Web-Based Deliberate Practice of Pediatric Point-of-Care Ultrasound Cases in Resource-Limited Settings

A Multicenter Implementation and Effectiveness Study

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Objectives—The main objective of this study was to implement an online pediatric case-based point-of-care ultrasound (POCUS) course in low-resource medical settings and examine learning outcomes and feasibility.

Methods—This was a multicenter prospective cohort study conducted in a convenience sample of clinicians affiliated with Médecins Sans Frontières (MSF) training sites. MSF POCUS trainers provided the standard hands-on, on-site POCUS training and supplemented this with access to a web-based course. Participants provided diagnoses for 400 image-based POCUS cases from four common pediatric POCUS applications until they achieved the mastery learning standard of 90% accuracy, sensitivity (cases with pathology), and specificity (cases without pathology). Each participant also completed a course evaluation.

Results—From 10 MSF sites, 110 clinicians completed 82,206 cases. There were significant learning gains across the POCUS applications with respect to accuracy (delta 14.2%; 95% CI 13.1, 15.2), sensitivity (delta 13.2%; 95% CI 12.1, 14.2), and specificity (delta 13.8%; 95% CI 12.7, 15.0). Furthermore, 90 (81.8%) achieved the mastery learning standard in at least one application, and 69 (62.7%) completed a course evaluation on at least one application for a total of 231 evaluations. Of these, 206 (89.2%) agreed/strongly agreed that the experience had relevance to their practice, met expectations, and had a positive user design. However, 59/110 (53.6%) clinicians reported a lack of protected time, and 54/110 (49.0%) identified challenges with accessing internet/hardware.

Conclusions—In resource-limited MSF settings, implementing web-based POCUS case practice demonstrated successful learning outcomes despite approximately half of the participants encountering significant technical challenges.

Key Words—competency; deliberate practice; education; global health; humanitarian health; online learning; point-of-care ultrasound; resource-limited settings

Received October 30, 2024, from the Faculty of Medicine, University of Toronto, Toronto, Ontario, Canada (A.R., D.L.); Médecins Sans Frontières, Geneva, Switzerland (C.S., E.S.); and Division of Pediatric Emergency Medicine, Department of Paediatrics, Hospital for Sick Children, Toronto, Ontario, Canada (M.L., K.B.). Manuscript accepted for publication February 23, 2025.

We thank the on-site medical supervisors and clinicians who participated in the pediatric POCUS courses. We also thank Dr. Martin Pecaric from Contrail Consulting Services Inc. for the technical support provided throughout the study.

Data used for this research was extracted from the ImageSim platform. Dr. Kathy Boutis is married to Dr. Martin Pecaric of Contrail Consulting Inc. Contrail Consulting Inc. provides technical support for ImageSim. This is managed with an agreement with the Hospital for Sick Children. Dr. Boutis and Dr. Pusic are unpaid co-academic directors for ImageSim. The other authors have nothing to declare.

No funding was received for this study.

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Abbreviations

CI, confidence interval; FAST, focused assessment with sonography for trauma; MSF, Médecins Sans Frontières; POCUS, point-of-care ultrasound

doi:10.1002/jum.16679

Resource-limited settings typically have more restricted access to medical resources, which results in disproportionately increased mortality rates in these settings.[1,2] In particular, there is often reduced access to rapid imaging diagnostics,[3] and according to the World Health Organization, 60% of the world does not have access to any diagnostic radiological services.[4] Point-of-care ultrasound (POCUS) is seeing an increased rate of usage globally as a method toward addressing some of these challenges.[5] POCUS offers a low-cost, radiation-free, efficient method to quickly aid in the diagnosis of many conditions in resource-limited settings.[6,7] In resource-limited and remote settings, teaching health-care workers how to properly utilize POCUS can transform patient care by providing real-time information at the bedside and empowering clinicians to treat patients with greater confidence.[8]

Common barriers to POCUS uptake in low-resource settings include inadequate access to training, cost, and lack of access to ultrasound machinery.[9] As ultrasound machines become increasingly portable and affordable,[10] different models of POCUS education and implementation are gaining momentum in resource-limited settings.[11] Several studies have been done across a wide range of locations, evaluating POCUS training programs in these settings.[6,8,12,13] The studies vary significantly in design, the type of educational intervention used, the target training population, and follow-up.[4] Existing training models have utilized a combination of didactics, workshops, simulations, and case-based or online modules to teach POCUS. Each study has significant variability in the duration of the intervention, ranging from a few hour-long workshops to years-long training programs.[6,14] Regardless of the type of intervention or duration, multiple studies have shown improvement in trainees' skills and confidence after training.[8,13,14] Nevertheless, there remains a lack of local POCUS experts available to teach and create a sustainable programs,[15] and existing programs rely heavily on visiting trainers to lead these programs.[13,16] Tele-educational interventions attempt to overcome these barriers of geography and lack of educators but are not always feasible.[16] Furthermore, attempts to increase the uptake of POCUS and certifying health care providers have been challenged by issues of retention and continual engagement of learners after the initial in-person training.[8] Participants reported traveling costs and busy and inflexible clinical schedules as factors that prevented them from attending follow-up sessions.[8] As such, once clinicians acquire core skills in POCUS via the standard face-to-face teaching sessions, there is a critical need for ongoing, easily accessible educational interventions that enable participants to expand their skills by accessing case-practice at their own pace and on their own time.

