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● *Original Contribution*

IMPLEMENTATION AND ASSESSMENT OF LUNG ULTRASOUND TRAINING CURRICULUM FOR PHYSIOTHERAPISTS WITH A FOCUS ON IMAGE ACQUISITION AND CALCULATION OF AN AERATION SCORE

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Abstract——Described here is the implementation of a lung ultrasound course for physiotherapists focused on the acquisition and retention of knowledge and skills. Initially, we provided online lectures in a virtual learning environment (VLE), in which we taught the semiquantification of edema through a lung ultrasound score (LUS). Afterward, the physiotherapists participated in face-to-face lectures (which resumed the online lectures), followed by hands-on training and simulation with ultrasound. We assessed knowledge acquisition through a multiple-choice test with 30 questions (totaling 10 points). The test was applied before accessing the VLE (pre-VLE), before the face-to-face course and at its end (pre- and post-course). Physiotherapists collected actual patients' ultrasound scans, which were uploaded to the VLE and assessed by three supervisors, who performed a consensus LUS calculation and gave virtual written feedback. Thirteen physiotherapists collected 59 exams. The test results were 3.60 ± 1.58 (pre-VLE), 5.94 ± 1.45 (pre-course) and 8.50 ± 0.71 (post-course), with $p < 0.001$ for all. The intraclass correlation coefficient for LUS between physiotherapists and supervisors was 0.814 ($p < 0.001$), with moderate-to-weak agreement for LUS of the lung apical, median and basal zones, with κ = 0.455.334, and 0.417 ($p < 0.001$ for all). Trainees were found to have increased short-term acquisition and retention of knowledge and skills, with a good intraclass correlation coefficient between them and the consensus of supervisors for the LUS of actual patients. (E-mail: didiamsfisio@gmail.com)

Key Words: **Ultrasonography, Physiotherapy, Intensive care unit, Mechanical ventilation.**

INTRODUCTION

Lung point-of-care ultrasound has been increasingly used in critically ill patients, integrated with physical examination and clinical reasoning for the diagnosis of acute respiratory conditions such as pulmonary edema, atelectasis, pneumothorax, pleural effusion and pulmonary consolidation (Faistauer et al. 2010; Koenig et al. 2011; Cortellaro et al. 2012; Leopoldo et al. 2015; Francisco et al. 2016).

In addition, lung ultrasound may provide greater accuracy than pulmonary auscultation and chest radiography for the diagnosis of inflammatory pulmonary edema, a consequence of acute respiratory distress syndrome (ARDS) (Lichtenstein et al. 2004; Faistauer et al. 2010; Santos et al. 2013; Mongodi et al. 2018). Furthermore, lung ultrasound allows the assessment of pulmonary edema severity using semiquantitative scores. Higher scores indicate worsening of gas exchange, clinical presentations and outcomes in diseases such as sepsis and ARDS (Lichtenstein and Mezière 2008; Caltabeloti et al. 2014; Lichtenstein et al. 2014; Chiumello et al. 2018; Riviello et al. 2016; Mongodi et al. 2018; Zhou et al. 2018; Costamagna et al. 2021). Additionally, significant acute complications of mechanical ventilation, such

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as pneumothorax and selective intubation, can be detected more accurately and rapidly with ultrasound than with chest radiography and auscultation (Corradi et al. 2014; Vezzani et al. 2014; Costamagna et al. 2021).

Despite physiotherapists having a crucial role in respiratory strategies, especially in patients on mechanical ventilation, they are not yet widely trained to perform lung ultrasound during patient care (Potter et al. 2012; Leech et al. 2015; Battaglini et al. 2020; Vieira et al. 2020). This study evaluated the effectiveness of a lung ultrasound course for physiotherapists, focusing on the acquisition and retention of knowledge and skills. We assessed physiotherapists' learning on lung ultrasound before and immediately after the course in healthy participants and then in real patients. For the latter, we compared the agreement between physiotherapists and the course supervisors regarding pulmonary aeration using a lung ultrasound score (LUS) (Santos et al. 2013).

