Point-of-Care Clinical Ultrasound for Medical Students

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Key words
- abdomen
- heart
- vascular
- ultrasound

Abstract

Purpose: Our institution has recently implemented a point-of-care (POC) ultrasound training program, consisting of an e-learning course and systematic practical hands-on training. The aim of this prospective study was to evaluate the learning outcome of this curriculum.
Materials and Methods: 16 medical students with no previous ultrasound experience comprised the study group. The program covered a combination of 4 well-described point-of-care (POC) ultrasound protocols (focus assessed transthoracic echocardiography, focused assessment with sonography in trauma, lung ultrasound, and dynamic needle tip positioning for ultrasound-guided vascular access) and it consisted of an e-learning course followed by 4 h of practical hands-on training. Practical skills and image quality were tested 3 times during the study: at baseline, after e-learning, and after hands-on training.
Results: Practical skills improved for all 4 protocols; after e-learning as well as after hands-on training. The number of students who were able to perform at least one interpretable image of the heart increased from 7 at baseline to 12 after e-learning, $p<0.01$, and to all 16 students after hands-on-training, $p<0.01$. The number of students able to cannulate an artificial vessel increased from 3 to 8 after e-learning and to 15 after hands-on training.
Conclusion: Medical students with no previous ultrasound experience demonstrated a considerable improvement in practical skill after interactive e-learning and 4 h of hands-on training.

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Introduction

During the past decade, point-of-care (POC) ultrasound has been rapidly evolving and the topic constitutes a steadily growing number of publications [1–5]. Previous studies have focused predominantly on feasibility, but newer studies based on randomized, blinded and controlled designs have pointed out significant advantages both as a potential life-saving diagnostic tool [6–8], and as a guiding instrument in daily clinical procedures [9,10]. However, implementation into daily clinical practice is challenging and requires efficient educational programs covering both theory and practical skills [11,12].
Medical students have been proven to learn quickly and may benefit from the skills achieved during their entire professional careers [13]. Several medical schools have integrated ultrasound as part of their teaching programs [14–16], but mainly as a learning tool in anatomy, physiology, and pathology [17–19]. The ultimate goal is to benefit the patients by increased use of POC ultrasound and therefore, a foundation in POC ultrasound should be taught early in medical education [1,11,20–22].
In 2011, a major revision of the medical school curriculum at X, X, gave ultrasound a far greater prominence. As part of this transformation, all medical students were offered an introduction to POC ultrasound; a program consisting exclusively of e-learning-based theory and a 1-day hands-on training session. Although the feedback has been very positive, the optimal educational program for the learning of ultrasound remains debatable. Thus, our objective was to assess the learning outcome from our ultrasound curriculum, with particular focus on differentiating the value of theoretical e-learning and practical hands-on training on medical students with no prior experience in ultrasound.

Methods

We conducted a single center, prospective trial to test an interactive e-learning program followed by 4 h of ultrasound hands-on training. The timeline is displayed in **Fig. 1**.

Study population

20 young medical students with no previous ultrasound experience, all in their third to fifth year of medical school (mean 4.5 ± 0.6), at the University of X were voluntarily recruited. 4 students served as ultrasound models and 16 comprised the study group according to our preceding sample size calculation.

Ultrasound curriculum

Our ultrasound curriculum is entitled "Introduction to ABC Ultrasound", as it presents ultrasound as a diagnostic tool to evaluate the functions vital for life: Airway, Breathing, and Circulation. The program covers a combination of 4 POC protocols: 1) Focus Assessed Transthoracic Echocardiography (FATE) [23], 2) Focused Assessment with Sonography in Trauma (FAST) [24, 25], 3) Lung Ultrasound (LUS) [22], and 4) Dynamic Needle Tip Positioning (DNTP) for ultrasound guided vascular access [26]. The program consists of 2 parts: an internet-based e-learning course and a systematic, structured hands-on training (HOT) session, as described below.