Supplemental to the standard face-to-face intensive pediatric POCUS curriculum offered by Médecins Sans Frontières (MSF) to clinicians who practice in resource-limited settings, we implemented online case-based practice of POCUS image interpretation in four common pediatric applications [soft tissue, lung, cardiac and focused assessment with sonography for trauma (FAST)]. We examined the learning outcomes, feasibility, and barriers of this approach.

Materials and Methods

Education Intervention

Theoretical Framework

Gaining POCUS expertise is multifaceted and complex since it requires proficiency in image acquisition, image interpretation, and integration of interpretation into clinical decision making.[17] To facilitate learning of complex tasks, instructional design models recommend integrating part-task with whole-task training.[18] Of relevance to the current study, e-learning provides an opportunity to expose learners to an image interpretation learning experience (ie, part-task) that could complement the current resource-intensive face-to-face teaching and learning at the bedside that addresses all facets of POCUS (ie, whole-task), which can typically only provide limited case exposure. Web-based learning and assessment image banks that provide intentional sequencing and targeted analytic feedback on hundreds of cases have demonstrated success in increasing skills in pediatric POCUS in emergency physicians in Canada and the United States.[17,19] In this learning experience, cases are cognitively simulated and then integrated into software that permits deliberate practice.[20] Participants get exposure to hundreds of cases representing a spectrum of pathology and receive corrective feedback after every case as they strive for a masterly learning standard.[20,21] An interesting finding from prior work in POCUS image interpretation was that there seemed to be no difference in the amount or rate of learning with respect to career stage, with junior post-graduate trainees having similar outcomes to highly experienced emergency physicians.[17,19]

Therefore, this type of training may be beneficial for the range of backgrounds in the clinicians who deliver care in resource-limited settings.[22]

Case Experience Development

We used previously established methods to develop the educational intervention, which is described elsewhere.[17,19,23] In brief, we collected de-identified sample videos relevant to the four most common and core POCUS applications relevant to pediatric practice: soft tissue, cardiac, lung, and FAST applications.[24] The key initial educational outcome for clinicians using bedside ultrasound is to accurately distinguish normal from abnormal cases since this distinction should then prompt the clinician to consider additional tests or consultations to confirm a specific diagnosis.[25] Nevertheless, learning the specific diagnosis from POCUS imaging findings is an important secondary goal. As such, cases were classified as "normal" and "abnormal," and abnormal cases were further annotated to locate the specific imaging pathology.[17,19] We created a course for each application, and each application contained 100 unique cases specific to that application, 50% of which demonstrated abnormal imaging findings. This number of cases allows for the presentation of a spectrum of cases with and without pathology relevant to each application. The 50/50 case mix also optimized the learning for developing a participant's diagnostic sensitivity (performance on cases with pathology) and specificity (performance on cases without pathology).[26]

Case Experience

The details of this are described elsewhere.[17] In brief, cases in each of the four courses were presented with a brief clinical stem, one video that represented a standard view for that application, and a respective still image. For FAST, the cardiac view included a video and still of the sub-xiphoid view, while the right upper quadrant, left upper quadrant, and pelvic views were presented with a still image. Cases were presented in a random order unique to each participant. When ready, the participant assigned the case as "probably normal," "definitely normal," "probably abnormal," or "definitely abnormal." The "probably/definitely" qualifiers were meant to reflect participant certainty in their response.[27] If a participant selected "abnormal," they were required to locate one abnormality on the case-specific still image. After a case response was submitted, the participant received immediate visual and text feedback, which included diagnostic-specific information, allowing for deliberate practice of cases. Participants could complete the 100 cases per application a maximum of five times. In line with principles of "mastery learning,"[21,28] participants were permitted to do as many cases as needed to reach a previously derived performance mastery learning standard of 90% accuracy, 90% sensitivity, *and* 90% specificity (Figure 1; Video 1).[29] The experience was only available in English. Elements of each case and participant engagement were integrated into an online customized software platform developed using HTML5, CSS3, JS, Laravel, PHP technologies and was hosted on a secure server.[19]

Study Design and Setting

This was a multicenter prospective cohort study. The supplemental case experience was conducted on a web-based platform. Two MSF POCUS course coordinators worked with on-site medical supervisors at five MSF branches (Spain, the Netherlands, France, Switzerland, and Belgium) to recruit a convenience sample of health care professionals at 10 resource-limited health care sites in Africa ($n = 7$) and the Middle East ($n = 3$) during the intervention period. The health care settings in these regions varied from rural-based with little ability to perform diagnostic testing and limited or no routine internet access to urban settings with more advanced imaging technology available and stable high-speed internet. This study was approved by the Institutional Review Boards at the Hospital for Sick Children and MSF. If clinicians opted in to participate, this was considered implied consent.

Integration of Education Intervention into POCUS Training

Standard MSF POCUS Education Program

Sites are selected after a needs assessment for developing capacity for pediatric POCUS, which included a review of available POCUS equipment, participant profiles, and health care delivery structure. A standard MSF curriculum is adapted and tailored to the specific clinical level, diagnostic scope, existing protocols, and common pathologies at each site. All "face-to-face" intensive training is provided by on-site MSF POCUS-certified trainers to a group of clinician learners. The training includes individualized and intensive sessions of six to eight full days for small groups with a maximum of four to six participants. Training includes both theory and practice, and there are pre- and post-intervention assessments. There are two rounds of intensive training separated by 6 to 9 months, and clinicians are assessed for competency. This longitudinal learning plan includes follow-up of scans until standard competency is reached.

