The Use of Point-of-Care Bedside Lung Ultrasound Significantly Reduces the Number of Radiographs and Computed Tomography Scans in Critically Ill Patients

Adriano Peris, MD,* Lorenzo Tutino, MD,* Giovanni Zagli, MD,* Stefano Batacchi, MD,* Giovanni Cianchi, MD,* Rosario Spina, MD,* Manuela Bonizzoli, MD,* Luisa Migliaccio, MD,* Lucia Perretta, MD,* Marco Bartolini, MD,† Kevin Ban, MD,‡ and Martin Balik, MD, PhD§

BACKGROUND: Chest radiography has been reported to have low diagnostic accuracy in critically ill intensive care unit (ICU) patients, and chest computed tomography (CT) scans require patients to be transported out of the ICU, putting them at risk of adverse events. In this study we assessed the efficacy of routine bedside lung ultrasound (LUS) in the evaluation of pleural effusions (PE) in the ICU.

METHODS: Three hundred seventy-six patients admitted to the ICU for major trauma (46.3%), medical pathology (41.5%), and postsurgical complications (12.2%) (May 2008 to April 2009) were included in this study. Patients were placed into either the control group (group C) or the study group (group S), on the basis of the introduction of routine LUS performed by a single group of intensivists in 1 tertiary care ICU. To reduce provider bias, the physicians conducting the LUS were not aware of the study. Collected data included patient demographics, clinical course, and number of chest radiographs and CT scans performed. As a secondary goal, we assessed the reliability of Balik's formula in PE estimation.

RESULTS: No significant differences were found between the 2 groups with regard to their demographics and ICU clinical course. Group S had a significant reduction in the total number of chest radiographs obtained (-26%; $P < 0.001$) and CT scans (-47%; $P < 0.001$) in comparison with the comparison group C. A 6-month follow-up analysis of the ICU LUS protocol revealed a time-dependent decrease in the number of radiological examinations requested for patients with PE. Lastly, PE volume estimation using the LUS and Balik's formula correlates well with the effective volume drained ($r = 0.65$; $P < 0.0001$).

CONCLUSIONS: Routine use of LUS in the ICU setting can be associated with a reduction of the number of chest radiographs and CT scans performed. (Anesth Analg 2010;111:687–92)

Critically ill patients admitted to the intensive care unit (ICU) frequently have limited mobility as a result of their underlying pathology or the invasive devices used for monitoring. Mobilization of ICU patients has long been recognized as a critical issue with high risk for potential complications and adverse events.[1,2] Significant hemodynamic and respiratory complications may occur during transport to the radiology department in as many as 40%–50% of critically ill ventilated patients.[3] In trauma patients, the execution of a control computed tomography (CT) scan within the first 12 hours after admission to the ICU contributes to a change in clinical management in <30% of cases, but still exposes the patient to significant transportation-related morbidity.[4] The potentially harmful effects of radiation or contrast dye exposure should also be taken into consideration.[5,6]

To increase patient safety and to reduce the time required for obtaining results, one should limit the use of chest radiographs and CT scans in ICU patients, and alternative diagnostic studies should be considered. Daily bedside lung ultrasound (LUS) has been shown to lack clinical usefulness because it does not reveal new or unexpected abnormalities in >90% of cases.[7] In addition, the elimination of daily routine chest radiographs in the ICU has not been associated with significant changes in patient mortality or the rate of readmission.[8,9] LUS offers numerous advantages both for patients and for caregivers: it is quick and easy to perform, harmless to the patient, and does not require patient transport. Whereas LUS may not necessarily reveal new diagnoses in patients, it can be used to provide an ongoing assessment of pleural fluid volume and may assist in the insertion of thoracic drainage tubes. Despite its many advantages, Nicolaou et al. found that bedside ultrasonography is still underutilized in the ICU setting.[10]

The aim of our investigation was to assess the impact of LUS evaluation on the quality of patient care in the ICU and on the number of other chest radiological examinations performed (chest radiographs and CT scans). As a secondary goal, we examined the usefulness of LUS in the estimation of pleural effusion before drainage.

