Bedside Diagnosis and Follow-up of Patients With Pleural Effusion by a Hand-Carried Ultrasound Device Early After Cardiac Surgery*

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Objectives: The aim of this study was to assess the potential value of hand-carried ultrasound (HCU) devices in the diagnosis and follow-up of patients with pleural effusion (PE) after cardiac surgery.

Methods: Seventy consecutive patients were evaluated at bedside early after cardiac surgery, in the upright sitting position, using an HCU device on hospital admission and every 3 days until hospital discharge. The posterior chest wall was scanned along the paravertebral, scapular, and posterior axillary lines. For each hemithorax, an effusion index was derived as the sum of the intercostal spaces between the lower and upper limits of the PE along the lines of scanning, divided by 3. A standard chest radiograph was performed in all patients on hospital admission and at hospital discharge, and was qualitatively scored (0, absent; 1, small; 2, large PE). The findings of the HCU device and radiograph were compared using $\kappa$ statistics and the Kruskal-Wallis test.

Results: A chest ultrasound was feasible in all patients (mean $\pm$ SD time, 5 $\pm$ 2 min). Compared with the chest ultrasound, a physical examination showed a sensitivity of 69% and a specificity of 77%. On hospital admission, the HCU device detected a PE in 72 of 140 hemithoraxes. Agreement with the finding of the radiograph was 76% ($\kappa = 0.52$). In 15 hemithoraxes, the HCU device revealed a PE that had not been diagnosed using the radiograph. Conversely, in 18 hemithoraxes a PE that had been diagnosed with a radiograph was not confirmed by the HCU device. The correlation between ultrasound and radiographic scores was statistically significant ($p < 0.001$). At hospital discharge, a PE was present in 31 of 140 hemithoraxes according to the findings of the HCU device, and in 38 of 140 hemithoraxes according to the findings of the radiograph (agreement, 78%; $\kappa = 0.44$).

Conclusions: In patients early after cardiac surgery, HCU devices allow rapid PE detection and improve the clinical diagnosis. Compared to a radiograph, this method offers the unique advantage of the bedside evaluation of patients without the need for radiation exposure.

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Key words: cardiac surgery; chest ultrasound; hand-carried ultrasound device; pleural effusion

Abbreviations: HCU = hand-carried ultrasound; PE = pleural effusion

Pleural effusion (PE) is a frequent complication in patients recovering from cardiac surgery.¹,² In this clinical setting, the detection and follow-up of PE is challenging due to the need for bedside diagnosis and the potential for radiation exposure. Hand-carried ultrasound (HCU) devices offer a noninvasive alternative for the rapid and accurate assessment of PE. This study aimed to evaluate the potential value of HCU devices in the diagnosis and follow-up of PE after cardiac surgery in the upright sitting position.

The study included 70 consecutive patients who were evaluated at bedside early after cardiac surgery. The posterior chest wall was scanned along the paravertebral, scapular, and posterior axillary lines. An effusion index was calculated for each hemithorax by summing the intercostal spaces between the lower and upper limits of the PE and dividing by 3. A standard chest radiograph was performed on hospital admission and at hospital discharge, and was scored qualitatively (0, absent; 1, small; 2, large PE).

The results showed that chest ultrasound was feasible in all patients, with a mean time of 5 minutes and 2 seconds. Compared to physical examination, ultrasound had a sensitivity of 69% and a specificity of 77%. The HCU device detected PE in 72 of 140 hemithoraxes on hospital admission, with a 76% agreement with the radiograph ($\kappa = 0.52$). In 15 hemithoraxes, PE was detected by ultrasound but not by radiography, while in 18 hemithoraxes PE was detected by radiography but not by ultrasound. The correlation between ultrasound and radiographic scores was statistically significant ($p < 0.001$). At hospital discharge, PE was present in 31 of 140 hemithoraxes according to ultrasound and in 38 of 140 hemithoraxes according to radiography (agreement, 78%; $\kappa = 0.44$).