E-learning

The e-learning course consisted of interactive internet-based modules developed especially for the medical student curriculum. The modules included a combination of text, pictures/photos, animations, movies and tests to ensure maximal knowledge retention. Each of the modules had a logic progression in the subject and held information of how to acquire an image as well as how to interpret it. Typically, an instruction of how to acquire or interpret an image was given both as a text and as a video illustration. From previous experience, the e-learning required approximately 5–8 h. As a part of the web-based e-learning program the students had their theoretical knowledge tested before and after the course with 56 multiple-choice questions, equally distributed among the 4 protocols. Students were requested to answer these questions without access to the internet or textbooks. Each of the 2 tests was done only once, and the response time and individual results of the students were automatically stored.

HOT-session

4 groups each consisting of 4 students, rotated between 4 HOT-stations with an instructor and an ultrasound model at each station. Each group received 1.5 h of FATE-training, 1 h of FAST-training, 30 min of LUS-training, and 1 h of training in DNTP. The instructors were responsible for strict adherence to a time schedule, allowing each student the same time exposure to every station.

Student evaluation

3 test sessions were held: at baseline, after the e-learning course (intermediate test), and after the 4-h HOT session (endpoint test). All test sessions were performed identically, with the same instructors, models and students at each station. The 4 models were used only during the test sessions, and the students were not allowed to 'practice' on these individuals. In brief, 4 students were simultaneously tested at different test stations with rotations every 20 min. 2 protocols were tested at each station with a total test time of 40 min per student. For each protocol, the tests comprised 2 types of evaluation: online testing of the students' practical skills by simple correct/incorrect questions, and offline evaluation of image quality in terms of adequacy of interpretation. For all 4 protocols the first practical exercise, before proceeding to the views, was to point out the most appropriate transducer. In case of an incorrect answer, the correct answer was given to make sure that the most appropriate transducer was used.

Prior to each test the instructor gave standardized information about the protocol tested:

A. Students were permitted 90 s for each view.
B. Students would receive help in storing and adjusting the image on request. Thereby, the students were responsible for determining when the image was an adequate representation of the expected image. Likewise, the image was only adjusted if the students requested a specific adjustment e.g., depth increase.
C. Up to 3 loops could be stored for each view.
D. Before each view the students had 30 s to examine a poster presented to them. While examining the poster the students were informed about the practical exercise related to the particular view, and that if he/she would not be able visualize the structures asked for, the exercise would be considered incorrect.
E. Time zero was the point at which the student first made contact with the volunteer. After 30 s they were reminded to store the images obtained, and after 60 s the instructor informed them that 30 s remained.

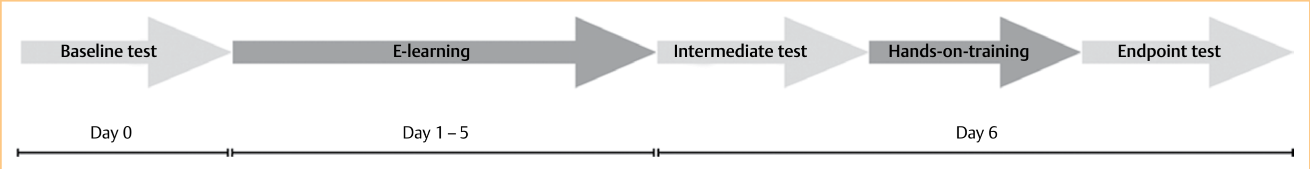

Fig. 1 Study timeline. Prior to the study, each student received a number from 1–16, and they were divided into groups of 4 (1–4, 5–8, 9–12, and 13–16). As displayed, they were tested 3 times during the study period: at baseline, after the e-learning course (intermediate test), and after the 4-h HOT session (endpoint test). Day 0: The students received an introduction of 15 min, which included the practical arrangements and general information about the study, including the hypothesis and aim. No ultrasound theory was taught at this stage. Immediately after the introduction, the baseline test was conducted. Day 1–5: Electronic access codes to the e-learning course were distributed after all students had completed the baseline test. Day 6: After initial registration, no instructions were given prior to the intermediate test. Before the handson-training session, the students were briefly informed about the rotation scheme, but no ultrasound theory was taught. The endpoint test was carried out immediately after the hands-on training session.

Models were only repositioned upon request, instructors answered no theoretical questions, and they responded similarly whether the exercises were solved correctly or not. The instructors were responsible for changing transducers between protocols, and keeping track of time.

1) The following cardiac and pleural views were tested

Subcostal 4-chamber view, apical 4-chamber view, parasternal long-axis view, parasternal short-axis view, right pleural view, and left pleural view (**Table 1a** and **Appendix 1a**).