Web-Based POCUS Case Experience

Course Access—The web-based supplemental case experience is offered by ImageSim (https://imagesimcme.com/), which is a medical education platform. MSF purchased the courses from ImageSim through an internal grant and provided them to their trainees free of charge.

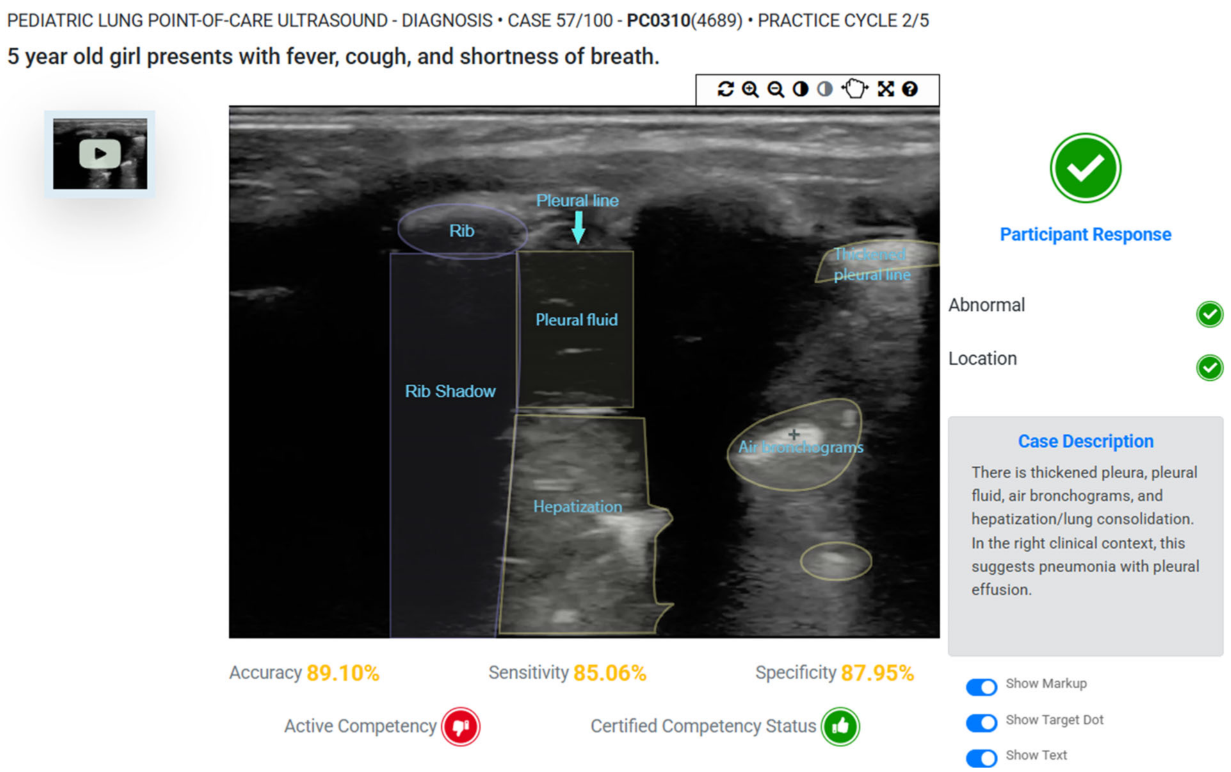
Participant Recruitment—Two full-time off-site MSF POCUS program faculty (who are also skilled in the standard face-to-face intensive training) acted as the MSF coordinators to facilitate the integration of the web-based case experience at participating MSF-affiliated sites. They disseminated the opportunity to the respective on-site medical supervisors, and these supervisors provided the opportunity to their respective clinicians for optional participation.

Implementation

Participants

Participants who expressed an interest were registered by one of the MSF POCUS Coordinators for the online case experience. Clinicians used the available hardware locally to participate, which included smartphones, laptops, or desktop computers. On-site medical supervisors were responsible for providing access to the internet and hardware, and time for their clinicians to participate.

Figure 1. Case experience: Participants decide on whether the case is normal or abnormal, and if abnormal, they have to locate the pathology. They get text and visual feedback after every case, and after about 60 cases, they get their summary performance metrics and whether they have achieved the mastery learning standard (Video 1).



Video 1. Video demonstration of point-of-care ultrasound case experience.

There was variation in when the supplemental experience was integrated with the standard POCUS curriculum. While most sites introduced the case experience after the first round of intensive training, this ranged from after the first round to during to after the second round of intensive face-to-face training due to logistical considerations. For example, at sites where clinicians reported a lack of access to internet/hardware to finish the web-based courses after the first round of intensive training, the POCUS coordinators encouraged the supplemental case experience to be an active part of the second round of training once the technological requirements were available.

Secure entry was ensured via unique participant login credentials, and access to the system was available 24 hours/day, 7 days/week. Participants were asked to complete an introductory tutorial and the four 100-case POCUS applications. The system automatically captured the participant response, the correctness of this response, and the time a case was started to the time a case response was submitted.[17] Participants had access to the cases for 2 years but were asked to complete the cases to the mastery learning standard within 3 months. Extensions were granted on a case-by-case basis. As an incentive for participation at a few sites, completion of the web-based cases was required to advance to further POCUS training. As a consequence of lack of participation, access to cases was withdrawn after 3 months and reassigned to a new participant.