The study concludes that HCU devices allow rapid PE detection and improve clinical diagnosis, offering the unique advantage of bedside evaluation without radiation exposure. This method is superior to chest radiography in identifying PE early after cardiac surgery.
ing pleural fluid and guiding thoracentesis. The advantage of chest ultrasound relies on the fact that it does not require the use of a radiograph, thus allowing repeatability of the examination at follow-up. However, chest ultrasound is usually performed with standard high-end ultrasound systems located in the radiology department, which actually limits the real applicability of this imaging technique in a routine clinical setting.

Advances in microprocessor technology have made the miniaturization of cumbersome ultrasound systems possible, leading to the introduction of hand-carried ultrasound (HCU) imagers in the clinical arena. The major advantage of these devices is prompt availability and the subsequent performance of a focused examination at the point of care, which makes these devices extremely versatile and potentially applicable for rapid and repetitive scanning in a variety of clinical situations in which quick decision making is essential. Based on these concepts and our previous experience, we designed this prospective study with the aim at assessing the potential value of HCU devices in the diagnosis and follow-up of patients with PE after cardiac surgery.

Materials and Methods

Seventy consecutive patients who were admitted to our center to participate in a cardiac rehabilitation program after cardiac surgery were enrolled into this study. The patients gave verbal informed consent, and the study was approved by our Internal review boards. Their demographic and clinical data are reported in Table 1. A clinical diagnosis of PE was based on the findings of the physical examination performed by the referring physician, who was unaware of the results of chest ultrasound and radiograph.

Chest Ultrasound

A chest ultrasonographic study was performed within 24 h after hospital admission, and every 3 days until hospital discharge, using an HCU device (OptiGo; Agilent; Andover, MA) with a 2.5-MHz transducer for two-dimensional imaging. Every patient was positioned in the upright sitting position on the edge of the bed, facing away from the investigator, with arms stretched out near the body. During quiet breathing, ultrasound scanning of the posterior chest was performed both in the right and left hemithoraces, using the intercostal spaces as ultrasound windows, along the paravertebral, scapular, and posterior axillary lines (Fig 1). The pleural space was identified by observing the normal motion of the lung during breathing. The air-filled lung surface totally reflects the ultrasound beam and produces a bright, echogenic line of sound reflection. This characteristic pattern of bright echoes produced by a reverberation artifact is recognized as normal for the air-filled lung and indicates the absence of a PE (Fig 2, left, A). PE was diagnosed by the presence of an anechoic space between the parietal pleura and the highly reflective visceral pleura-lung interface (Fig 2, right, B). In patients with a PE, the upper and lower limits along the three lines of scanning were recorded for each hemithorax, using the scapular angle as a marker of the seventh intercostal space. The sum of the number of intercostal spaces between the upper and lower limits of the PE measured along the three lines of scanning divided by 3 represented a score for the semiquantitative evaluation of the PE. The cardiologist who scored the chest ultrasound was unaware of the results of chest radiography.

Chest Radiograph

Upright posteroanterior and lateral chest radiographs were obtained within 24 h after hospital admission (on the same day of the

Table 1—Clinical Characteristics of Study Group*  

<table>
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<tr>
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<tr>
<td>Patients, No.</td>
<td>70</td>
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<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>51 (73)</td>
</tr>
<tr>
<td>Female</td>
<td>19 (27)</td>
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<tr>
<td>Age, yr</td>
<td>68 ± 9</td>
</tr>
<tr>
<td>Time after cardiac surgery, d</td>
<td>9 ± 2</td>
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<tr>
<td>Type of surgery</td>
<td></td>
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<tr>
<td>CABG</td>
<td>40 (57)</td>
</tr>
<tr>
<td>Valve replacement</td>
<td>19 (27)</td>
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<td>CABG + valve replacement</td>
<td>8 (12)</td>
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<tr>
<td>Vascular replacement</td>
<td>3 (4)</td>
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*Values given as No. (%) or mean ± SD. CABG = coronary artery bypass graft.

