Cardiopulmonary Limited Ultrasound Examination for “Quick-Look” Bedside Application

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Although taking a “quick look” at the heart using a small ultrasound device is now feasible, a formal ultrasound imaging protocol to augment the bedside physical examination has not been developed. Therefore, we sought to evaluate the diagnostic accuracy and prognostic value of a cardiopulmonary limited ultrasound examination (CLUE) using 4 simplified diagnostic criteria that would screen for left ventricular dysfunction (LV), left atrial (LA) enlargement, inferior vena cava plethora (IVC+), and ultrasound lung comet-tail artifacts (ULC+). The CLUE was defined a priori to consist of 4 video-looped views: the cardiac parasternal long-axis view of the left ventricle, 2 longitudinal anterior views of the lung apices, and a subcostal longitudinal view of the inferior vena cava (IVC). Therefore, we sought to test the diagnostic accuracy and prognostic importance of a simple CLUE on patients already referred for echocardiography.

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Methods

Data were obtained retrospectively from consecutive comprehensive transthoracic echocardiograms performed using conventional, fully featured echocardiographs (Philips iE33, Philips Healthcare, Andover, Massachusetts) and low-frequency 3-MHz phased-array cardiac transducers, during a 3-month period in a 300-bed tertiary medical center. Repeated, follow-up, or limited examinations were not included. The echocardiographic evaluation included parasternal, apical, and subcostal imaging using 2-dimensional, color, and spectral Doppler and M-mode according to published guidelines\textsuperscript{4} and 2 views of the lung apices to evaluate for lung comet tail artifacts as a part of the institution’s routine standard echocardiographic imaging protocol. Each echocardiogram was acquired by 1 of 7 randomly available experienced registered cardiac sonographers, and interpreted by 1 of 12 board-certified cardiologists rotating as reader-of-the-day. The Scripps Institutional Review Board for Scripps Mercy Hospital (San Diego, California) approved the study.

CLUE was defined a priori to consist of 4 video-looped views (Figure 1) within the comprehensive echocardiographic study. The 4 specific CLUE views were interpreted by 1 cardiologist-echocardiographer who was unaware of the results of the comprehensive study and based his interpretation using the predetermined subjective “quick-look” criteria as follows. The first CLUE view was the standard echocardiographic parasternal LV long-axis view for the
evaluation of LV systolic dysfunction and LA enlargement. LV dysfunction was defined as present by quick-look subjective estimation if the anterior leaflet of the mitral valve during diastole did not appear to encroach on the LV outflow tract and approach the septum to within 1 cm.5–7 LA enlargement was defined as present if the LA anteroposterior diameter appeared larger than the anteroposterior diameter of the overlying ascending aorta at the sinuses of Valsalva, throughout the cardiac cycle.8 The second CLUE view was the standard echocardiographic subcostal longitudinal view of the proximal intrahepatic inferior vena cava as it entered the right atrium. Elevated central venous pressures were considered present (IVC) if the IVC subjectively appeared plethoric and dilated, as noted by parallel vessel walls and a luminal diameter reduction of <50% with respiratory motion of the diaphragm, without forced “sniffing”.9,10 The final 2 CLUE views were bilateral longitudinal views taken with the transducer probe in the midinfraclavicular region in the second intercostal space of each lung apex demonstrating the pleural line, typically framed by both rib shadows. An ultrasound lung comet tail artifact was considered present (ULC+) if, in this view, ≥3 vertical hyperechoic lines were seen to emanate from the pleural line in the near field and reach the far field, moving with respiration.11 The data were recorded as whether ULCs were demonstrated in either lung, noted as “any ULC+,” or both lungs, noted as “bilateral ULC+.”