2) The following abdominal views were tested

Subcostal 4-chamber view, right upper quadrant view, left upper quadrant view, and transverse pelvic view (**Table 1b** and **Appendix 1b**).

3) The following lung ultrasound features were tested

"BAT-sign" in longitudinal view (across the ribs) and "lung sliding" in transverse view (intercostal space) (**Table 1c** and **Appendix 1c**).

4) The following vascular views were tested

Transverse views of peripheral vessels, artery and vein on the right forearm, and transverse view of the internal jugular vein. Tourniquets were only handed out when requested by the student (**Table 1d** and **Appendix 1d**).

Offline analysis

The stored images were evaluated in random order, and 2 blinded observers (JH, LSH) scored the best loops after consensus based on 10 full datasets. Scoring also required selection of the best loop. In case of divergence between the observers consensus was reached.

1) Cardiac and pleural ultrasound

An R-wave-triggered cine-loop was scored from 1–5 in terms of image quality, using a previously published algorithm [27] as follows: 1 = no image, 2 = poor and unusable image quality, 3 = usable image quality, 4 = good image quality, and 5 = perfect image quality. An image score ≥ 3 was judged sufficient to assess dimensions, free fluid, and global function; in such cases the image could contribute to clinical decision-making.

In order to assess inter-observer variability, the 2 observers (JH, LSH) scored all images from the 3 test sessions. Likewise, in order to assess intra-observer variability, one observer (JH) re-scored all 3 sets of cardiac and pleural images from 4 randomly selected students for each of the protocols. In total, the inter- and intra-observer variability tests compared 48 pairs and 12 pairs of observations, respectively.

2–4) Abdominal, lung, and vascular ultrasound

Loops of 3 s were scored on a 2-point scale, signifying whether the image was interpretable or not (0 = uninterpretable, 1 = interpretable).

Statistical analysis

For statistical analyses and graphical description we used Stata/IC 12.1 for Mac (StataCorp, TX, USA) and Graph Pad Prism 6 (GraphPad Software, La Jolla, CA, USA). Continuous, normally distributed data are reported as mean (standard deviation [SD]), otherwise as median and range, and the normally distributed data were compared applying one-way analysis of variance (ANOVA). If appropriate, paired Student's *t*-tests with either equal or unequal variance were used. The Wilcoxon rank sum test was applied for paired, continuous, non-normally distributed variables. Binominal data are presented as absolute numbers, and compared applying the chi-squared test. Correlations were checked applying simple linear regression analyses. We set a significance level of 95 %, but adjusted appropriately for multiple comparisons by the Bonferroni correction. Therefore, only *p*-values < 0.01 were considered statistically significant.

Our preceding sample size calculation was based on the overall image score in cardiac and pleural ultrasound in which we hypothesized an increase of 20 % from baseline test to endpoint test and standard deviations of 15 % in both tests. With a statistical power of 90 % and a level of significance of 95 %, we therefore needed 12 students to participate in the study.

Ethics

Prior to the study, The Human Research Ethics Committee of the Faculty of Health Sciences of the University of X approved the study. It was exempt from formal ethics approval in X, according to The Regional Committee on Biomedical Research Ethics of the X. Each student signed an informed consent form agreeing to participate in the study.

Results

The median e-learning score was 69 (53–86 %) in the pre e-learning test vs. 98 (88–100 %) in the post e-learning test, $p < 0.01$. The time required for the pre e-learning test was 14:56 min (9:56–25:38) vs. 10:43 min (5:04–53:18) for the post e-learning test, $p = 0.08$. All the students completed the e-learning course, although 2 did not do the pre- and post e-learning test in succession, and their test time could therefore not be reliably assessed. The overall progress in test scores and image quality is shown in **Fig. 2a**, **c**.