METHODS

Study design and recruitment

This was a pre- and post-test prospective study conducted in intensive care units, wards and the emergency department of a tertiary university hospital from July 2018 to August 2019. The research was approved by the institution's research ethics committee (CAAE: 75831417.9.0000.5404). To avoid unnecessary exposure and not interfere with patient care, the exams were performed during patients' respiratory therapy routine, as long as they did not interfere with the necessary procedures. In conscious patients, physiotherapists always asked for consent.

We included physiotherapists employed at the participating hospital. Exclusion criteria were failure to sign the informed consent, absence at any stage of the course and failure to acquire at least three image collections during the research period.

Training design

The lung ultrasound course comprised three phases.

Phase 1. Virtual learning environment. We launched video lessons 1 wk before the face-to-face training on the institutional virtual learning environment (VLE) platform (Moodle). After logging into the platform, trainees had to answer the 30-question pre-test to gain access to the lectures. To avoid recall bias, we asked the participants not to share their answers to the questions with each other. Additionally, participants did not receive feedback on the knowledge test. Then, two lectures were provided: (i) Ultrasound knobology (30 min) included basic ultrasound physics, basic machine and probe manipulation and basic pre-sets (depth, gain, time gain compensation). (ii) Lung ultrasound (45 min) included normal findings and pathologic findings (edema, consolidation, pneumothorax, pleural effusion and atelectasis).

Phase 2. Face-to-face training. The face-to-face training occurred in 1 d and lasted 5.5 h. The training started with theoretical review classes in knobology and lung ultrasound. We also taught image acquisition, LUS calculation and video loop recording.

The hands-on activity had an average of one supervisor for every six physiotherapists trainees and was divided into two stations: (i) The six lung windows were trained in B-mode and named Z1 to Z6. (ii) A respiratory failure case was simulated using a high-fidelity mannequin with an ultrasound simulator, with subsequent debriefing, in groups of four to five people. The ultrasound simulator is a prototype developed for our study group by a team of engineers from the Eldorado Institute (based in Campinas, State of Sao Paulo, Brazil) and consists of a sham transducer embedded with a radiofrequency identification (RFID) reader. Six different RFID round tags were placed in the mannequin thorax to simulate the six LUS zones. In the simulator software, each of these tags had an identification code that led to a corresponding pre-recorded real lung ultrasound image intended for the activity.

Phase 3. Hands-on with actual patients. After the course, the trainees performed lung ultrasound exams in actual patients during their daily routine, with the aim of performing 10 exams per participant. In the first exams, they received help switching on the equipment to save and store the images, probe handling and guidance on the equipment's resources for better image acquisition. As the trainees performed the exams, the aid decreased until there was no further assistance. As part of the training, they calculated the LUS of the six B-mode images acquired. Trainees also received online feedback on image quality and LUS calculation from the three supervisors.

The supervisors' experience with lung ultrasound includes: experience in cardiac and lung POCUS research (T.M.S., T.G.); the development of POCUS didactic content (T.M.S., T.G.); the teaching of POCUS to residents and medical students; and the use of POCUS in clinical practice (T.M.S., T.G., M.H.F.).

Lung ultrasound protocol

Healthy participants (from the face-to-face course) and patients were positioned in a semirecumbent position. The anterolateral thoracic region was divided into six zones, three per hemithorax, with the scans initiated by the right hemithorax. In each hemithorax, the first zone was located in the midclavicular line between the first and second intercostal spaces; the second zone was in the anterior axillary line between the third and the fourth intercostal spaces; and the third zone corresponded to the posterior axillary line at the topography of the diaphragm, as illustrated in Figure 1 (Santos et al. 2013).

According to the first international consensus conference on point-of-care lung ultrasound, the following findings were considered for calculation of LUS: Lung sliding is the movement of the pleural line along with the respiratory rate. The A-lines are repetitive horizontal artifacts that are parallel to the pleural line, caused by the preponderance of air in the lung parenchyma and, thus, represent the absence of lung edema. The B-lines are vertical hyperechoic reverberation artifacts that originate from the pleural line, extend to the bottom of the screen and move synchronously with lung sliding. Lung consolidation was considered when a subpleural echo-poor region or one with a tissue-like echotexture was found (Faistauer et al. 2010; Volpicelli et al. 2012; Lichtenstein et al. 2014).