METHODS

Patient Selection and Data Collection

This observational controlled study was performed in a 10-bed medical, surgical, and trauma ICU in a tertiary care referral center. Data on 376 patients with an ICU length of

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From the *Anaesthesia and Intensive Care Unit of Emergency Department and †Diagnostic Imaging Department, Careggi Teaching Hospital, Florence, Italy; ‡Department of Emergency Medicine, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, Massachusetts; and Anaesthesia and Intensive Care, General Teaching Hospital, Prague, Czech Republic.

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Address correspondence to Giovanni Zagli, Anesthesia and Intensive Care Unit of Emergency Department, Careggi Teaching Hospital, Viale Morgagni 85, 50134, Florence, Italy. Address e-mail to giovanni.zagli@unifi.it.

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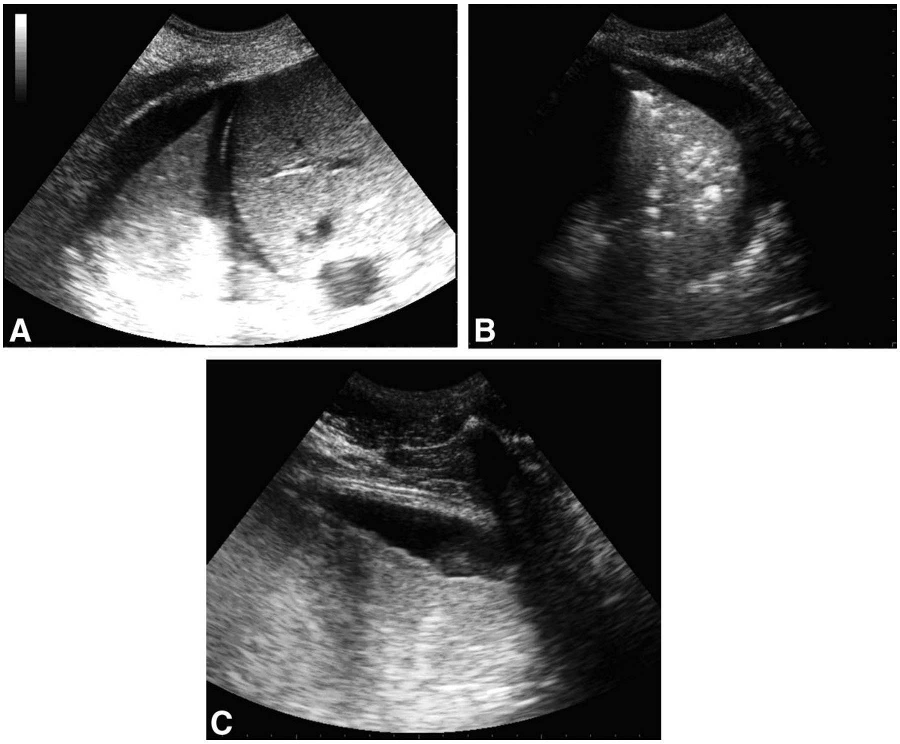

Figure 1. A, Pleural effusion with atelectatic lung floating; B, infiltrates with effusion; and C, posttraumatic lung contusion.

stay (LOS) of at least 2 days were collected and evaluated between May 2008 and April 2009. The study was divided into 2 phases. The first phase was from May to October 2008 and was designated as the control group (group C). During this time period the chest radiographs and CT scans were counted, and their indications were analyzed. ICU physicians underwent intensive training in the clinical use of LUS and became proficient in its use. The second phase of the study was from November 2008 until April 2009 and was designated as the study group (group S). During this period, postinterventional data were collected after the routine use of daily LUS in the ICU. The same 5 intensivists performed all of the LUS studies on patients with known pleural effusions. The intensivists were unaware of the ongoing data collection so as to reduce provider bias, and all data collection was done by an ICU attendant and fellow.