1) Cardiac and pleural ultrasound

The number of correct answers increased from baseline to intermediate test in all the evaluated views except the ability to point out the right diaphragm (**Table 1a**). Also, the number of students able to perform an interpretable image increased in all the views, (**Table 2a**). We evaluated the ability to perform at least one interpretable image of the heart, and a significant increase from 7 at baseline to 12 at the intermediate test, $p < 0.01$ was shown. The overall image score from the 6 views as percentage of the highest possible score rose from 38.3 ± 11.0 % of possible score at baseline to 54.0 ± 14.0 % at the intermediate test, $p < 0.01$. From the intermediate test the students improved in all practical exercises except selection of transducers, which were chosen correctly by 15 out of 16 students at the endpoint test. All 16 students performed one or more interpretable images of the heart at the endpoint test with a significant increase from the intermediate test, $p < 0.01$. The image score rose to 73.1 ± 12.0 % of highest possible score at the endpoint test, $p < 0.01$, (**Fig. 2d**). In 2 students intermediate test scores were lower than baseline. One student had a lower endpoint score than intermediate score. In all students image scores improved from the baseline to the endpoint test.

Table 1 Practical exercises in cardiac and pleural (**a**), abdominal (**b**), lung (**c**), and vascular ultrasound (**d**). Students with correct answers to each of the exercises.

	Baseline-test (N=16)	Intermediate test (N=16)	Endpoint test (N=16)	*p*-value
a – Cardiac and pleural ultrasound				
Exercise				
Selection of transducer?	14	15	15	0.76
Point on the subxiphoid view:				
LV (no.)	2	12	14	<0.01 *
RV (no.)	3	12	15	<0.01 *
LA (no.)	2	10	13	<0.01 *
RA (no.)	2	8	13	<0.01 *
Point on the apical 4-chamber view:				
LV (no.)	4	7	15	<0.01 *
RV (no.)	2	5	15	<0.01 *
LA (no.)	2	5	14	<0.01 *
RA (no.)	1	4	13	<0.01 *
Point on the parasternal long-axis view:				
LV (no.)	1	10	15	<0.01 *
RV (no.)	2	9	14	<0.01 *
LA (no.)	1	8	14	<0.01 *
Aortic outflow tract (no.)	2	5	14	<0.01 *
Point at the parasternal short-axis view:				
LV (no.)	5	14	16	<0.01 *
RV (no.)	4	11	14	<0.01 *
Point on the left pleural view:				
Diaphragm (no.)	10	13	16	0.03
Liver (no.)	13	14	16	0.21
Point on the right pleural view:				
Diaphragm (no.)	7	5	11	0.11
Spleen (no.)	3	9	15	<0.01 *
b – Abdominal ultrasound				
Exercise				
Selection of transducer?	10	15	16	<0.01 *
Point on the subxiphoid view:				
LV (no.)	4	7	11	0.05
RV (no.)	4	7	11	0.05
LA (no.)	3	6	10	0.04
RA (no.)	3	7	12	<0.01 *
Point on the left upper quadrant view:				
Liver (no.)	11	16	16	<0.01 *
Kidney (no.)	5	11	12	0.03
Point on the right upper quadrant view:				
Spleen (no.)	5	9	14	<0.01 *
Kidney (no.)	3	7	15	<0.01 *
Point on the transverse pelvic view:				
Bladder (no.)	4	8	12	0.02
c – Lung ultrasound				
Exercise				
Selection of transducer?	12	12	15	0.29
Point on a transverse view:				
Costa shadow (no.)	6	15	16	<0.01 *
Pleura line (no.)	7	15	16	<0.01 *
Point on a longitudinel view:				
Pleura line (no.)	8	16	16	<0.01 *
Lung sliding (no.)	1	13	15	<0.01 *
d – Vascular ultrasound				
Exercise				
Selection of transducer? (no.)	10	14	16	0.02
Perform finger test? (no.)	3	8	16	<0.01 *
Perform compression test? (no.)	1	9	11	<0.01 *
Point out the following vessels:				
Peripheral vein (no.)	6	5	10	0.17
Int. jugular vein (no.)	14	16	16	0.12
Carotid artery (no.)	15	16	16	0.36
Vascular access in a phantom: * *				
Within 90 s? (no.)	3	8	15	<0.01 *

* Significant difference between tests by one-way analysis of variance, $p < 0.001$

* * The ability to perform Dynamic Needle Tip Positioning[29] was tested using a Vessel Ultrasound Training Block (Blue Phantom, CAE Healthcare, FL, USA). The instructor was responsible for adjusting the image upon request and checking the needle position after 90 s