The accuracy of the CLUE findings of LV dysfunction or LA enlargement were assessed using the results reported from the corresponding reference standard echocardiogram. As is common in standard “real-world” practice, multiple techniques provided estimates of the LV ejection fraction and LA size to the reader during the comprehensive study, each with a perceived accuracy dependent on the known limitations of the technique, patient body habitus, and the specific quality of the study data. For the ejection fraction, the techniques included Teicholz-based M-mode,12 the Simpson’s biplane method of disks (modified Simpson’s rule),13 and subjective estimates by the sonographer. For LA size, the standard anteroposterior LA diameter was obtained from M-mode and the LA volume index was routinely measured using the area-length method,13 with mild LA enlargement considered present when >4.0 cm and >28 ml/m², respectively. The final interpretation of the LV ejection fraction and LA size was according to the discretion of the reader-of-the-day after the synthesis and review of all available data and subjective determinations and was included in the echocardiographic final report. Because CLUE acquisition and interpretation of the IVC+ and ULC+ findings used the same method as in the comprehensive echocardiogram, no separate reference standard echocardiographic assessment existed for validation of these parameters. The final standard echocardiographic reports were scrutinized for the presence of LV systolic dysfunction defined as a LV ejection fraction of ≤40% or any mention of greater than moderate systolic dysfunction. The presence of LA enlargement was considered present if any mention of its enlargement was found in the report or, in the absence of such, if the LA anteroposterior diameter using M-mode was >4.5 cm.
A comprehensive echocardiogram was considered “technically inadequate” if technically poor, limited, or difficult images were mentioned, and no interpretation of the LV ejection fraction or LA size was provided in the final report. Technically inadequate studies were excluded from the diagnostic analysis. CLUE images were thought to be technically inadequate if the data acquired were of such poor target resolution that they did not permit subjective evaluation by the predefined criteria or if the data were nonexistent owing to an inability to access the proper window because of bandages, wounds, or patient discomfort.

Inpatient echocardiographic mortality was defined as the ratio of the number of deaths of inpatients who had undergone echocardiography during their admission divided by the total number of inpatients undergoing echocardiography during the 3-month study period. Deaths that occurred within the emergency department were considered inpatient deaths. Outpatients were not included in the mortality analysis, because their outcomes were not known. The total number of deaths divided by the total number of inpatients undergoing echocardiography during their admission divided by the total number of deaths. Outpatients were not included in the mortality analysis, because their outcomes were not known.

For the finding of LV ejection fraction of \( \leq 40\% \) and LA enlargement, comprehensive echocardiography showed technical inadequacy in 2 (0.2%) and 28 (2.8%) final reports, respectively, and these were excluded from the diagnostic accuracy analysis. Because the CLUE findings were limited to an assessment from a single view, as expected, the rates at which each CLUE finding could not be delineated owing to technical limitations were greater: LV systolic dysfunction, 5.4%; LA enlargement, 4.3%; IVC+, 17%; and ULC+, 5.7%. Overall, the LV ejection fraction was 62.3 ± 13.8% (inpatients 61.6 ± 9.9% and outpatients 64.9 ± 14.7%, \( p = 0.0001 \)), and the LA size was 3.9 ± 0.8 cm (inpatients 4.0 ± 0.9 cm and outpatients 3.8 ± 0.7 cm, \( p < 0.0001 \)). As expected, all CLUE findings were significantly more prevalent in the inpatients than in the outpatients (Table 1).

For the finding of LV ejection fraction of \( \leq 40\% \), and the relation with age examined using univariate logistic regression analysis. Odds ratios (ORs) with 95% confidence intervals (CIs) were computed for each variable of interest. Multivariate logistic regression analysis examined the joint effect of these predictors on mortality. The best-fit multivariate model using CLUE findings, patient age, and gender variables was selected using the Akaike Information Criterion. Significance was assessed at \( \alpha = 0.05 \).

### Results

Data consisted of 1,016 echocardiograms, of which 224 (22%) were outpatient and 792 (78%) were inpatient. The overall patient age was 65.6 ± 16.8 years (range 16.0 to 97.0), and 51% were male. Outpatients, compared to inpatients, were significantly younger (61.7 ± 17.0 years, range 18.0 to 94.0, vs 66.5 ± 16.6 years, range 16.0 to 97.0, \( p = 0.0002 \)), and 48% were male compared to 52% of the inpatients (\( p = NS \)).