For all patients admitted to the ICU, the following data were collected: age, gender, body mass index (BMI), admission diagnosis, simplified acute physiology score II, number of chest radiographs and CT scans performed, radiologic indication for imaging (e.g., central venous catheter placement, pleural effusions drainage, and tracheostomy control), duration of mechanical ventilation, ICU LOS, and mortality. In addition, for group S, the volume drained within the first 30 minutes after thoracic drainage tube insertion, along with the interpleural distance before drainage, was recorded.

All data were coded so as to protect patient privacy, and subsequently collected from the ICU database (Filemaker Pro 5.5 1984 to 2001 Filemaker, Inc.). This study was performed in accordance with the principles of the Declaration of Helsinki, and was approved by the IRB, which waived the need for informed consent.

Bedside Lung Ultrasound (LUS) Protocol

LUS was performed on all patients after admission to the ICU, between the third and the fifth day of their ICU stay, or more frequently if clinically necessary. In all patients, LUS was performed using a Mylab TM 30CV ultrasound machine (ESAOTE, Genova, Italy) with a multifrequency convex probe (3.5 to 5 MHz). Patients were examined in the supine position with the convex probe applied perpendicularly to the chest wall, being sure to screen all the intercostal spaces bilaterally from the base of the lung to the apex of the chest cavity. Transversal thoracic scans were performed to assess for the presence and extent of pleural effusions. An example of a typical LUS image is seen in Figure 1.

Identification of Pleural Effusions and the Use of US-Guided Thoracentesis

Radiologic evidence of an anechoic space between the visceral and parietal pleura varying with the respiratory cycle was used as the principle diagnostic criterion for pleural effusions.[11] In cases in which a definitive diagnosis was difficult, the presence of parenchymal atelectasis (presenting a short lingula floating in an anechoic space) helped confirm the presence of pleural fluid.[12] With regard to pleural effusion volume estimation, the maximum end-expiratory distance between the parietal and visceral pleura in a supine-positioned patient was measured at the end of expiration. The estimated volume of the pleural effusion (in milliliters) was then obtained using the formula proposed by Balik et al. (mm × 20 = mL of pleural effusions estimation).[13] Three measurements of the interpleural distance were obtained and averaged to determine a value for each patient.

Table 1. Comparison of Baseline Characteristics Between Patients of Pre-LUS Period (Group C) and Patients Studied After LUS Introduction (Group S)

	Group C	Group S	*P*
Number	187	189	
Male sex, % (*n*)	71.1% (133)	66.7% (126)	0.393
Age (years)	51 (32–71)	52 (34–78)	0.711
BMI	25.1 (23.2–27.6)	24.8 (22.9–27.7)	0.794
SAPS II score	41 (26–54)	37 (22–51)	0.073
Admission diagnosis, % (*n*)			
Trauma patient with head injury	36.9% (69)	33.9% (64)	0.252
Trauma patient without head injury	11.8% (22)	10.1% (19)	0.145
Medical patient	34.2% (64)	48.7% (92)	0.111
Surgical patient	17.1% (32)	7.3% (14)	0.091
Chest pathology, % (*n*)			
Lung contusion	25.7%, (48)	28.1% (53)	0.092
Pneumonia	35.8% (67)	40.7% (77)	0.089
Pleural effusion	40.1% (75)	37.6% (71)	0.227
Interstitial edema	30.5% (57)	36.5% (69)	0.141
Total chest radiographs (*n*)	803	589**	<0.001
Chest radiographs for parenchymal investigation (*n*)	471	267***	<0.001
Chest radiographs for device control (*n*)	332	322	0.549
Chest CT, (*n*)	274	145***	<0.001
VAP, % (*n*)	13.1% (9)	9.4% (6)	0.089
Length of intracranial hypertension (in ICP monitoring) (days)	7 (3–11)	4 (2–7)*	0.032
Length of MV (days)	6 (2–10)	4 (1–7)	0.274
ICU LOS (days)	9 (5–14)	7 (3–11)	0.131
Mortality, % (*n*)	16.6% (31)	18.5% (35)	0.225

Length of intracranial hypertension was related to patients with head injury and was defined as an intracranial pressure increase more than 20 mmHg or >40% of the basal value.