LV: left ventricle; RV: right ventricle; LA: left atrium; RA: right atrium

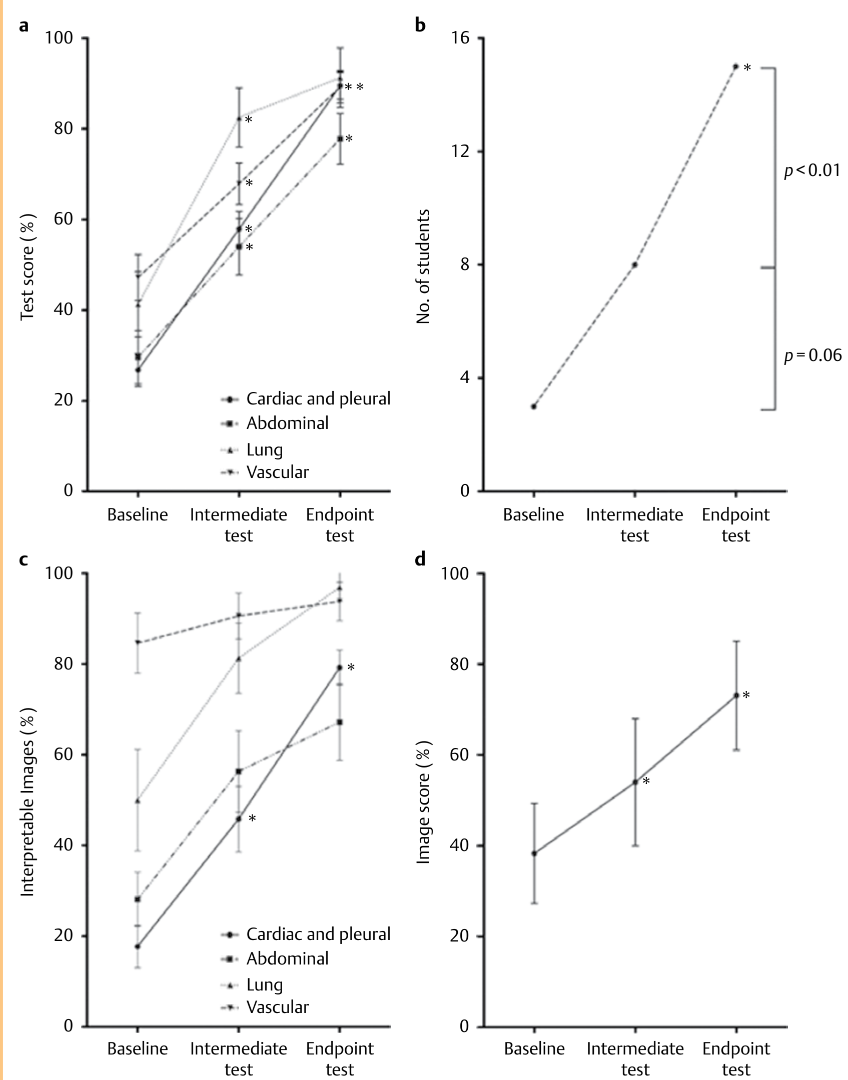

Fig. 2 Development in practical exercise scores and image quality. Online evaluation of practical skills **a, b** and offline evaluation of image quality **c, d**. **a** Scores as percentage of highest possible score for each protocol, p<0.001 (ANOVA) for all 4 protocols. **b** Example of development in practical skills; vascular access performed within 90 s, at the 3 tests, p<0.001 (ANOVA). **c** Number of interpretable images as percentage of highest possible number for each protocol, p<0.001 (ANOVA) for FATE, FAST, and LUS; **d** Image score from FATE presented as percentage of the highest possible score, p<0.001 (ANOVA). * Significantly different from previous test, p<0.001. ANOVA: one-way analysis of variance.

2) Abdominal ultrasound

From baseline to the intermediate test the number of correct answers in the practical exercises improved in all the questions (**Table 1b**). Likewise, an increasing number of students performed interpretable images in all evaluated views (**Table 2b**). From intermediate test to endpoint test, a similar trend was seen with improvement in all exercises and image quality in all views. In 4 students, image scores were lower for the intermediate test than the baseline test, and in another 4 students performance was weaker in the endpoint test than the intermediate test. All students had higher image scores at the end of the study than at baseline.