MSF POCUS Coordinator Responsibilities

The two MSF POCUS coordinators had administrative access to assign courses to individual participants and track participant progress. These coordinators also met remotely with the on-site medical supervisors to explain the intervention and gain supervisor support. They were informed about MSF's financial investment, the technology necessary for course participation (hardware and reliable internet), completion goals, and timelines. It was recommended that on-site supervisors provide protected time and technology for clinicians to complete the cases. Given local challenges with digital literacy, one of the MSF POCUS coordinators prepared a document that explained how to access their web-based courses, expected goals and definitions of competency, technical requirements, and how to contact technical support. The MSF POCUS coordinators tracked participant progress via a dashboard and would relay concerns about the lack of progress to the on-site medical supervisors or participants via a WhatsApp chat.

Adaptation and Course Feedback

Participants

The online learning system allowed for each participant to submit comments on every case as needed and report any technical challenges. Issues were resolved within 72 hours. Upon completion of cases to the performance standard, participants had the option to complete a 6-question post-course evaluation for each POCUS application to receive their certificate of completion. The questions ranked their agreement with the following questions on a five-point Likert scale (strongly disagree, disagree, neither agree/disagree, agree, strongly agree) 1) learning objectives were met; 2) relevance to practice; 3) skills taught were transferable to practice; 4) course was well designed and organized; 5) course met expectations; and 6) barriers to participation (time, support from manager, internet speed/access, lack of bedside exposure to these types of images).

MSF POCUS Course Coordinators

The two MSF POCUS course coordinators were sent a survey to identify the type of participants, methods of implementation at each of their respective sites (synchronous or asynchronous), hardware and internet needs, report on administrative time commitment and specific interventions, ranking of barriers (strongly disagree/disagree/neither/agree/strongly agree) to case completion (internet, hardware, time, language, support from colleagues/managers, computer literacy), and suggestions for improvement.

Outcomes and Analyses

Learning Outcomes

Case Scoring—Participants were scored on the category selections of "normal" or "abnormal" and not the sub-assignments of "probably or definitely" normal/abnormal. Normal items were scored dichotomously (correct or incorrect), and abnormal items were scored correct if the participant classified the case as abnormal and correctly identified the region of abnormality.

Change in Performance—The performance scores of diagnostic accuracy, sensitivity, and specificity were calculated.[17,19] Accuracy was calculated as the participant's correct number of cases with and without pathology/total number of cases. Sensitivity was calculated as the participant's correct number of cases with pathology (true positives)/[correct number of cases with pathology (true positives) plus incorrect number of cases with pathology (false negative)]. Specificity was calculated as the participant's correct number of cases without pathology (true negatives)/[correct number of cases without pathology (true negatives) plus incorrect number of cases without pathology (false positives)]. Specifically, the initial and final 25 cases with and without pathology were used to calculate pre- and post-accuracy, which is in keeping with practice standards to assess POCUS diagnostic performance.[24] The sample of initial and final cases to calculate pre- and post-sensitivity included a minimum of 25 cases with pathology, and for specificity, it included a minimum of 25 cases without pathology. Given there was a random presentation of cases, typically participants reviewed about 60 cases to ensure the minimum sample of cases with and without pathology to calculate these pre- and post-performance metrics.[17,19] Pre- and post-performance scores were compared using the paired Student's *t*-test. A one-way ANOVA was used to make comparisons between applications, professional types, and MSF sites for changes in accuracy. Post hoc analyses were performed using Bonferroni for any significant differences detected in the ANOVA analyses. Furthermore, we compared the change in participant confidence measured as the percent of cases with "definite" qualifiers and compared this change with the change in accuracy.

Achievement to Performance Benchmark—For those participants who achieved the performance benchmark, we reported the median (with respective interquartile range [IQR]) number of cases completed. For all participants, we determined the proportion of participants who achieved the mastery learning standard (with respective 95% confidence interval [CI]). An independent-samples Kruskal-Wallis test was used to compare the median number of cases required to achieve the performance benchmark between applications. We also compared the number of cases completed to achieve the performance standard between profession types and MSF site of participation.

Feasibility and Acceptability

Participants—We reported the median time (IQR) in minutes it took to complete a case overall and in each application. We also determined the median time to achieve the performance standard with respective IQR and minimum and maximum values to complete each and all applications. We used the Kruskal-Wallis test to compare the median time per case between applications. Using descriptive statistics, we also reported on the frequency and types of barriers reported by the participants on the course evaluation questionnaire.

MSF POCUS Course Coordinators—Using descriptive statistics, we reported on the frequency and types of administrative burdens, and the barriers and opportunities for improvement reported by the MSF POCUS course directors.

Sample Size Considerations

A sample size of 90 participants achieved a power of 80% and a two-sided significance of 5% for detecting a meaningful difference of 15% in diagnostic accuracy error.[17] (PASS 11 software, Kaysville, UT).

All analyses were carried out using SPSS (Version 29, IBM 2023).

Results

Participant Demographics

From December 19, 2018 to April 28, 2023, at 10 MSF-training sites (Table 1), 152 healthcare providers registered to participate in the online case experience in the geographic regions of Africa and the Middle East. Furthermore, most of the participants were clinical officers (n = 104; 68.4%), Table 1.