Data are represented as medians with 25th to 75th interquartile range (IQR). Percentage data refer to the total population of each group. Statistical analysis: 2-tailed Mann–Whitney test and 2-tailed Fisher's exact test. *P* significant if <0.05.

LUS = lung ultrasound; BMI = body mass index; SAPS = simplified acute physiology score; CT = computerized tomography; VAP = ventilator-associated pneumonia; ICP = intracranial pressure; MV = mechanical ventilation; ICU = intensive care unit; LOS = length of stay.

After sonographic demonstration of a pleural effusion, the fluid was tapped under LUS guidance through the intercostal space, and adjacent to the largest interpleural distance noted. In all cases, the pleural tap was performed with a pigtail catheter (8 Fr, Boston Scientific Corp., Boston, Massachusetts) using the Seldinger technique and following the upper margin of the rib.[14] At least 2 cm of interpleural distance on LUS were required as a minimum indication to perform the procedure.

Statistical Analysis

GraphPad Prism 5 (GraphPad Software Inc., San Diego, California) was used for statistical analysis. Data on volumetric measurements were compared with those estimated with the Balik et al.'s formula using Pearson's test. Continuous data were compared with a 2-tailed Mann–Whitney test, and the χ^2 test was used for categorical data. Data were expressed as medians with 25th to 75th interquartile range (IQR), with a *P* value <0.05 considered statistically significant. Comparisons of pleural effusions volume estimation using Balik et al.'s formula[13] and the effective pleural effusions volume drained were performed using the method described by Bland and Altman.[15]

RESULTS

There were 376 patients admitted to the ICU during the study period requiring >48 hours of intensive care. Admission criteria included major trauma (46.3%); medical diseases including sepsis and respiratory/cardiac/renal failure (41.5%); and postsurgical complications (12.2%). All of the patients in our study cohort required mechanical ventilation during their ICU stay. The median duration of mechanical ventilation and time spent in the ICU were 5 and 8 days, respectively. Overall, the intra-ICU mortality rate in the population studied was 17.6%. In total, 1392 chest radiographs and 419 thoracic CT scans were performed.

Both study groups were similar with respect to sex, age, BMI, and simplified acute physiology score II at admission (Table 1). The admission diagnoses were slightly different between the 2 study groups. There was an increase in medical admissions from group C to group S of 34.2% to 48.7%, and a reduction of surgical patients from 17.1% to 7.4%. Patients from both groups had similar chest pathologies (Table 1).

No significant intergroup variations with regard to the duration of mechanical ventilation (6 vs. 4 days, respectively; $P = 0.274$), ICU LOS (9 vs. 7 days, respectively; $P = 0.131$), ventilator-associated pneumonia (13.1% vs. 9.4%, respectively; $P = 0.089$) nor intra-ICU mortality rate (16.6% vs. 18.5%, respectively; $P = 0.225$) were found, even if group C showed a longer duration of mechanical ventilation and ICU LOS and a higher mortality rate (Table 1). The duration of increased intracranial hypertension in patients with closed head injuries (defined as an intracranial pressure increase >20 mm Hg or >40% of the basal value) was significantly longer in group C when compared with group S (7 vs. 4 days; $P = 0.032$) (Table 1).