3) Lung ultrasound

The students improved from baseline to intermediate test in all the exercises except transducer selection (**Table 1c**), and the number of interpretable views increased similarly (**Table 2c**). At the endpoint test all 16 students were able to point out the pleura line and the rib shadow, likewise 15 out of 16 students answered the 2 remaining questions correctly at the final test. Offline image evaluation showed that all 16 students were able to perform the transverse view suitably for interpretation, and 15 of the students performed a clinically usable longitudinal view at the endpoint test.

4) Vascular ultrasound

There was an increase in the number of correct answers in all exercises from baseline to intermediate test (**Table 1d**). All 16 students were able to perform an interpretable image of the internal jugular vein as well as the carotid artery, and could also identify the structures correctly (**Table 2d**). Within 90 s, 3 students succeeded in vessel cannulation at baseline compared with 8 in the intermediate test. At the last test 15 performed a successful vascular access (**Fig. 2b**). Likewise, 15 students produced interpretable images at the endpoint test (**Table 2d**).

Discussion

This study establishes that interactive e-learning in combination with 4 h of systematic hands-on training can provide considerable improvement in ultrasound competence among medical students with no previous ultrasound experience. Our data reflected the transition from absolute no training, wherefore rapid progression must be expected no matter the type of training. However, clearly the learning curves in practical skills after the theoretical e-learning course alone are remarkably steep.
Today only few medical schools have POC ultrasound as an integrated part of their curricula [14–16]. Hoppmann et al. described

	Baseline-test * * (N=16)	Intermediate test (N=16)	Endpoint test (N=16)	*p*-value
a – Cardiac and pleural				
Subcostal 4-chamber view (no.)	2	8	15	<0.01 *
Apical 4-chamber view (no.)	4	6	13	<0.01 *
Parasternal long-axis view (no.)	3	7	12	<0.01 *
Parasternal short-axis view (no.)	2	10	12	<0.01 *
Right pleural view (no.)	5	9	16	<0.01 *
Left pleural view (no.)	1	4	8	0.02
b – Abdominal				
Subcostal 4-chamber view (no.)	6	8	10	0.37
Right upper quadrant view (no.)	7	12	13	0.06
Left upper quadrant view (no.)	2	8	12	<0.01 *
Transverse pelvic view (no.)	3	8	8	0.11
c – Lung				
BAT-sign (no.)	8	12	16	<0.01 *
Lung sliding (no.)	8	14	15	<0.01 *
d – Vascular				
Peripheral vessels (no.)	10	13	15	0.42
Central vessels (no.)	12	16	15	0.55

* Significant difference between tests by one-way analysis of variance, $p<0.001$

* * For lung and vascular ultrasound only 15 tests were stored at the baseline test

Table 2 Interpretable images Students with interpretable images at each view.

an ultrasound program implemented across all 4 years in medical school at the University of South Carolina [14], while others have reported on programs introduced during the last year of medical school [15,16]. These previous experiences all demonstrated how POC ultrasound could be successfully implemented in medical schools with high learning outputs and excellent student feedback. Other studies have evaluated various methods of POC ultrasound training programs for medical students; however, these were mainly non-implemented programs conducted on a pilot basis [28,29]. These investigations also concluded that ultrasound training should be included in the undergraduate medical school curriculum. Clearly, no course is complete without both a theoretical as well as a hands-on component, but the present study went beyond the above quoted studies in that the outcome was assessed after each separate element of the course, i.e., the theoretical and the practical training (**Fig. 3**).

In the current study we evaluated an ultrasound curriculum without 'classic' didactic lecturing, but instead with an internet-based e-learning course. E-learning offers substantial advantages. Firstly, the e-learning concept includes an increased accessibility to information, e.g., the students can access what is needed, when it is needed. Secondly, the electronic content is easy to update in comparison with printed material, and can quickly be revised or simplified. Thirdly, students are in control of their learning sequence, pace of learning, and study venue. Fourthly, e-learning standardizes the course content and delivery, in contrast to a lecture. Lastly, e-learning can be designed to include an outcome assessment to determine whether knowledge has been acquired. Although our study was not designed to compare e-learning-based theory with other teaching modalities, our data suggest that didactic lecturing can be replaced with an interactive e-course without compromising the acquisition of knowledge and understanding.

