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ORIGINAL RESEARCH

Diagnostic Accuracy of Hospitalist-Performed Hand-Carried Ultrasound Echocardiography After a Brief Training Program

Brian P. Lucas, MD, MS
Carolina Candotti, MD
Bosko Margeta, MD
Arthur T. Evans, MD, MPH
Benjamin Mba, MBBS, MRCP
Joshua Baru, MD
Joseph K. Asbury, MD
Abdo Asmar, MD
Rudolf Kumapley, MBCHB
Manish Patel, MD
Shane Borkowsky, MD
Sharon Fung, RN
Marjorie Charles-Damte, RN

Department of Medicine, Stroger Hospital of Cook County and Rush Medical College, Chicago, Illinois.

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BACKGROUND: The duration of training needed for hospitalists to accurately perform hand-carried ultrasound echocardiography (HCUE) is uncertain.
OBJECTIVE: To determine the diagnostic accuracy of HCUE performed by hospitalists after a 27-hour training program.
DESIGN: Prospective cohort study.
SETTING: Large public teaching hospital.
PATIENTS: A total of 322 inpatients referred for standard echocardiography (SE) between March and May 2007.
INTERVENTION: Blinded to SE results, attending hospitalist physicians performed HCUE within hours of SE.
MEASUREMENTS: Diagnostic characteristics of HCUE as a test for 6 cardiac abnormalities assessed by SE: left ventricular (LV) systolic dysfunction; severe mitral regurgitation (MR); moderate or severe left atrium (LA) enlargement; moderate or severe LV hypertrophy; medium or large pericardial effusion; and dilatation of the inferior vena cava (IVC).
RESULTS: A total of 314 patients underwent both SE and HCUE within a median time of 2.8 hours (25th to 75th percentiles, 1.4 to 5.1 hours). Positive and negative likelihood ratios for HCUE increased and decreased, respectively, the prior odds by 5-fold or more for LV systolic dysfunction, severe MR regurgitation, and moderate or large pericardial effusion. Likelihood ratios changed the prior odds by 2-fold or more for moderate or severe LA enlargement, moderate or severe LV hypertrophy, and IVC dilatation. Indeterminate HCUE results occurred in 2% to 6% of assessments.
CONCLUSIONS: The diagnostic accuracy of HCUE performed by hospitalists after a brief training program was moderate to excellent for 6 important cardiac abnormalities. ***Journal of Hospital Medicine*** **2009;4:340–349.** *© 2009 Society of Hospital Medicine.*

KEYWORDS: **echocardiography, hospitalists, point-of-care systems, sensitivity and specificity.**

Hand-carried ultrasound echocardiography (HCUE) can help noncardiologists answer well-defined questions at patients' bedsides in less than 10 minutes.[1,2] Indeed, intensivists[3] and emergency department physicians[4] already use HCUE to make rapid, point-of-care assessments. Since cardiovascular diagnoses are common among general medicine inpatients, HCUE may become an important skill for hospitalists to learn.[5]

However, uncertainty exists about the duration of HCUE training for hospitalists. In 2002, experts from the American Society of Echocardiography (ASE) published recommendations on training requirements for HCUE.[6] With limited data on the safety or performance of HCUE training programs, which had just begun to emerge, the ASE borrowed from the proven training recommendations for standard echocardiography (SE). They recommended that all HCUE trainees, cardiologist and noncardiologist alike, complete level 1 SE training: 75 personally-performed and 150 personally-interpreted echocardiographic examinations. Since then, however, several HCUE training programs designed for noncardiologists have emerged.[2,5,7–10] These alternative programs suggest that the ASE's recommended duration of training may be too long, particularly for focused HCUE that is limited to a few relatively simple assessments. It is important not to overshoot the requirements of HCUE training, because doing so may discourage groups of noncardiologists, like hospitalists, who may derive great benefits from HCUE.[11]

To address this uncertainty for hospitalists, we first developed a brief HCUE training program to assess 6 important cardiac abnormalities. We then studied the diagnostic accuracy of HCUE by hospitalists as a test of these 6 cardiac abnormalities assessed by SE.