The LUS was calculated as follows: 1 point in normal pulmonary aeration (A-lines or two isolated B-lines); 2 points for moderate loss of pulmonary aeration (three or more well-defined B-lines); 3 points for severe loss of pulmonary aeration (thick, coalescent B-lines); and 4 points for pulmonary consolidation, as illustrated in Figure 2. The LUS could then vary between 6 points and a theoretical upper limit of 24 points, representing bilateral and total lung consolidation, which was not found in any patient (Santos et al. 2013) (Fig. 2).

LUS video samples

Four video loop samples are listed below and were acquired by the physiotherapists; therefore, some

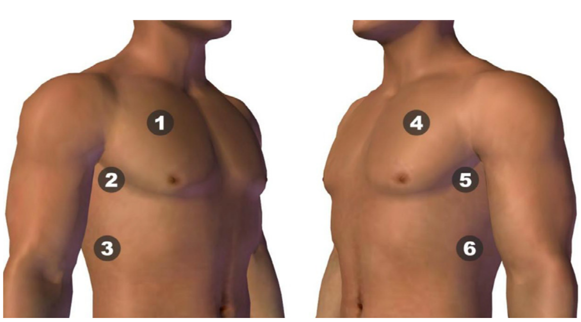

Fig. 1. The six thoracic zones used to calculate the lung ultrasound score. 1 Point = normal aeration (presence of lung sliding with A-lines or fewer than two isolated B-lines). 2 Points = moderate loss of lung aeration (≥3 well-defined B-lines). 3 Points = severe loss of lung aeration (multiple thick and/or coalescent B lines). 4 Points = lung consolidation.

inadequacies were observed by the supervisors and addressed for the trainees in their feedback. Because there was not a lung pre-set in one piece of the US equipment, the abdominal pre-set was used. Preset, gain and focal zone were not standardized, as we expected the physiotherapists to choose the best combination to produce the loops.

- Video 1: LUS = 1 (thoracic zone 2). In this loop, the focal is set at 10.5 cm, even though its ideal location is at the topography of the pleura. This was cited in one supervisor's feedback.
- Video 2: LUS = 2 (thoracic zone 2). In this loop, the focal is set at 6 cm. Two supervisors mentioned the augmented gain and centralization of the intercostal space in the image.
- Video 3: LUS = 3 (thoracic zone 3). In this loop, the transition to the abdomen can be seen.
- Video 4: LUS= 4 (thoracic zone 3). In addition to the consolidation, this video illustrates a pleural effusion. The presence of pleural effusion did not affect the LUS.

All examinations were performed with portable ultrasound equipment with a 2- to 5-MHz convex probe (Logiq-E and Venue models, GE Medical Systems, Milwaukee, WI, USA). In phase 3, trainees recorded the loops, which were then converted to .avi or .wmv formats and sent by e-mail to the supervisors.

Instruments

Cognitive test. The acquisition and retention of knowledge were assessed by a questionnaire with 30 objective questions with four alternatives concerning knobology, normal lung, pulmonary pathological changes and clinical cases. The test was given at three points: at the VLE, before access to virtual classes (pre-VLE) and immediately before and immediately after the face-to-face course (pre-course, post-course). Each correct question was equivalent to 0.33 point, totaling a minimum score of 0 and a maximum of 10 points. Figure 3 illustrates two examples of questions included in the test.

Image quality assessment. The images collected were stored in the machine and transferred to a pen drive. The patient was anonymized, and the six B-mode video loops were e-mailed to all three supervisors, who were blinded to the identity of the examiner and the LUS result. In the e-mail, there was also a link for a Google Form designed for the assessment of the exams. On the first page of the form, the supervisor could evaluate the videos of each lung zone, scoring the LUS from 1 to 4