Participant Engagement

Of the 152 enrolled, 110 (72.4%) started the case experience and completed a total of 82,206 cases. There was no difference in professional type

Table 1. Clinicians that Participated in Point-of-Care Ultrasound Case Experience at Médecins Sans Frontières (MSF) Training Sites

MSF Site	Total *N* = 152	Clinical officer *n* = 104	Physician *n* = 35	Physician assistant *n* = 13
Bangladesh	15 (9.9%)	13 (12.5%)	2 (5.7%)	0
Democratic Republic of Congo	17 (11.2%)	6 (5.7%)	11 (31.4%)	0
Kenya	27 (17.8%)	19 (18.3%)	2 (5.7%)	6 (46.2%)
Liberia	6 (3.9%)	0	0	6 (46.2%)
Mozambique	2 (1.3%)	0	2 (5.7%)	0
Sierra Leone	11 (7.2%)	11 (10.6%)	0	0
South Sudan	11 (7.2%)	11 (10.6%)	0	0
State of Palestine	21 (13.8%)	21 (20.2%)	0	0
Tanzania	20 (13.2%)	18 (17.3%)	1 (2.9%)	1 (7.6%)
Yemen	22 (14.5%)	5 (4.8%)	17 (48.6%)	0

($P = .06$) or MSF site of participation ($P = .56$) between those who did versus those who did not start the cases.

Learning Outcomes

Change in Performance

Of the 110 who did at least one case, 93 (84.5%; 95% CI 76.4, 90.7) participants completed at least 60 cases to measure changes in learning. There were significant pre- to post-learning gains from across the four applications among the MSF participants with respect to accuracy (delta 14.2%; 95% CI 13.1, 15.2), sensitivity (delta 13.2%; 95% CI 12.1, 14.2), and specificity (delta 13.8%; 95% CI 12.7, 15.0). This was also true when the applications were analyzed separately (Table 2). There were differences in the accuracy knowledge gains between the applications ($P < .001$). Specifically, the initial lung accuracy was higher than the other applications (soft tissue delta 6.8%; 95% CI 4.0, 9.7; cardiac delta 9.4%; 95% CI 6.5, 12.2; FAST delta 5.6%; 95% CI 2.8, 8.4) and as a result, gains were lower than soft tissue (difference −6.7%; 95% CI −10.4, −3.0), cardiac (difference −8.6%; 95% CI −12.3, −4.8) and FAST (difference −4.6%; 95% CI −0.9, −8.3). Furthermore, there was a greater change in accuracy for cardiac relative to FAST (difference 4.0%; 95% CI 0.3, 7.7). There was no difference between professional types in accuracy gains achieved ($P = .07$). There was a difference in knowledge gains between participating countries ($P < .001$). Of note, there was significantly greater accuracy gained in the Kenya MSF site versus Yemen (difference 6.0%; 95% CI 0.3, 11.8) and Sierra Leone versus Liberia (16.1%; 95% CI 1.3, 30.9) and Yemen (9.4%; 95% CI 1.2, 17.7). The Cohen's effect size of the intervention was large across all metrics[30] (Table 2).

The initial mean percentage of participants that were "definite" in their responses for all applications was 79.4% versus a final of 88.3% (difference 8.9%; 95% CI 6.8, 11.0). Per application: soft tissue initial

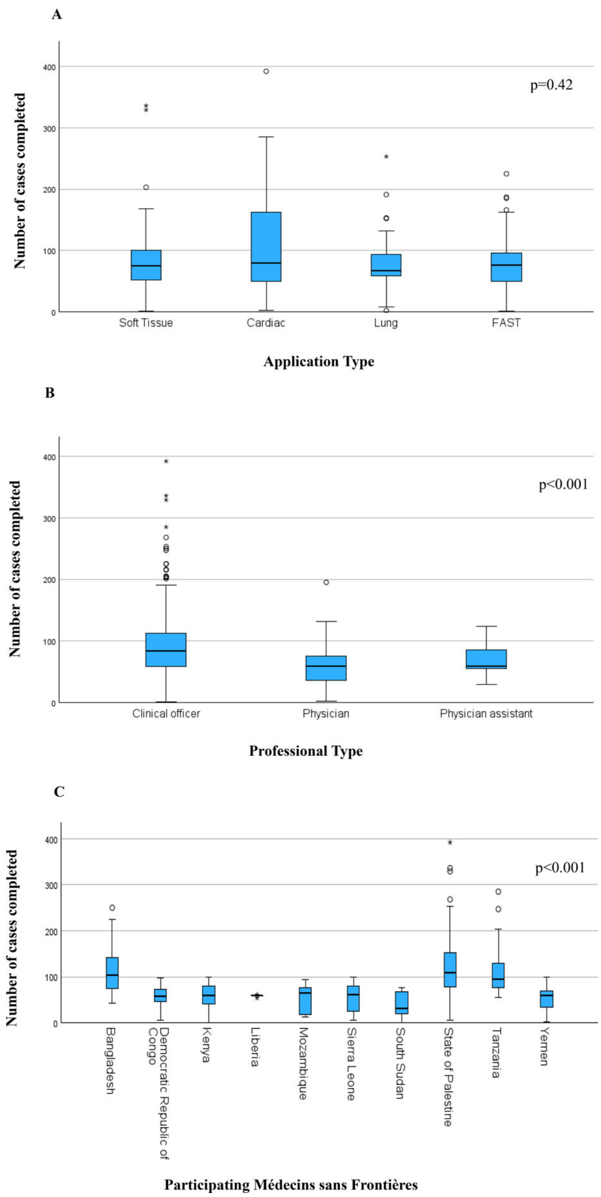
Table 2. Learning Performance Metrics Among Médecins Sans Frontières Participants