FIGURE 1. Schematic drawing of the posterior chest, representing the lines of interrogation of ultrasound scanning. In case of PE, the operator recorded the lower and upper intercostal spaces from which fluid could be visualized. A = paravertebral line; B = scapular line; C = posterior axillary line.
chest ultrasound) and at hospital discharge. All radiograms were evaluated for the presence or absence of PE by the same experienced radiologist (E.M.), who was blinded to the echographic findings. Each hemithorax was scored independently. The size of the PE was visually estimated by evaluating the percentage of the area of the hemithorax that was occupied by pleural fluid. Briefly, a PE occupying > 25% of the hemithorax was defined as large, whereas all other PEs were defined as small.

Statistical Analysis

The data are expressed as the mean ± SD, unless stated otherwise. Statistical analysis was carried out using a statistical software package (SPSS, version 12.0; SPSS; Chicago, IL). Agreement between the findings of the chest ultrasound and those of either the physical examination or radiograph was assessed from 2 × 2 tables with weighted κ statistics. On the basis of the Fleiss classification, κ values < 0.4, between 0.4 and 0.75, and > 0.75, respectively, were considered as indicating poor, fair to good, and excellent agreement. Comparisons between groups (for ultrasound and radiographic score) were made using the Kruskal-Wallis test. A p value of < 0.05 was considered to be statistically significant.

Results

It was feasible to carry out a chest ultrasound in all patients, and 140 hemithoraxes were evaluated. The mean time for chest ultrasound scanning was 5 ± 2 min.

Findings on Hospital Admission

At time of the chest ultrasound, a PE was present in 72 of 140 hemithoraxes (51%; left hemithorax, 53; right hemithorax, 19), with a mean score 1.73 ± 1.04. Examples of PEs, as revealed by chest ultrasound, are depicted in Figure 3. Compared to chest ultrasound, the physical examination showed a sensitivity and a specificity to detect PE of 69% and 77%, respectively. The overall agreement between the findings of chest ultrasound and a chest radiograph was 76% (κ = 0.52) [Fig 4]. In 18 hemithoraxes (18%), PE diagnosed by the radiograph was not confirmed by chest ultrasound. An example of this type of discrepancy is represented in Figure 5. Conversely, in 15 hemithoraxes (11%) the chest ultrasound revealed the presence of a PE, which had not been diagnosed with the radiograph (Fig 6). The mean ultrasound score in these 15 hemithoraxes was 1.30. To assess the correlation between ultrasound and radiographic scores, the hemithoraxes were divided according to the radiograph score (ie, 0, 1, and 2). As depicted in Figure 7, a large PE on a radiograph was associated with a significantly higher mean ultrasound score (2.41 ± 1.48) compared to small or absent PE (1.02 ± 0.90 and 0.30 ± 0.62, respectively; p < 0.001).

Findings During Hospital Stay

The time course of PEs during the hospital stay is represented in Figure 8. During the hospital stay, two patients with bilateral PEs required thoracentesis on clinical grounds. The ultrasound scores in these patients were 4.33 (left hemithorax) and 4 (right hemithorax) in the first patient, and 4 (left hemithorax) and 3 (right hemithorax) in the second patient. Thoracentesis was performed under ultrasound monitoring (Fig 9) with 1,300 mL of PE fluid drained in the first patient and 1,500 mL drained in the second patient.