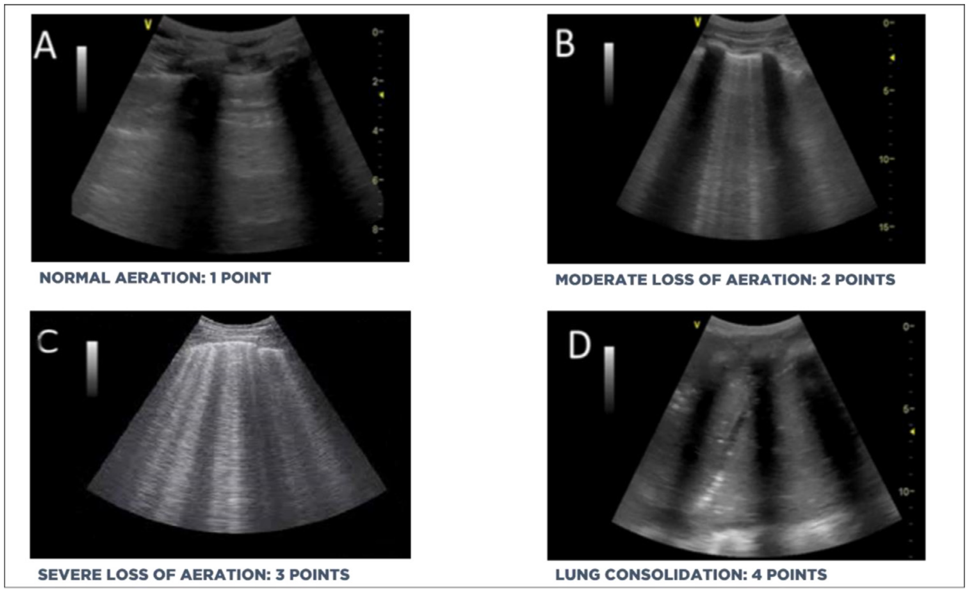

Fig. 2. (A) Presence of lung sliding with A-lines or fewer than two isolated B-lines: 1 point. (B) Three or more well-defined B-lines: 2 points. (C) Multiple thick and/or coalescent B-lines: 3 points. (D) Lung consolidation: 4 points.

points or *Inconclusive* in cases in which the LUS could not be calculated. On the second page, supervisors classified the images as appropriate or not with respect to the following technical criteria: depth, gain, time gain compensation, video length and overall technique. The last page was dedicated to the written feedback. The completion of the form generated a line in the form's spreadsheet (generated by Google Sheet), which was then

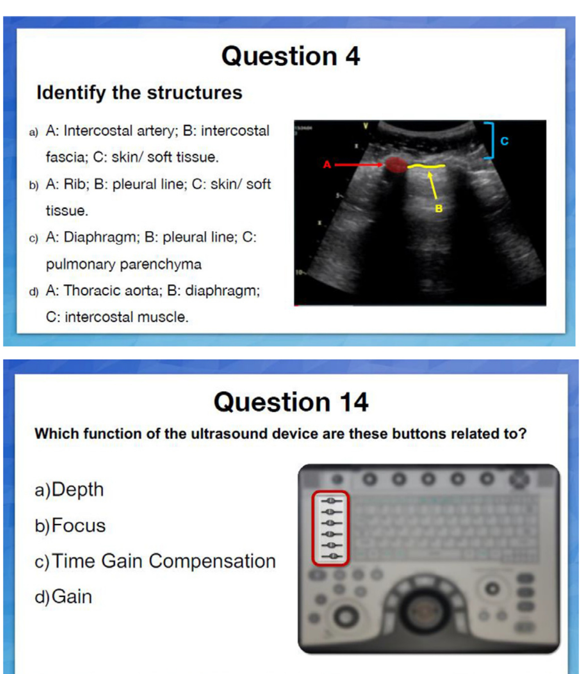

Fig. 3. Examples of questions included in the test.

converted to Microsoft Excel format and posteriorly analyzed by the authors.

Consensus of supervisors

The three supervisors first separately calculated LUSs and gave feedback to the physiotherapists. Afterward, the main author compared the score of each loop, given by each supervisor, to assess whether it was concordant or discordant among the supervisors. When all three agreed on the score, it was considered valid. Scores with discordant values were discussed by the supervisors to reach a consensus. To do so, they reviewed each video loop with different LUSs previously attributed.

Data analysis

For the demographic variables, we used absolute frequency (n) and percentage (%) when categorical and the mean and standard deviation when continuous. For the quality of the images, we used the mean, interquartile range and percentage (%).