	Accuracy (95% CI)			Sensitivity (95% CI)			Specificity (95% CI)			Cohen's *d* Effect Size for Change in Accuracy (95% CI)
Application	Pre	Post	Difference	Pre	Post	Difference	Pre	Post	Difference	
Soft Tissue N = 95	82.3	98.1	15.8 (13.3, 18.2)	83.2	96.4	13.1 (11.0, 15.3)	76.4	95.3	18.9 (16.1, 21.7)	1.3 (1.0, 1.6)
Cardiac N = 93	79.8	97.6	17.7 (15.6, 19.7)	77.3	93.6	16.3 (14.3, 18.3)	81.1	96.1	15.0 (12.6, 17.4)	1.8 (1.5, 2.2)
Lung N = 93	89.2	98.4	9.1 (7.6, 10.6)	85.4	94.8	9.3 (7.5, 11.0)	89.8	97.8	8.0 (6.6, 9.4)	1.3 (1.0, 1.5)
FAST N = 101	83.6	97.3	13.7 (11.8, 15.4)	80.2	93.8	13.5 (11.1, 16.0)	82.8	95.0	13.1 (11.0, 15.2)	1.5 (1.2, 1.7)

Note: Pre denotes the performance on the initial 25 cases; Post denotes the performance on the final 25 cases; N denotes the number of participants.

78.1%, final 88.0% (difference 9.9%; 95% CI 5.4, 14.4); cardiac initial 78.1%, final 88.8% (difference 10.7%; 95% CI 5.3, 16.0); lung initial 85.1%, final 88.9% (difference 3.8%; 95% CI 1.6%, 6.0%); FAST initial 76.5%, final 87.4% (difference 10.9; 85% CI 6.8, 15.0). The change in accuracy (13.2%) was significantly higher than the change in confidence (8.9%; difference 4.2%; 95% CI 1.9, 6.5).

Figure 2. Number of cases completed by (**A**) application type, (**B**) professional type, and (**C**) participating Médecins Sans Frontières sites to achieve the mastery learning standard.



Achievement to the Performance Benchmark

Of the 110 who did at least one case, 90 (81.8%; 95% CI 73.3, 88.5) achieved the mastery learning standard in at least one application. More specifically, 90/107 (84.1%; 95% CI 75.8, 90.5) completed cases to achieve the mastery learning standard for soft tissue, 75/100 (75.0%; 95% CI 65.3, 83.1) for cardiac, 88/100 (88.0%; 95% CI 74.2, 89.8) for lung, and 89/110 (80.9%; 95% CI 72.3, 87.8) for FAST. The median number of cases completed to achieve the performance standard overall was 75 (IQR 54, 100; min 54, max 392). There was no difference between the applications in the median number of cases completed to achieve the standard ($P = .42$, Figure 2A). Overall, 23.6% of the participants had to complete more than 100 cases to achieve the mastery learning standard, and 5.0% had to complete more than 200 cases. The physicians relative to clinical officers ($P < .001$) and physician assistants ($P < .023$) needed to complete a fewer number of cases to achieve the performance standard (Figure 2B). There was also a difference in the number of cases completed to achieve the standard between participating MSF sites ($P < .001$, Figure 2C). Of note, significantly more cases were completed by participants at Bangladesh, Tanzania, and State of Palestine MSF sites relative to the Democratic Republic of Congo, Kenya, Mozambique, South Sudan, Sierra Leone, and Yemen sites, $P < .001$ for all comparisons.

Feasibility and Acceptability

Participants

Median Time on Case—The median time to complete each case was 35.5 seconds (IQR 24.3, 57.9; min 8.7,

Figure 3. Median time per case for each point of care ultrasound application.