The majority of studies in the field are conducted employing time-consuming programs, whereas only a few studies have addressed learning outcomes after a shorter exposure, i.e., 1 day or less [28–30]. In the present study, a limited program of only 4 h of practical hands-on training was evaluated. **Fig. 2** shows the rapid progress made. For example, 15 out of 16 students were able to place a needle in an artificial vessel at the end of the study. In our opinion, this strongly emphasizes the importance of an appropriate approach to the practical teaching, i.e., not spending excessive amounts of time showing the students a particular procedure, but allowing them to practice themselves from the beginning under the guidance of a supervisor. Moreover, it should be added that in the current study we restricted the HOT session to 4 h, which was practically feasible and relatively easy to extend. In the ultrasound-training program implemented at Aarhus University, the HOT-session has a 6-h timeframe. Thus, the HOT session can easily be extended and still be completed within a 1-day time period. Such an extension may further improve the learning outcomes.

Danish medical students are all exposed to ultrasound techniques during their education. We therefore enrolled medical students from the University of X, X, who had no previous ultrasound experience. Our data therefore exclusively reflects the learning achieved by the interventions. Furthermore, the models used for the tests were only examined during these test sessions, and no 'practicing' was allowed on these individuals. Although the students might become more familiar with a particular model's anatomy from one test to another, the benefit of using the same models for all the test sessions, significantly outweighs this potential risk.

As previous suggested [11,13], our data indicate that medical students are relatively quick learners in comparison with their older colleagues. In addition, we believe that clinicians are more likely to incorporate ultrasound into their daily practice if it is introduced at an early stage of their careers. Therefore, it is very important to integrate POC ultrasound into early medical education. The current study conducted on medical students at minimal cost and effort has shown significant improvement in their ability to obtain and interpret ultrasound images.

Limitations

Firstly, we designed our study to focus more on the student's practical and technical ultrasound skills than on 'knobology',

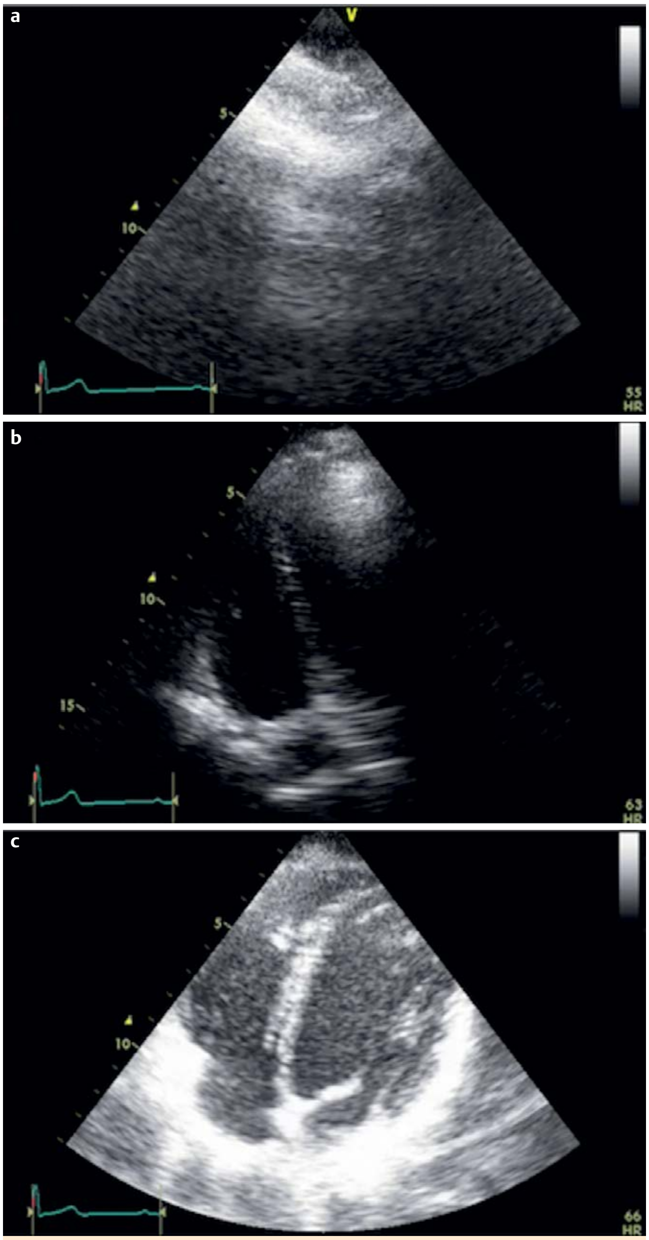

Fig. 3 Example of image quality development. Apical 4-chamber view from the 3 tests (student no. 15). **a** Baseline test; **b** Intermediate test; **c** Endpoint test.