Significant differences between the 2 groups were noted in the number of radiological examinations performed. The number of chest radiographs performed decreased from 803 (4.3 per patient) to 589 (3.1 per patient) ($P < 0.001$), and

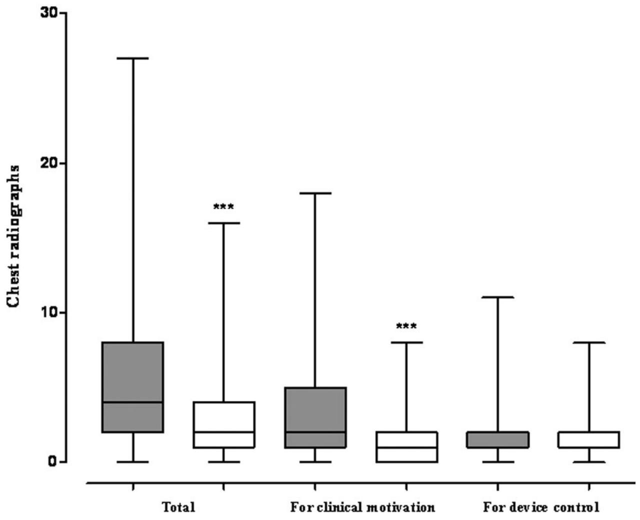

Figure 2. Decrease of means of chest radiographs per patient after bedside lung ultrasound (LUS) introduction. The reduction was related to the examinations requested for clinical reasons, whereas the number of chest radiographs for device control did not substantially change. Values represent medians with 25th to 75th interquartile range. Statistical analysis: 2-tailed Mann–Whitney test. ***$P <$ 0.001. Gray boxes: group C. White boxes: group S.

the number of chest CT scans performed decreased from 274 (1.5 per patient) to 145 (0.8 per patient) ($P < 0.001$) (Table 1). Of note, the reduction in chest radiographs between the 2 groups was limited predominantly to studies requested for diagnostic purposes (471 to 267; $P < 0.001$). The number of chest radiographs performed to assess device placement did not change between the 2 study periods (332 to 322; $P = 0.549$) (Table 1; Fig. 2).

In group S, 71 patients were found to have significant pleural effusions requiring thoracic drainage. Comparing the preprocedural pleural effusion volume estimation using LUS and Balik et al.'s formula with the actual amount of fluid drained, we found a positive correlation between the estimated and actual volume (Pearson r coefficient: 0.65; $P < 0.0001$). Statistical analysis found no significant differences between overall measurements, nor between subgroups stratified according to measured interpleural distance (Fig. 3). This positive correlation between the estimated and actual volume drained was also confirmed using the Bland–Altman method (Fig. 4). Patients' BMI did not significantly influence pleural effusion estimation.

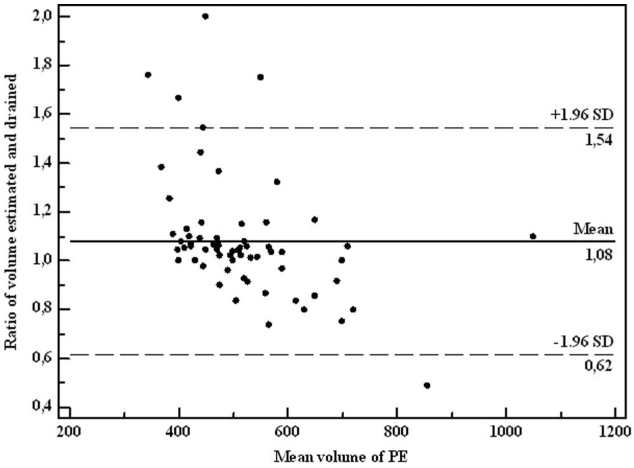

Figure 4. Bland–Altman plot showing the ratio of the mean difference and 95% limits of agreement for (ultrasound estimation − volume drained). PE = pleural effusion.

DISCUSSION

After the recent introduction of portable and affordable high-resolution ultrasound devices into daily clinical practice, bedside ICU ultrasonography has become a safe and cost-effective initial step in the evaluation of chest, abdomen, and vascular pathologies, and it offers significant assistance for invasive procedures.[6,16] The clinical utility of LUS has also been reinforced by literature reporting the poor utility of daily chest plain films in ICU patients.[7,9]

This study addresses the effectiveness of bedside ultrasonography in the ICU setting as an alternative to chest radiographs and CT scans. After the introduction of routine LUS in our ICU, we found a significant decrease in the number of chest radiographs (−26%) and CT scans (−47%) performed, with no significant adverse changes to patient