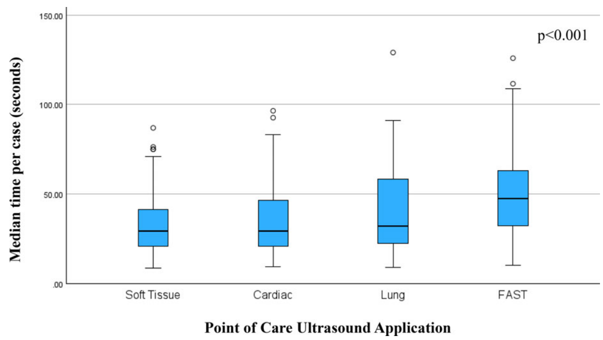
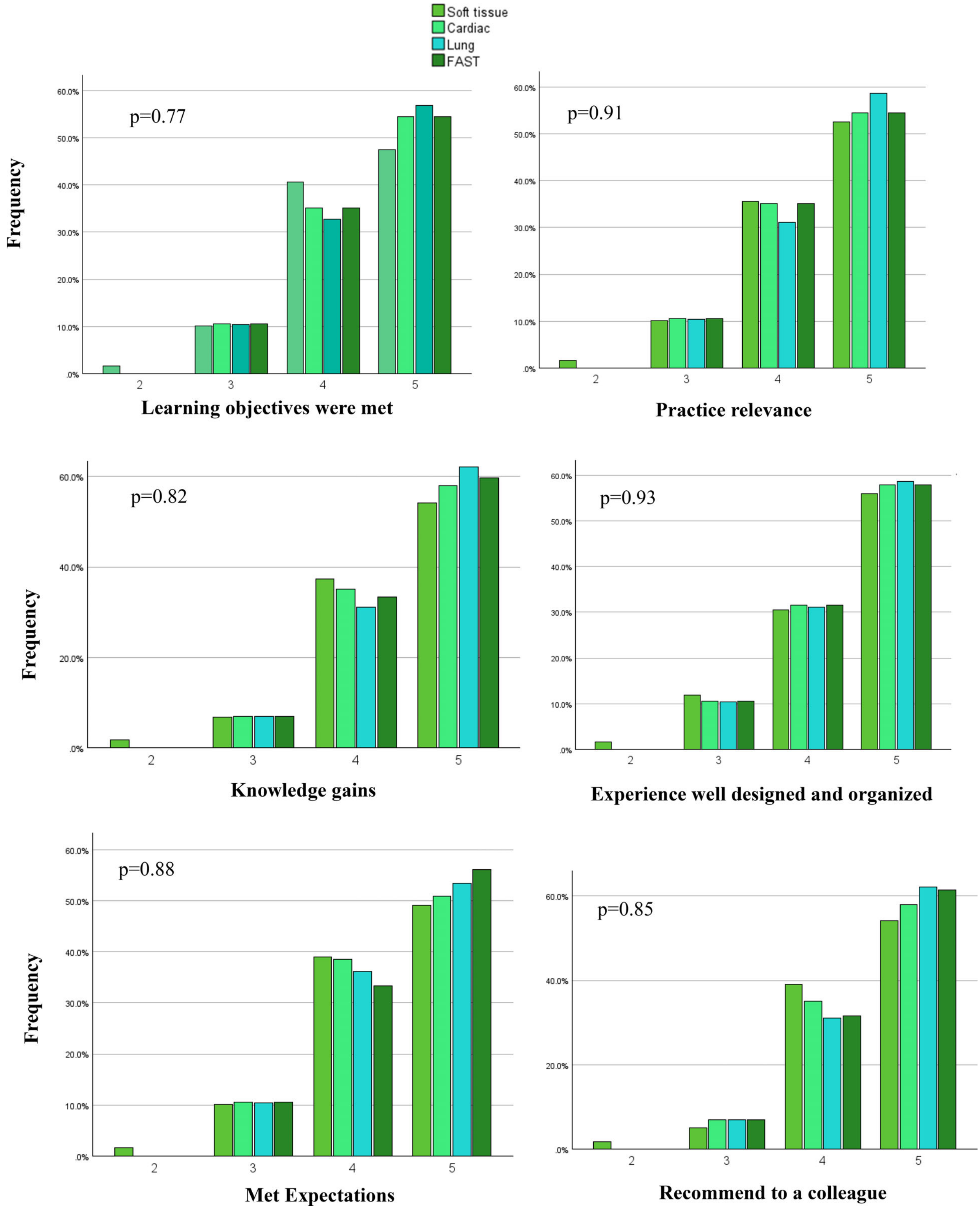


Figure 4. Médecins Sans Frontières Clinician Feedback rated at the degree of agreement (1 = strongly disagree; 2 = disagree; 3 = neither agree/disagree; 4 = agree; 5 = strongly agree).



max 300) and the median time per case did vary between applications (Figure 3). Specifically, FAST application images (with four images per case) took longer than the other applications (one image per case), $P < .001$. The median time it took to complete each application to the performance standard was 36.5 minutes (IQR 27.0, 49.1; 24.5 min, 165.2 max) for soft tissue, 38.8 minutes (IQR 27.0, 82; 25.2 min, 192.2 max) for cardiac, 35.9 minutes (IQR 31.7, 50; 27.0 min, 136.2 max) for lung, and 60.4 minutes (IQR 43.7, 76.3; min 40.7, max 178.8) for FAST. To complete all four applications to the performance standard took a median of 2.86 hours (IQR 0.93, 3.63), with a maximum of 11.2 hours for about 5% of the participants.

Participant Evaluations and Comments—Of the 110 participants, 69 (62.7%) completed a course evaluation on at least one application, and there were 231 completed evaluations. Of these, 214 (92.6%) agreed/strongly agreed that they had significant knowledge gains. Furthermore, 206 (89.2%) agreed/strongly agreed that learning objectives were achieved, the experience had relevance to their practice, met expectations, and the experience was well designed and organized. There was no difference between applications (Figure 4). Finally, 59 (53.6%) participants reported time as a barrier to completing cases, 54 (49.0%) reported challenges with internet/access to hardware, and 6 (5.5%) felt they did not have support from their managers.

MSF POCUS Course Coordinators

One MSF course coordinator oversaw operations for 67 (44.0%) of clinicians from four sites, while the other did so for 85 (56.0%) clinicians from six sites.

Administrative Time Burden—One MSF course coordinator reported up to about 10 hours of administrative time to coordinate the supplemental web-based case experience, while the other reported up to about 20 hours. The course coordinators described that the biggest reasons for the administrative burden were related to obtaining hardware, internet access, getting participants started, and following up with on-site medical supervisors and clinicians to complete the cases. Obtaining laptops was particularly laborious and time-consuming, considering that negotiations for laptops with MSF had to be completed over long distances.

Barriers—Both course coordinators strongly agreed that internet connection and hardware were barriers to the implementation of the experience. Internet and hardware access had to be navigated and supported for five (50%) of the MSF sites. Both agreed strongly that a lack of support from on-site medical supervisors with respect to providing promised technical requirements and protected time was a barrier. Clinician computer literacy was also a significant challenge. Clinicians who had limited English could not participate, which was an issue for about 50% of the MSF-affiliated sites.