and therefore, we chose to have the instructors assist with the storing of images if requested. Likewise, the instructors were responsible for changing transducers between protocols.

Secondly, we did not assess the students' ability to interpret their images, but for the clinician it is a prerequisite to be able to immediately interpret the dynamic images and correlate the ultrasound findings with the patient's symptoms and signs. This emphasizes the need for future studies to investigate whether placing ultrasound devices in the hands of medical students will improve medical practice at the point of care.

Conclusion

Medical students with no previous experience of ultrasound techniques demonstrated a significant increase in their ability to acquire and interpret an ultrasound image after completion of interactive e-learning, and this competence was further improved after 4 h of systematic hands-on training. Such training should translate into improved medical care in qualified doctors.

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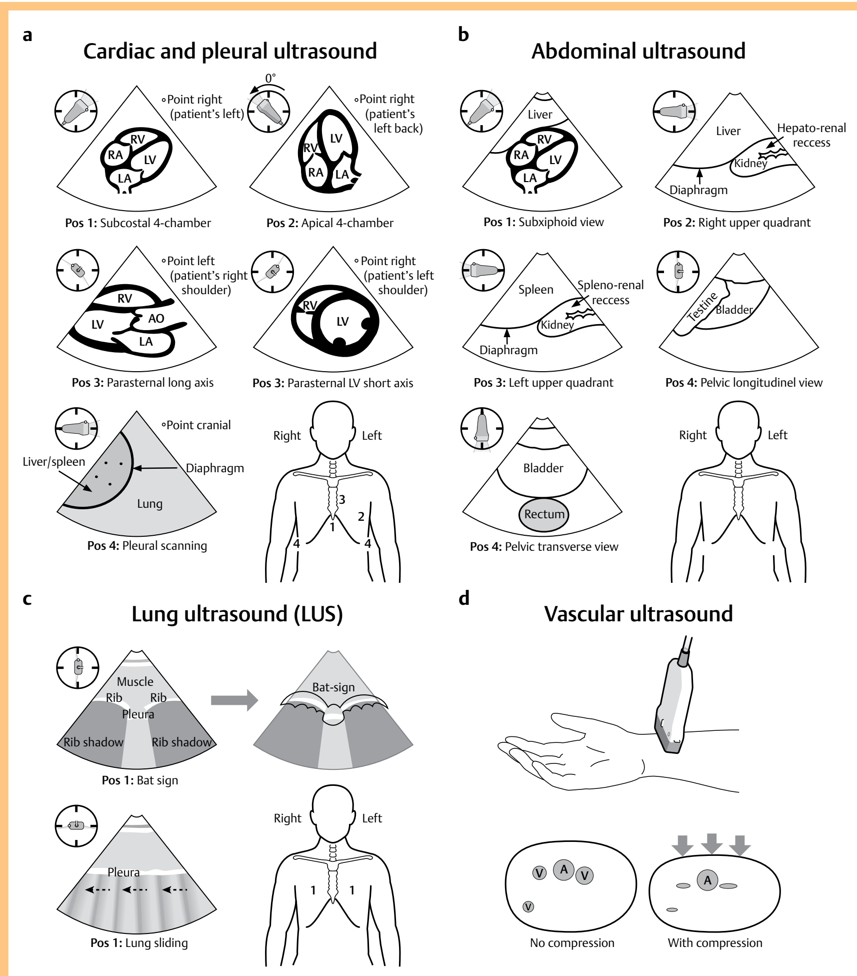
Appendix



Appendix 1 Posters. Posters presented to students during test sessions. **a** Cardiac and pleural ultrasound; **b** Abdominal ultrasound; **c** Lung ultrasound; **d** Vascular ultrasound.