into account self-confidence level)

Settings	Mean score (start of the study)	Mean score (end of the study)	*P* value
Self-confidence knee arthrocentesis	1.03/5	3/5	<0.01
Self-confidence shoulder arthrocentesis	0.76/5	2.8/5	<0.01
Arthrocentesis indications	1.31/2	1.34/2	NS
Arthrocentesis contraindications	1.31/4	2.2/4	<0.01
Knee arthrocentesis landmarks	0.14/1	0.97/1	<0.01
Shoulder arthrocentesis landmarks	0/1	0.83/1	<0.01
Arthrocentesis complications	1.6/5	2.7/5	<0.01
Total	4.34/13	8.31/13	<0.01

Abbreviation: NS, not significant.

Table 3. Comparison between group A (knee group) and group B (shoulder group) confidence levels in knee and shoulder arthrocentesis at the beginning and end of the study on a 5-point Likert scale

Confidence Level in Arthrocentesis	Group A (Knee), n (%)	Group B (Shoulder), n (%)	*P* Value
Confidence in knee arthrocentesis, start			0.42
0	4 (28.6)	9 (60.0)	
1	4 (28.6)	4 (26.7)	
2	2 (14.3)	1 (6.7)	
3	3 (21.4)	1 (6.7)	
4	1 (7.1)	0 (0.0)	
5	0 (0.0)	0 (0.0)	
Confidence in knee arthrocentesis, end			<0.001
0	0 (0.0)	0 (0.0)	
1	0 (0.0)	3 (20.0)	
2	0 (0.0)	8 (53.3)	
3	2 (14.3)	4 (26.7)	
4	10 (71.4)	0 (0.0)	
5	2 (14.3)	8 (0.0)	
Confidence in shoulder arthrocentesis, start			0.4
0	6 (42.9)	10 (66.7)	
1	4 (28.6)	3 (20.0)	
2	3 (21.4)	1 (6.7)	
3	0 (0.0)	1 (6.7)	
4	1 (7.1)	0 (0.0)	
5	0 (0.0)	0 (0.0)	
Confidence in shoulder arthrocentesis, end			<0.001
0	3 (21.4)	0 (0.0)	
1	3 (21.4)	0 (0.0)	
2	5 (35.7)	0 (0.0)	
3	3 (21.4)	2 (13.3)	
4	0 (0.0)	12 (80.0)	
5	0 (0.0)	1 (6.7)	

clinical landmarks learned on simulators were easily found on cadavers.

We found that a minimum number of 4.0 arthrocentesis training sessions on a simulator was required to achieve competency on cadavers. This is in agreement with previous studies that found a minimum number of two to five arthrocentesis training sessions necessary (5,9,12).

Seventy-two percent of students report that having done arthrocentesis on a cadaver made them more comfortable with the technical procedure than if they had only trained on simulators, as reported by Berman et al (24). However, it seems difficult to generalize training on cadavers due to the difficulty of access and the complexity of their positioning. Since simulators are portable, readily available, and reusable, they are much more suitable for training (25).

On the student training evaluation questionnaire, 36% of group A students felt able to perform real shoulder arthrocentesis, whereas 80% of group B students felt able to carry out a real knee arthrocentesis. Therefore, shoulder arthrocentesis generates more fear among students who have not received dedicated training.

Our study has several weaknesses, the most important of which is the lack of power due to the small sample size, which probably partly explains the non-significant differences on cadaver arthrocentesis when comparing the two simulator training groups. Secondly, results on cadavers must be interpreted with caution. Indeed, students performing arthrocentesis on cadavers are less concerned with structures to avoid (vessels, nerves, and tendons) and with patient pain during the procedure than when performing the procedure on living patients (18). Consequently, technical procedures on living patients are more difficult than on cadavers (26). Moreover, despite an evaluation carried out on "fresh" cadavers, tissue properties may be altered, which modifies the sensations during the procedure (15,26). Another limitation of our study is that the raters were not blinded to the participation status of the students because it was not possible to prevent the trainer from being one of the two raters. Apart from this, we trained and assessed students on the glenohumeral joint arthrocentesis, and not on the subacromio-deltoid bursa (BSAD), although the latter is more frequently pathological. We chose the glenohumeral joint for a technical reason, ie, with cadavers, in the event of intra-tendinous fissures within the rotator cuff, a large part of the liquid injected into the BSAD would disperse into these fissures. The injected liquid, therefore, could not have been recovered by the students to confirm a successful arthrocentesis. Inversely, the glenohumeral joint retains almost all of the fluid injected via the intra-articular catheter. We chose to train students in arthrocentesis guided by clinical landmarks despite the echogenic properties of procedural simulators because it seems essential to begin learning arthrocentesis using clinical landmarks before United States-guided arthrocentesis, especially since training students in in interventional ultrasound when they have no previous experience is time-consuming. Moreover, the superiority of ultrasound-guided arthrocentesis over using clinical landmarks is still debatable. Berona et al compared arthrocentesis success rates in 2016 for hip, ankle, and wrist joints under ultrasound guidance and using clinical landmarks with emergency department residents. They did not find any significant difference (18). However, as ultrasound-guided arthrocentesis has become routinely used in rheumatology, it was essential to introduce students to diagnostic ultrasound to complete their training.

To our knowledge, this is the first study to train students on procedural simulators and assess them on cadavers, which best brings students closer to realistic conditions, allowing them to better experience the sensation of patient tissue (26). Previous studies have compared different arthrocentesis training methods (theoretical courses, patient "bedside" training, procedural simulators, and cadavers), but objective evaluation is rarely done. It is often based on the students' confidence level before and after the training. However, we know that it is an imperfect criterion (1,2,9–12,27). For example, in 2019, Fortuna et al analyzed a 4-year procedural curriculum directed at joint injections for physicians and residents. They observed an improvement in the comfort level in knowledge of indications and performance of procedures via surveys administered every 6 to 12 months, but they did not evaluate them objectively (28). In our study, we used an objective evaluation grid to measure the success rate of arthrocentesis, the mastery of asepsis rules, as well as several parameters concerning the technical gesture. We sought to determine the minimum number of training procedures on a simulator needed to achieve competence in arthrocentesis on cadavers. This has a dual interest: "educational" and "economic" (simulator lifespan is inversely proportional to the number of arthrocentesis procedures performed). All of the students were trained by the same instructor, which reinforces the comparability of the two groups. The current study is innovative through the use of new generation procedural simulators (both of them allowing fluid aspiration, an added value according to students) (25). The intra-articular catheter system for creating joint effusions was developed by Ross et al for the ankle joint (16) but was used for the first time for shoulder and knee joints in our study. We promoted "blended learning" (13), namely a multiplication of learning supports (didactic session, hands-on US training, online videos, new generation procedural simulators) and assessment on cadavers to increase the level of attention in students and improve their theoretical knowledge and know-how over the long term.

In conclusion, knee and shoulder arthrocentesis success rates were not statistically different between the two training groups. A minimum number of 4.0 arthrocentesis training sessions on a simulator is needed to achieve competency on a cadaver.

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