For the knowledge test (pre-VLE, pre-course, post-course), only the pre-VLE was not normally distributed. Subsequently, we conducted a non-parametric test (Friedman test and Wilcoxon signed-rank test). As we have two variables that are normally distributed and the results of the parametric and nonparametric analyses were similar, we decided to use parametric analyses. For the knowledge score, we used the mean and standard deviation values. Students' knowledge growth was analyzed by repeated-measures analysis of variance.

To analyze LUS score agreement, we calculated Cohen's κ coefficient between the physiotherapists and the consensus of supervisors. The data were analyzed using SPSS version 21.0 (IBM Corp., Armonk, NY, USA).

RESULTS

The study period ranged between July 2018 and August 2019. We invited the entire team of physiotherapists of the hospital (N = 41), 24 of whom agreed to participate in the research as trainees. Of those, 5 were excluded because of absence from the face-to-face course and/or participation in phase 3, and 6 were excluded for presenting fewer than three exams. Therefore, 13 physiotherapists completed the entire training protocol as trainees. The trainees had a mean age of 34.89 (±4.51) y. The mean training time in physiotherapy was 11.94 (±4.24) y; most of them had a specialist title (52.63%), 21.05% had a master's degree and 26.31% had a Ph.D.

During the research, 59 patients admitted to the intensive care unit were evaluated, with a mean age of 54.9 y and a male predominance (43 men, 72.9%). The majority of patients, 57, were under mechanical ventilation. The most common diagnoses were sepsis (18.64%) and traumatic brain injury (15.25%), followed by trauma and acute respiratory failure (11.86%) (Table 1).

Knowledge acquisition and retention

There was a progressive and significant increase in trainees' knowledge from pre-VLE to post-course ($F[2, 24] = 90.087$, $p < 0.001$) with an effect size of 0.882. The score on the knowledge test was higher post-course (8.5 ± 0.71), pre-course (5.94 ± 1.45) and pre-VLE (3.60 ± 1.58) (Fig. 4).

Table 1. Characteristics of patients

Number of patients	59
Age (y), mean ± SD	54.9 ± 17.9
Male sex (%)	43 (72.9)
Mechanically ventilated (%)	57 (96.61)
Inpatient diagnosis, n (%)	
Acute myocardial infarction	4 (6.78)
Post-cardiovascular surgery	4 (6.78)
Acute respiratory failure	7 (11.9)
Traumatic brain injury	9 (15.25)
Nervous system diseases	4 (6.78)
Sepsis	11 (18.64)
Systemic inflammatory response system	4 (6.78)
Diseases of the gastrointestinal system	2 (3.39)
Gastrointestinal surgery	3 (5.08)
Liver transplant	2 (3.39)
Kidney transplant	2 (3.39)
Autoimmune diseases	2 (3.39)
Trauma	7 (11.86)

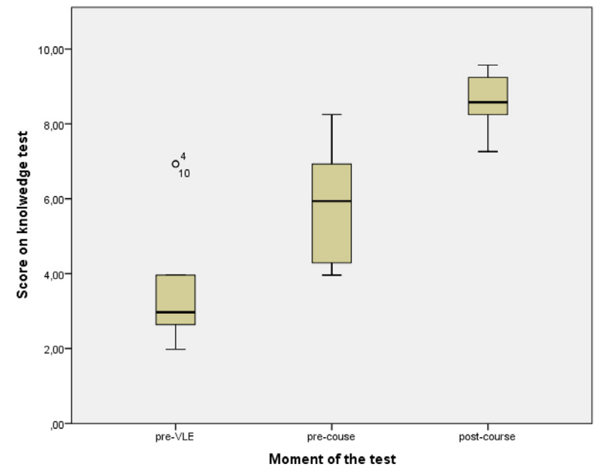

Fig. 4. Progression of the acquisition of knowledge of the trainees in pre-VLE, pre-course and post-course. VLE = virtual learning environment.

Skill acquisition and retention results

Trainees performed 59 lung ultrasound exams, with an average of 4.54 and a median of 5 exams per trainee. In total, they produced 354 video loops in B-mode.

Among the parameters evaluated as adequate, those that obtained the best average percentages among the three supervisors were video length time, time gain compensation and gain (97.55%, 89.45% and 88.42%, respectively). The parameters with the worst average percentage of adequate examinations among the three supervisors were depth (79,10%) and overall technique (63.84%) (Fig. 5).