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### Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Outpatients</th>
<th>Inpatients</th>
<th>ORs for Inpatient Mortality (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age ( &gt; 65 ) years</td>
<td>103/224 (46%)</td>
<td>447/792 (56%)*</td>
<td>0.68 (0.35–1.33)</td>
</tr>
<tr>
<td>Men</td>
<td>108/224 (48%)</td>
<td>415/792 (52%)</td>
<td>2.5* (1.2–5.2)</td>
</tr>
<tr>
<td>CLUE results</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LV dysfunction</td>
<td>16/219 (7%)</td>
<td>117/742 (16%)*</td>
<td>1.65 (0.69–3.95)</td>
</tr>
<tr>
<td>LA enlargement</td>
<td>85/221 (38%)</td>
<td>398/751 (53%)*</td>
<td>0.77 (0.37–1.61)</td>
</tr>
<tr>
<td>IVC+ (any)</td>
<td>27/199 (14%)</td>
<td>222/648 (34%)*</td>
<td>6.36* (2.66–15.21)</td>
</tr>
<tr>
<td>ULC+ (any)</td>
<td>19/215 (9%)</td>
<td>209/743 (28%)*</td>
<td>4.6* (2.21–9.56)</td>
</tr>
<tr>
<td>ULC+ (bilateral)</td>
<td>9/215 (4%)</td>
<td>115/743 (16%)*</td>
<td>5.3* (2.58–11.01)</td>
</tr>
<tr>
<td>LV dysfunction ( \leq 40% )</td>
<td>10/224 (5%)</td>
<td>89/790 (11%)*</td>
<td>2.47* (1.08–5.62)</td>
</tr>
<tr>
<td>LA enlargement</td>
<td>79/218 (36%)</td>
<td>396/770 (51%)*</td>
<td>1.0 (0.5–2.0)</td>
</tr>
</tbody>
</table>

Total represents number of adequate studies for each entity; for correlation with inpatient mortality, only CLUE studies with all 4 components adequate were used (\( n = 576 \)).

\* \( p \leq 0.05 \) (outpatient vs. inpatient; univariate ORs).
The value of CLUE was 75% (95% CI 70% to 79%), 72% (95% CI 66% to 76%), 73% (95% CI 70% to 77%), 75% (95% CI 70% to 79%), and 72% (95% CI 67% to 77%), respectively.

The overall inpatient mortality rate was 1.8% (101 of 5,665). The inpatient echocardiographic mortality rate was 4.9% (39 of 792) and significantly greater (p < 0.0001), reflecting the greater acute mortality of inpatients with known or suspected cardiovascular disease referred for echocardiography. Of the 39 inpatients who died, 28 men versus 11 women (p = 0.010) died, with a male decedent mean age of 66 ± 14 years versus 60 ± 16 years for women (p = NS). CLUE studies that were technically adequate in all 4 views were obtained for 576 inpatients (73%). An analysis of the inpatient CLUE studies with any 1 technically inadequate view (n = 216) versus technically adequate 4-view CLUE studies (n = 576), showed a mortality of 7.9% versus 3.8% (OR 2.2; p = 0.03), likely representing the more frequent instrumentation and difficult imaging of the critically ill patient. The presence of all 4 CLUE signs was seen in 24 inpatients (4.2%) and was associated with a high mortality rate of 21%. The absence of all 4 CLUE signs was seen in 176 inpatients (31%) and was associated with a minimal mortality rate of 1%. In considering the presence of any ULC+ (n = 209) versus bilateral ULC+ (n = 115), the OR for inpatient mortality was 4.6 (95% CI 2.21 to 9.60) versus 5.3 (95% CI 2.6 to 11.0), respectively. The univariate ORs (with 95% CIs; Table 1) and the best multivariate logistic model (Table 2) were significant for the presence of IVC+, any ULC+, and male gender.

Discussion

The present observational study investigated a cardiopulmonary-limited ultrasound examination designed for quicklook application and found diagnostic accuracy for LV dysfunction and LA enlargement and prognostic value for the 2 ultrasound signs of apical lung comet tail artifacts and plethora of the IVC. The examination required only 4 images, used simplified subjective interpretation, and could be obtained in acutely ill patients.