Findings at Hospital Discharge

The mean length of hospitalization was 19 ± 8 days (range, 10 to 60 days). At hospital discharge, PE was present in 31 of 140 hemithoraxes (22%) accord-
ing to chest ultrasound, and in 38 of 140 hemithoraces (27%) according to chest radiographs (overall agreement, 78%; κ = 0.44) [Fig 10]. The mean ultrasound score was 1.08 ± 0.68. Similar to findings on hospital admission, PE was more frequent on the left side than on the right side, both with the HCU device (24 of 70 ultrasounds [32%] vs 7 of 70 ultrasounds [10%], respectively; p < 0.001) and radiographs (27 of 70 radiographs [38%] vs 11 of 70 [16%], respectively; p < 0.001) and the correlation between ultrasound and radiographic scores was statistically significant (p < 0.001).

**DISCUSSION**

The results of the present study indicate that chest ultrasound performed with HCU devices is feasible for the bedside evaluation and follow-up of PE, and improves the diagnostic accuracy of the physical examination. Compared with a radiograph, the agreement was 76%, with a high correlation between ultrasound and radiographic scores (p < 0.001). In particular, chest ultrasound can be repeated without discomfort for the patients or radiation exposure, allowing accurate and tailored monitoring of the PE during a hospital stay.

**PE After Cardiac Surgery**

PE is a frequent complication after cardiac surgery. In the present study, the prevalence of PEs seen on radiographs was 54% on hospital admission and 26% at hospital discharge, which is consistent with previous findings both in the early and late
Quantitative Evaluation of Chest Ultrasound in the Diagnosis of PE

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Kappa value = 0.52

**Figure 4.** Overall agreement of chest ultrasound and radiograph on hospital admission.

Stages after cardiac surgery. Although clinical assessment is the recommended method for detecting PE and a suitable site to thoracentesis, if needed, the diagnostic accuracy of the physical examination is challenging, even when performed by expert operators. Moreover, chest radiography, which is the standard noninvasive technique, is a suboptimal diagnostic method for assessing PE. After cardiac surgery, patients often complain of chest pain, decreased pulmonary function, prolonged immobilization, and cerebral complications. Sometimes, patients are imaged in the supine or sitting position with varying degrees of lung inflation, leading to the frequent underestimation of PE. Although thoracic CT scanning is the “gold standard” for diagnosing the presence or absence of PE, the high exposure of patients to radiation actually limits the use of this method for their routine evaluation and follow-up after cardiac surgery.

**Chest Ultrasound in the Evaluation of PE**

Chest ultrasound has been suggested as an alternative method for evaluating chest pathologies, and for guiding a variety of diagnostic and therapeutic procedures. This method can easily and accurately detect PE and is superior to clinical examination. In the present study, physical examination showed a sensitivity of 69% and a specificity of 77% in the correct identification of the presence or absence of PE assessed by ultrasound, which is in agreement with previous data. Similar findings have also been reported in patients with decompensated chronic heart failure, in whom chest ultrasound associated with conventional echocardiography showed a very high prevalence of PE (91%). When associated with clinical examination and radiographic findings, the prevalence of the signs of body fluid accumulation was modest to low (56% and 33%, respectively). These findings confirm that chest ultrasound is a noninvasive, simple, and accurate method that can be repeated frequently. However, the use of conventional, relatively large, diagnostic ultrasound instruments can be cumbersome, and they are not always readily available.

The outstanding technological developments of the last decade have made the miniaturization of ultrasound systems possible, and consequently ultrasound procedures have been applied as an extension of the physical examination. These new tools allow the assessment of the heart and its pathologies during a physical examination at the point of care. This results in quick goal-oriented echocardiographic examinations to answer specific clinical questions.

PE represents a clinical situation in which HCU devices can be best utilized. Performing ultrasound scanning at the patient’s bedside during clinical ward rounds allows for immediate answers to questions about the absence/presence of PE and the amount of fluid in it. Results are available quickly, and chest ultrasound can be repeated frequently for timely and accurate evaluation.