LUS agreement between trainees and supervisors

As outlined in Table 2, of the 59 exams performed, 29 had at least one of the six video loops considered inconclusive for the consensus of supervisors, so the data presented refer to the 30 valid exams. Thus, we analyzed the images establishing the agreement between the apical (Z1 + Z4, 111 valid images), intermediate

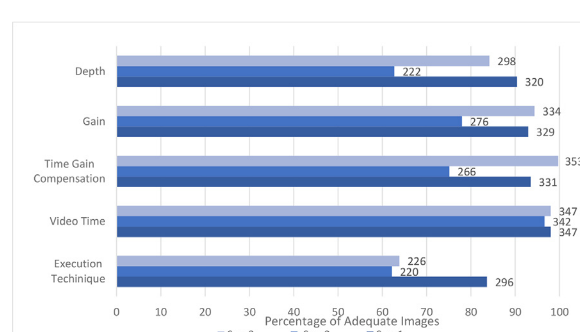

Fig. 5. Percentage of lung images classified as adequate. The numbers at the right side of the bars represent the total amount of adequate images. Sup = supervisor.

Table 2. Cohen's κ coefficient between the physiotherapists and the consensus of supervisors regarding the calculation of LUSs in the bilateral apical, intermediate and basal lung zones

LUS zone	Lung ultrasound video loops		κ
	Valid (n, %)	Inconclusive (n, %)	
Apical (Z1 and Z4)	111 (94, 1)	7 (5, 9)	0.455
Intermediate (Z2 and Z5)	107 (90, 7)	11 (9, 3)	0.334
Basal (Z3 and Z6)	84 (71, 2)	34 (28, 8)	0.417

LUS = lung ultrasound score.
$p < 0.001$ for all. This table also lists the numbers of valid and inconclusive lung ultrasound video loops. A loop was considered valid when both trainees and supervisors could calculate the LUS, and inconclusive when trainees, supervisors or both could not calculate the LUS.

(Z2 + Z5, 107 valid images) and basal (Z3 + Z6, 84 valid images) lung zones. There was moderate-to-weak agreement on the LUSs of the lung apical, median and basal zones (κ = 0.455, 0.334 and 0.417, $p < 0.001$ for all). Among the 30 exams from which the LUS could be calculated, we analyzed the agreement between the trainees and the consensus of supervisors and obtained an intraclass correlation coefficient (ICC) of 0.814.

DISCUSSION

This study aimed to evaluate the impact of a blended learning lung ultrasound course for physiotherapists. Combining online activities, face-to-face courses, clinical simulation and practical activities in simulated and actual patients, our course seemed to improve the trainees' skills and knowledge in obtaining images with adequate techniques and in the evaluation of pulmonary edema through calculation of the LUS.

In their daily practice, physiotherapists need to integrate information from physical examinations, mechanical ventilators and lung imaging (such as X-ray and computed tomography scan results). However, these imaging methods cannot be assessed at the bedside as repeatedly and in a timely manner as lung ultrasound. Thus, a myriad of parameters, such as chest semiology, respiratory compliance, resistance to flow and positive end-expiratory pressure (PEEP) calculations, among others, must be interpreted together to deliver optimal respiratory care. For example, the response to recruitment maneuvers and prone positioning can be assessed by changes in lung ultrasound scores (Battaglini et al. 2020; Vieira et al. 2020). Thus, a team of physicians and physiotherapists trained in using the LUS might benefit from their complementary evaluations when discussing the therapeutic plan at the bedside. A potential issue regarding physiotherapists training in lung ultrasound is the lack of knowledge of the method by the attending physician. Fortunately, lung ultrasound has been increasingly used by physicians, and adequate multidisciplinary work should be favorable to the interchange of knowledge between different professionals.