The development of an ultrasound-assisted physical examination with a pocket-size or hand-carried device has the potential to augment the detection of clinically important entities, particularly those not well detected by expert practice of physical techniques. Up to this point, however, it has been difficult to project the efficacy of ultrasound-assisted bedside examination owing to the heterogeneity in imaging protocols, each of which require varying degrees of expertise in echocardiography. The present investigation demonstrated a conceptual framework for construction of a simplified examination prototype, in which evidence-basis is used from conventional ultrasound fields to derive an imaging protocol limited to specific findings fundamentally important to the initial diagnosis.

Systolic LV dysfunction to an ejection fraction of ≤40% is an important clinical entity for detection at the bedside. In addition to the possible initiation of evidence-based, antiadrenergic therapies to improve the prognosis, the discovery of LV systolic dysfunction can cause immediate changes in the management plan in unexplained hypotension, dyspnea, or in newly diagnosed arrhythmias. Using a subjective criterion, the present study found that a single parasternal long-axis view has an accuracy of 89% for the detection of LV ejection fraction of ≤40%. LA enlargement detected by echocardiography is a marker for the presence of significant cardiac pathologic features and also has prognostic implications. In the present study, CLUE subjectively compared the LA diameter to that of the overlying aorta in the parasternal long-axis view, a method that has been shown to relate to the LA volume index. LA enlargement found using the CLUE had a greater prevalence in inpatients compared to outpatients (53% vs 38%, respectively, p = 0.0002) and an accuracy of 73% compared to standard echocardiography. Subjective recognition of LA enlargement is simple, had the least technically difficult data in the present investigation (4.3% of studies), and, similar to the recognition of LV systolic dysfunction, can be performed by novices to improve bedside diagnosis.

The presence of pulmonary edema is critical in respiratory failure or shock and is related to a worse prognosis whether cardiogenic or noncardiogenic. The ULC artifact has recently been described as a sign of pulmonary edema and is easily detected by novice users but can also be present as a normal finding in the lung bases. Similar to results from an outcome study that used a complex 28-site lung imaging protocol on 290 inpatients, the present study observed a significant relation between the comet tail artifacts and inpatient mortality but with a larger sample of 792 inpatients and using a simpler, 2-site protocol.

The IVC diameter response to inspiration has been shown to relate to the right atrial pressures. In a recent study of hand-carried ultrasonography used by briefly trained resident physicians, the noncollapsible IVC demonstrated prognostic value in 75 patients with acute decompensated heart failure by its relation to hospital readmission. In the present study in which all inpatients referred for echocardiography were included, IVC plethora was present in 34% and demonstrated a very strong relation (OR 6.36, 95% CI 2.66 to 15.21) to inpatient mortality, perhaps as a general sign reflecting severe respiratory failure. The present study did not analyze whether tachypnea, positive pressure ventilation, greater intra-abdominal pressures, or diminished mental status were present during the echocardiogram, all factors that could have confounded the relation of the IVC to right atrial pressure but could have still contributed to a worse prognosis.

The present study was limited by its use of a retrospective review of standard echocardiograms and was not a validation of CLUE when performed by new users with pocket-size devices during the initial patient examination. Because device capabilities and teaching curriculum are still

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>OR</th>
<th>95% CI</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male gender</td>
<td>0.820</td>
<td>2.270</td>
<td>0.889–5.799</td>
<td>0.08656</td>
</tr>
<tr>
<td>IVC+</td>
<td>1.765</td>
<td>5.842</td>
<td>2.079–16.414</td>
<td>0.000081</td>
</tr>
<tr>
<td>ULC+ (any)</td>
<td>1.257</td>
<td>3.515</td>
<td>1.409–8.771</td>
<td>0.00705</td>
</tr>
</tbody>
</table>
in development, we used the “best-case scenario” of optimal acquisition and expert interpretation of data to investigate the ultimate potential of the CLUE. The CLUE was designed as a grossly simplified, 2-dimensional general-purpose ultrasound examination and should be differentiated from a “limited” or “focused” echocardiogram in which a specific clinical or follow-up question is fully answered using an abbreviated imaging protocol and conventional echocardiographs. In the future, it might be possible for the more advanced practitioner of bedside ultrasonography to diagnose other less common entities from the acquired CLUE views or expand CLUE to include the use of Doppler in specific clinical circumstances.

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