Suggestions for Improvement—Course directors felt that an offline application available in multiple languages (French, English, Arabic, and Spanish) would be most beneficial for resource-limited settings. Furthermore, support from the clinical team to provide dedicated time would be an asset.

Discussion

In resource-limited health care settings affiliated with MSF, the online case-based education intervention demonstrated significant knowledge and confidence gains. Of those who started in the intervention, over 80% achieved the mastery learning standard within a median time of about 3 hours for all four applications. Most participants were also very positive about the experience. Nevertheless, given that the intervention was internet-based, about half of the participating sites needed additional internet and/or hardware to be provided to engage in the experience. Overall, these data provide information on the successes and challenges of these technology-dependent education experiences in resource-limited settings.

There were notable differences between applications, sites, and professional types with respect to learning outcomes. In particular, owing largely to a higher initial accuracy in lung POCUS, knowledge gains were lower in this application relative to the others, which is consistent with prior literature that included practicing physicians in Canada and the

United States.[19] Since there is often limited access to chest radiography in resource-limited settings and respiratory illness is common, the lung application is increasingly used in these clinical environments[7,31]; thus, this added clinical exposure may explain the higher initial accuracy in lung POCUS. Nevertheless, the majority of MSF participants achieved the mastery learning standard in all applications, and there was no difference in the number of cases required to achieve this across the applications. This study did note that the physician participants required fewer cases compared with the clinical officers and physician assistants. While the reasons for this are unknown, it may reflect higher baseline expertise and experience of the physicians, allowing them to integrate the new learning more quickly. This research can only provide preliminary evidence on any observed disparities in learning outcomes between MSF sites, as differences cannot exclusively be attributed to internet or hardware accessibility. There may be geopolitical factors such as ongoing conflicts or socio-economic challenges that can significantly affect a learner's ability and capacity to engage with educational material. Future research could examine what variables, in addition to language and internet barriers, contribute to more successful and efficient learning in some resource-limited settings versus others.

The vast majority of participants who completed course evaluations reported a very positive experience. However, about one-quarter of the participants enrolled in the experience did not start it, and of those who did start it, a further one in five participants did not complete cases to achieve the mastery learning standard. Attrition in participation rates has been reported in asynchronous online learning across a variety of settings.[19,32] Lack of available time is often described as one of the major barriers to completing the cases, as was reported by the participants of this study. If possible, integrating this type of learning as required with added incentives versus optional may enhance completion rates.[33] Another key previously noted barrier, and one also reported by this study's participants was internet connectivity and speed, which may also explain why about 5% of participants took threefold the amount of time to achieve the learning standard compared with the median.[12,34] Even though there is increasing access to internet globally, there are still an estimated 2.6 billion people who do not have internet access.[35] There has been prior success with the implementation of offline, self-directed, multimedia educational material to teach POCUS in Kenya.[36] Thus, development of offline education experiences for these geographic areas should be a priority to optimize successful integration of online education initiatives. The availability of hardware was also a reported barrier, similar to what has been reported for POCUS teaching initiatives in Ethiopia.[15] Computer literacy was another challenge with implementation; this was partly overcome by the technical document and availability provided by the MSF POCUS course coordinators. Yet another difficulty with creating POCUS curricula for global use is the potential for language barriers. Some clinicians did not participate in this study's intervention due to language barriers. This underscores the need for localized language support or embedding translation software into educational experiences to facilitate learning.[37,38] The hope is that over time, the education community can overcome these technical barriers to optimize outcomes. However, it will require a substantial financial investment to adapt existing education solutions so that they can be completed offline in a variety of languages, and it is an opportunity for medical educators to partner with technology companies to create an interface that operates efficiently in these environments.

This study had limitations that warrant consideration. Clinician participation included a convenience sample of MSF sites and those with sufficient English language skills. Furthermore, there were committed MSF course coordinators who facilitated the intervention. Thus, our learning outcomes likely represent those of more motivated participants with specific language skills and may not be generalizable to all resource-limited settings. We did not collect any data on the amount of POCUS experience the participants had before participation, and thus we do not know how this variable influenced the learning performance outcomes reported in this study. This study did not collect qualitative data to provide another dimension of data to better understand site-specific learning outcomes and other relevant perspectives from directors and study participants. To balance education and feasibility goals, this education platform presented preselected videos and stills for participants to review.

However, in practice, clinicians have the ability to acquire multiple views before diagnosing cases. Thus, it is uncertain to what degree the skill gained via this tool will translate to patient-level skill diagnostic performance, and learning this skill should optimally include both bedside and asynchronous learning experiences.

In conclusion, implementing an online POCUS educational intervention demonstrated successful learning outcomes and positive evaluations among clinicians who work in resource-limited health settings affiliated with MSF. However, about half of the participating sites reported significant managerial, technical, and/or language barriers. Thus, it would be critical for similar web-based initiatives to examine local challenges before implementation. Nevertheless, the fact that our participants still completed over 80,000 cases under these challenging circumstances speaks to the strong dedication and interest of both course coordinators and participating clinicians to obtain POCUS training when it was accessible to them. To optimize outcomes for a broader group of clinicians in resource-limited settings, these results may also serve as motivation for future web-based education interventions to include the functionality that serves the needs of these health care environments.

Data Availability Statement

Research data are not shared.

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