There are other protocols with different numbers and/or locations of thoracic zones for the assessment of the lungs by point-of-care ultrasound (Lichtenstein and Mezière 2008; Volpicelli et al. 2012). For example, the BLUE protocol also comprises three zones per hemithorax in slightly different locations compared with our protocol. Similar to the BLUE, our protocol also included two anterior zones. In the more caudal zones at the topography of the diaphragm—zones 3 (left) and 6 (right)—physiotherapists were instructed to slide the probe as posteriorly as possible to seek pathologies at the more dependent lung regions bilaterally. In our previous lung ultrasound study, on which this protocol was based, the six SLESS points correlated with sepsis severity and other clinical parameters. For example, SLESS had a negative correlation between the LUS and the PaO_2/fraction of inspired oxygen ratio in the initial assessment of 61 septic patients at the emergency department ($r = -0.62$, $p < 0.001$) (Santos et al. 2013). Thus, despite the differences among protocols, the one proposed in our study seems to be suitable for the assessment of the lungs by ultrasound.

Although most lung ultrasound teaching curriculums were designed for physicians or medical students, there are a few with specific training for physiotherapists (Paganini and Rubini 2015; Edrich et al. 2016; Paganini et al. 2017; Ntoumenopoulos et al. 2018). For example, See et al. (2016) implemented a training program that allowed physiotherapists to independently perform lung ultrasound after at least 10 directly supervised scans. In their study, trainees also made images in B-mode and evaluated similar lung ultrasound alterations but without calculating the LUS. In our course, we included other pulmonary findings, especially regarding the calculation of LUS.

The educational design proposed for the lung ultrasound course was based on evidence in both the educational and cognitive psychology fields. First, the material was available 1 wk before the day of the face-to-face course so that students could study the material beforehand. Second, we used the test for two purposes: to verify students' knowledge and to take advantage of the testing effect. The testing effect indicated that testing produces better retention than re-studying (Roediger and Karpicke 2006). Furthermore, before the face-to-face course, supervisors reviewed the theoretical content based on the spacing effect. The spacing effect has revealed that studying the material spaced in time is better than studying it in one session (Roediger and Karpicke 2006; Cecilio-Fernandes et al. 2018).

Third, simulated training plays an essential role in the practice of lung ultrasound skills, starting from less complex activities and with a lower cognitive load (CL) (de Araujo Guerra Grangeia et al. 2016; Chen et al. 2018; Pietersen et al. 2018). For this reason, we started training with healthy participants and a high-fidelity mannequin (Paganini et al. 2017; Mongodi et al. 2018; Ntoumenopoulos et al. 2018). After this initial training, trainees performed the exams at the bedside of actual patients. Finally, during the training session, the feedback was provided to trainees by supervisors, and the amount of feedback was reduced as the students progressed in acquiring skills. This reduction in feedback is effective so that the student does not remain dependent on the expert's feedback (Cecilio-Fernandes et al. 2020).

Feedback is essential to support students' 3-D reasoning and mental reconstruction of the visualized structures as ultrasound generates 2-D images on the screen. Mentally transforming 2-D to 3-D is one of the most complex components of learning ultrasound images (Weidenbach et al. 2005; Cecilio-Fernandes et al. 2020). In general, we learn anatomy from a 3-D perspective, for example, when we study anatomy in cadavers. Augmented reality can also be used to understand 3-D anatomy using computer programs that generate two images, one for each eye, offering the notion of depth. However, the anatomical image on the US is two-dimensional, and the position of the structures on the screen often does not correspond to the actual presentation if they were seen with the naked eye (Leung et al. 2020; Tori and Hounsell 2020). Although lung ultrasound is based mainly on artifact interpretation, the occurrence of actual images is also possible, such as when consolidations and pleural effusions are found. Therefore, feedback also helped the trainees understand these peculiarities of 2-D images, often requiring the naming of anatomical structures that the trainees already know but cannot recognize.

We observed a relatively moderate agreement between trainees and supervisors concerning LUS. This could be explained because the absolute number of B-lines might be influenced by the width of the intercostal space and by the orientation of the probe (longitudinal *vs.* transverse to the intercostal space). To overcome these limitations, a modified LUS has been proposed, considering the percentage of occurrence of B-lines in the intercostal space and not their absolute number. This LUS had a better correlation with extravascular lung water measured by thermodilution than the semiquantitative score we adopted in our study. This study also obtained promising results regarding a computer-aided LUS (Corradi et al. 2016; Mongodi et al. 2017). Furthermore, a relatively low agreement based on κ indexes in more lateral to basal lung zones was also reported in other publication. Possible explanations include the presence of the heart and adipose tissue in more dependent regions of the thorax. Moreover, technical challenges regarding probe positioning in more lateral regions might also hinder the acquisition and interpretation of the images, but these assumptions need further evidence and might be an interesting source of research (Gullett et al. 2015; Vieira et al. 2019).