**Figure 5.** In this patient who was evaluated after undergoing a Bentall procedure, the chest radiograph revealed a right-sided PE (left, A). Chest ultrasound scanning at the eighth intercostal space along the right scapular line demonstrated the presence at this level of hepatic parenchyma (right, B; asterisk), which is consistent with the diagnosis of right diaphragm relaxation.
accurate monitoring. In the present study, we demonstrated that during a hospital stay there is a progressive and continuous decrease in the prevalence of PE, both for right and left hemithoraces, from hospital admission to day 12, without any further changes until hospital discharge. Furthermore, in two patients we used HCU devices for guiding thoracentesis. The two-dimensional capabilities of these devices seem to be sufficient for these focused procedures, and permit the selection of the ideal entry site and needle trajectory at the patient’s bedside.

The evaluation of PE by ultrasound can be performed with the patient in the erect or recumbent position. The upright sitting position allows posterior thoracic evaluation, while the lateral decubitus position discloses the anterior and lateral chest. Our experience in patients after cardiac surgery indicates that the upright sitting position may be preferred since the lateral decubitus position turns out to be a difficult and painful one to achieve in these patients and is potentially harmful because of the presence of sternotomy.

**Chest Ultrasound vs Radiograph for the Evaluation of PE**

A PE diagnosed with a radiograph was not validated in some cases by chest ultrasound examination findings, and vice versa. A chest ultrasound detected small PEs (mean ultrasound score, 1.31), which had been occult on the radiograph examination. The presence of >175 mL of pleural fluid is necessary to determine costophrenic obliteration that is detectable on posteroanterior radiographs, and sometimes PEs with up to 500 mL of fluid can be present without costophrenic obliteration. Conversely, images described as “PE” on a chest radiograph may be due to atelectasis, pleura thickening, or other pathologies. Ultrasound and CT scanning are inherently superior to the chest radiograph for detecting minimal and localized interlobular effusions, and to
differentiate atelectasis from effusion. There are several advantages to using chest ultrasound in this clinical setting. In particular, it is readily available, does not involve radiation, and is in agreement with the 2001 medical imaging guidelines of the European Commission, which clearly state that “a non-ionising examination should always be preferred to a ionising one when the information provided is comparable.” Furthermore, the use of portable systems allows repeatable examinations when the doctor needs them, with an immediate answer capable of being given at the patient’s bedside and at low cost. Finally, the capital investment for such a device is economic, and the maintenance costs are low. Compared to a chest radiograph, the estimated cost for a chest ultrasound examination is lower (2 vs 12 Euros), and a significant cost reduction with the use of HCU devices can be anticipated.

Study Limitations

We compared chest ultrasound procedures and radiographs for the detection of PEs. The lack of a standard reference did not allow us to derive the sensitivity and specificity of both methods. However, performing CT scans as the “gold standard” in all patients after cardiac surgery may be unethical. A semiquantitative comparison of chest ultrasound procedures and radiographs was based on empirical scores, without the objective quantification of the PE. However, a lack of anatomic landmarks at the time of the chest ultrasound prevented other semiquantitative measures, including the accurate and reproducible identification of the horizontal coordinate of the PE.

Conclusion

In patients early after cardiac surgery, HCU devices allow rapid and reliable detection and monitoring of PEs, and avoid the diagnostic drawbacks of physical examination. Compared to the radiograph, a chest ultrasound procedure performed with HCU devices offers the unique advantage of a bedside evaluation of patients and repeatability, which significantly reduces the use of economic and logistic resources.

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![Figure 9. HCU-guided thoracentesis. Scanning along the right posterior axillary line revealed a large PE (asterisks) with lung collapse. The tip of the draining needle is visible within the fluid (arrow).](http://www.chestjournal.org)

**Figure 9.** HCU-guided thoracentesis. Scanning along the right posterior axillary line revealed a large PE (asterisks) with lung collapse. The tip of the draining needle is visible within the fluid (arrow).

**Figure 10.** Overall agreement of chest ultrasound and radiograph at hospital discharge.

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Kappa value=0.44
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