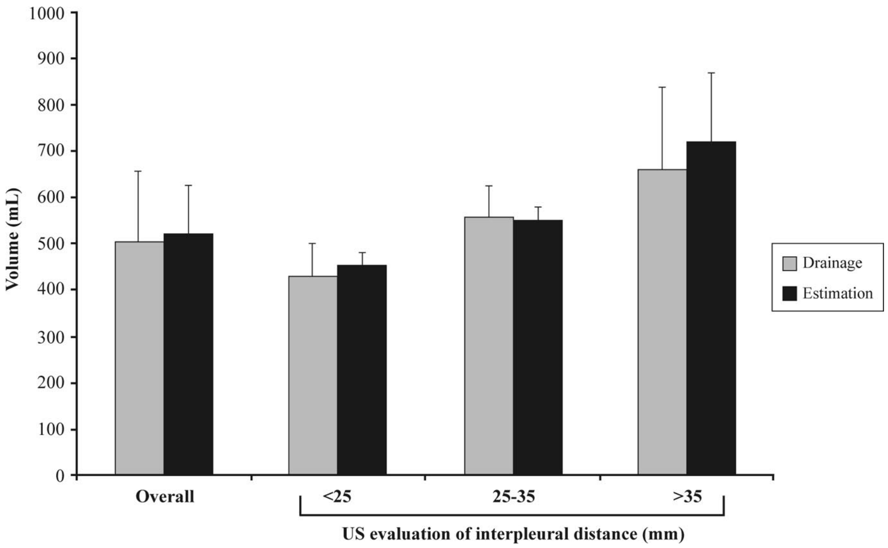

Figure 3. Comparison between pleural effusion (PE) drained volume and previous ultrasound estimation of PE volume with Balik et al.'s formula (mm of interpleural distance * 20 = mL of estimated PE) in the study group (n = 71). US = ultrasound. Statistical analysis: Mann–Whitney test. P was considered significant if <0.05. Data are expressed as mean ± SD.

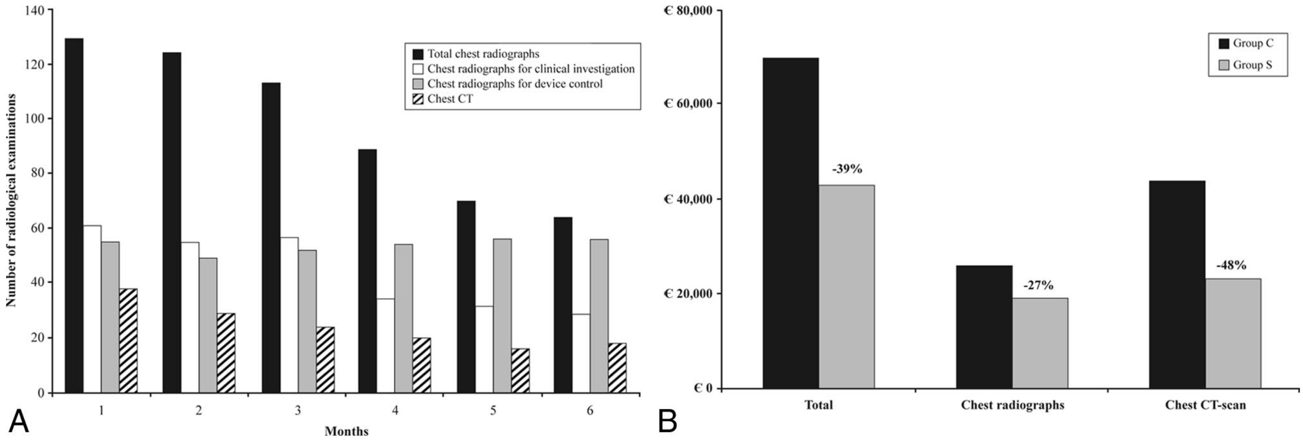

Figure 5. A, Time-dependent variation in radiological examinations during the 6 months of bedside lung ultrasound (LUS) protocol application. Total chest radiographs (black bars) and chest radiographs performed for clinical investigation (white bars) decreased significantly after the third month. Chest computed tomography (CT) scans also decreased significantly after the third–fourth month of protocol application. B, Radiological examinations cost saving in the control group (without bedside chest ultrasound) and the study group (with routine bedside chest ultrasound). Total columns represent the sum of chest radiographs and chest CT-scan.