These difficulties might be overcome by the development of a computer-based, clinically easy-to-use tool aimed at reducing inter- and intra-observer variability (Corradi et al. 2020). The development of such algorithms requires large amounts of data, and in this sense, several international initiatives have already started, with thousands of open-source lung ultrasound videos. Some of these data sets are based on COVID-19 images (Gullett et al. 2015; Vieira et al. 2019).

Our study describes our first steps toward the implementation of a lung ultrasound course that might improve the way physiotherapists perform their therapies at the bedside. However, we must continue the training and oversight and implement new research protocols to improve our capacity not only to assist trainees in their exam collection but also to observe the impact of lung ultrasound in their respiratory therapy as publications addressing this issue are still lacking.

As an additional benefit, lung ultrasound may reduce the need for chest X-rays, affecting hospital costs (Zieleskiewicz et al. 2015; Brogi et al. 2017; Vetrugno et al. 2020). Leech and colleagues suggest that the use of lung ultrasound increases the efficiency of the respiratory therapy session by assisting in a faster and more specific diagnosis and intervention. They also argue that lung ultrasound could have a beneficial impact on mortality, time on mechanical ventilation and length of hospital stay, but this assumption lacks the scientific basis for its confirmation (Leech et al. 2015).

Limitations of the study

Our study has some significant limitations. We planned to capture the acquisition of knowledge and skills in a short period because the goal was for physiotherapists to first learn to acquire and interpret basic lung ultrasound findings. We attempted to reinforce their learning by giving them written virtual feedback from the three supervisors. However, further research is needed with several standardized measurement moments to assess students' knowledge and skills growth. Additionally, as our training is focused primarily on work-based learning, further assessment and education intervention may be necessary to maintain a level of proficiency. In this sense, examinations were carried out during the physiotherapists' routine, which limited both the number of trainees and the number of collections per professional because of the high demand for care and logistical difficulties of the intensive care unit. This leads to a discrepancy in the number of examinations among physiotherapists, thereby reducing the total number of exams in the sample. Thus, our sample size is low compared with those in other publications assessing lung ultrasound training (Pietersen et al. 2018). Our moderate to low inter-rater agreement might be partially explained by the fact that other modalities of LUS validated by invasive thermodilution methods attribute higher scores when B-lines occupy more than 50% of the screen (Brusasco et al. 2019; Mongodi et al. 2021).

Furthermore, we acknowledge the lack of clinical context or advanced training in this initial step of our teaching strategy. However, we decided to limit the cognitive load by exploring their short-term knowledge acquisition and their performance at the bedside calculating the LUS. Some exams or video loops were more challenging to assess because of technical difficulties, especially with obese patients; however, we did not count the number of exams with this particular difficulty. Therefore, if LUS could not be calculated in only one of the six video loops constituting the exam, the sum could not be calculated as well. The patient population studied had overall lower scores in the context of the scoring system, as the upper limit of the score was not reached.

We used the abdominal pre-set for lung ultrasound exams for two reasons. First, the pre-set was automatically loaded with the convex probe, and second, one of the machines did not have a lung pre-set. Such encountered challenges are inherent in data collection in the real practice environment and even more so in an intensive care unit environment.

Although diaphragm assessment is a cornerstone for lung function, we decided not to include it because we had limited experience in this technique. In the future, we plan to further learn to assess diaphragm function using ultrasound and include it in the physiotherapist's training. It is hoped that those trainees will become instructors in lung ultrasound.

CONCLUSIONS

Our study suggests that a blended-learning lung ultrasound course led to an increase in the degree of acquisition and retention of knowledge and skills by physiotherapists. Additionally, the use of newer and automated LUS might lead to better agreement between trainees and supervisors. We believe that in addition to the availability of the online material throughout the course duration, the easy application and understanding of the LUS allowed professionals to have a reference to produce the images, optimizing the acquisition of knowledge of lung ultrasound.

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SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.ultrasmedbio.2022.06.002.

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