mortality (Table 1). Because the 2 study groups were similar in terms of demographics and clinical characteristics (Table 1), and because the ICU physicians were unaware of the study, the observed differences in the number of radiological studies performed might be directly attributed to the introduction of LUS into our ICU. This decrease in the number of chest radiographs and CT scans obtained by our staff was particularly notable after the third month of the insertion of the protocol into the routine care of patients (Fig. 5, panel A). This suggests that 2 to 3 months of experience with LUS is required to observe a relevant change in the decision-making patterns of the clinicians. No significant changes in radiological examination requests were noted during the control/LUS training period. Considering the decrease in number of patients transported out of the ICU to radiology,[2,17] and the decrease in patient exposure to radiation and CT-scan contrast medium,[18] we believe that these changes present a notable improvement in overall patient safety and care.

The cost savings related to the reduction in radiological studies in group S have been estimated to be approximately 27,000€ (almost 40% less than group C; Fig. 5, panel B). As was expected, the reduction of cost was more significant for CT scans (around 19,000€, −48%; Fig. 5, panel B) than for chest radiographs (around 7000€, −27%; Fig. 5, panel B). The overall cost of equipment and physician training was estimated at approximately 25,000€. These results, obtained after only 6 months of routine LUS use, are a good argument for significant cost effectiveness of portable ultrasound, in addition to its clinical efficacy and safety.

It has been reported that in the ICU setting, 20% of critically ill patients develop pleural effusions, typically due to sepsis, late phase of trauma, massive fluid/hemotransfusion therapy, abdominal diseases, or recovery of lung contusion/infection.[19] Diagnosis and treatment of pleural effusions in the ICU with ultrasonography have been reported to be both feasible and accurate.[5,11,20,21] In our study , we found a positive correlation between the mean effective fluid evacuated from the interpleural space and the pleural effusion estimate derived using LUS measurements and Balik et al.'s formula. Interestingly, we did not find significant differences between the actual and estimated pleural effusion volume using the interpleural distance measurements of <25 mm (Fig. 3), even though many studies report that ultrasound measurement is not accurate enough to quantify small (≤500 mL) pleural effusions.[22] It must be noted that our findings might be limited by the relatively small sample size (71 patients). However, the analysis using the Bland–Altman method, validating the overall reliability of Balik et al.'s formula, confirmed that the accuracy was higher when pleural volume was between 500 and 800 mL (Fig. 4), in agreement with what has been previously reported.[22]

Study Limitations

The use of a before-and-after design could be considered problematic because of the different pathologies encountered during different seasons of the year, with more trauma admissions during summer and more medical admissions during fall and winter months. This difference exists in our sample, and whereas not significant, it must be taken into consideration as an indicator of possible differences in the 2 patient populations. However, differences in groups do not represent a critical aspect, because the aim of the study was to quantify the effects of bedside ultrasound with respect to the need for traditional radiological studies in the ICU setting. Chest drainage performed in group S might have influenced outcome variables (mechanical ventilation duration, ICU LOS, and mortality) even if these data were not found to be significant.

CONCLUSIONS

The present study underlines the importance and effectiveness of bedside ultrasound in the ICU setting. In general, bedside care of patients should be encouraged in the ICU whenever possible because transport increases risk and discomfort in critically ill patients. Bedside LUS may decrease the number of chest radiographs and CT scans without adversely affecting the patients' overall outcome. In addition, LUS seems to be more cost-effective than other radiologic studies. Finally, Balik et al.'s formula was confirmed to be a simple and reliable system for estimating pleural effusion volume. ■

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