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Patients and Methods

Setting and Subjects

This prospective cohort study was performed at Stroger Hospital of Cook County, a 500-bed public teaching hospital in Chicago, IL, from March through May of 2007. The cohort was adult inpatients who were referred for SE on weekdays from 3 distinct patient care units (Figure 1). We used 2 sampling modes to balance practical constraints (short-stay unit [SSU] patients were more localized and, therefore, easier to study) with clinical diversity. We consecutively sampled patients from our SSU, where adults with provisional cardiovascular diagnoses are admitted if they might be eligible for discharge with in 3 days.[12] But we used random number tables with a daily unique starting point to randomly sample patients from the general medical wards and the coronary care unit (CCU). Patients were excluded if repositioning them for HCUE was potentially harmful. The study was approved by our hospital's institutional review board, and we obtained written informed consent from all enrolled patients.

SE Protocol

As part of enrolled patients' routine clinical care, SE images were acquired and interpreted in the usual fashion in our hospital's echocardiography laboratory, which performs SE on over 7,000 patients per year. Echocardiographic technicians acquired images with a General Electric Vivid 7 cardiac ultrasound machine (General Electric, Milwaukee, WI) equipped with a GE M4S 1.8 to 3.4 MHz cardiac transducer (General Electric). Technicians followed the standard adult transthoracic echocardiography scanning protocol to acquire 40 to 100 images on every patient using all available echocardiographic modalities: 2-dimensional, M-mode, color Doppler, continuous-wave Doppler, pulse-wave Doppler, and tissue Doppler.[13] Blinded to HCUE results, attending physician cardiologist echocardiographers then interpreted archived images using computer software (Centricity System; General Electric) to generate final reports that were entered into patients' medical records. This software ensured that final reports were standardized, because echocardiographers' final qualitative assessments were limited to short lists of standard options; for example, in reporting left atrium (LA) size, echocardiographers chose from only 5 standard options: "normal," "mildly dilated," "moderately dilated," "severely dilated," and "not interpretable." Investigators, who were also blinded to HCUE results, later abstracted SE results from these standardized report forms in patients' medical records. All echocardiographers fulfilled ASE training guidelines to independently interpret SE: a minimum of 150 personally-performed and 300 personally-interpreted echocardiographic examinations (training level 2).[14]

HCUE Training

Based on the recommendations of our cardiologist investigator (B.M.), we developed a training program for 1 hospitalist to become an HCUE instructor. Our instructor trainee (C.C.) was board-eligible in internal medicine but had no previous formal training in cardiology or echocardiography. We a priori established that her training would continue until our cardiologist investigator determined that she was ready to train other hospitalists; this determination occurred after 5 weeks. She learned image acquisition by performing focused SE on 30 patients under the direct supervision of an echocardiographic technician. She also performed focused HCUE on 65 inpatients without direct supervision but with ongoing access to consult the technician to review archived images and troubleshoot difficulties with acquisition. She learned image interpretation by reading relevant chapters from a SE textbook[15] and by participating in daily didactic sessions in which attending cardiologist echocardiographers train cardiology fellows in SE interpretation.

This hospitalist then served as the HCUE instructor for 8 other attending physician hospitalists who were board-certified internists with no previous formal training in cardiology or echocardiography. The training program was limited to acquisition and interpretation of 2-dimensional grayscale and color Doppler images for the 6 cardiac assessments under study (Table 1). The instructor marshaled pairs of hospitalists through the 3 components of the training program, which lasted a total of 27 hours.

First, hospitalists attended a 2-hour lecture on the basic principles of HCUE. Slides from this lecture and additional images of normal and abnormal findings were provided to each hospitalist on a digital video disc. Second, each hospitalist underwent 20 hours of hands-on training in 2-hour sessions scheduled over 2 weeks. Willing inpatients from our hospital's emergency department were used as volunteers for these hand-on training sessions. During these sessions the instructor provided practical suggestions to optimize image quality, such as transducer location and patient positioning. In the first 3 sessions, the minimum pace was 1 patient per hour; thereafter, the pace was increased to 1 patient per half-hour. We chose 20 hours of hands-on training and these minimum paces because they allowed each hospitalist to attain a cumulative experience of no less than 30 patients—an amount that heralds a flattening of the HCUE learning curve among medical trainees.[9] Third, each pair of hospitalists received feedback from a cardiologist investigator (B.M.) who critiqued the quality and interpretation of images acquired by hospitalists during hands-on training sessions. Since image quality varies by patient,[16] hospitalists' images were compared side-by-side to images recorded by the instructor on the same patients. The cardiologist also critiqued hospitalists' interpretations of both their own images and additional sets of archived images from patients with abnormal findings.

HCUE Protocol

After completing the training program and blinded to the results of SE, the 8 hospitalists performed HCUE on

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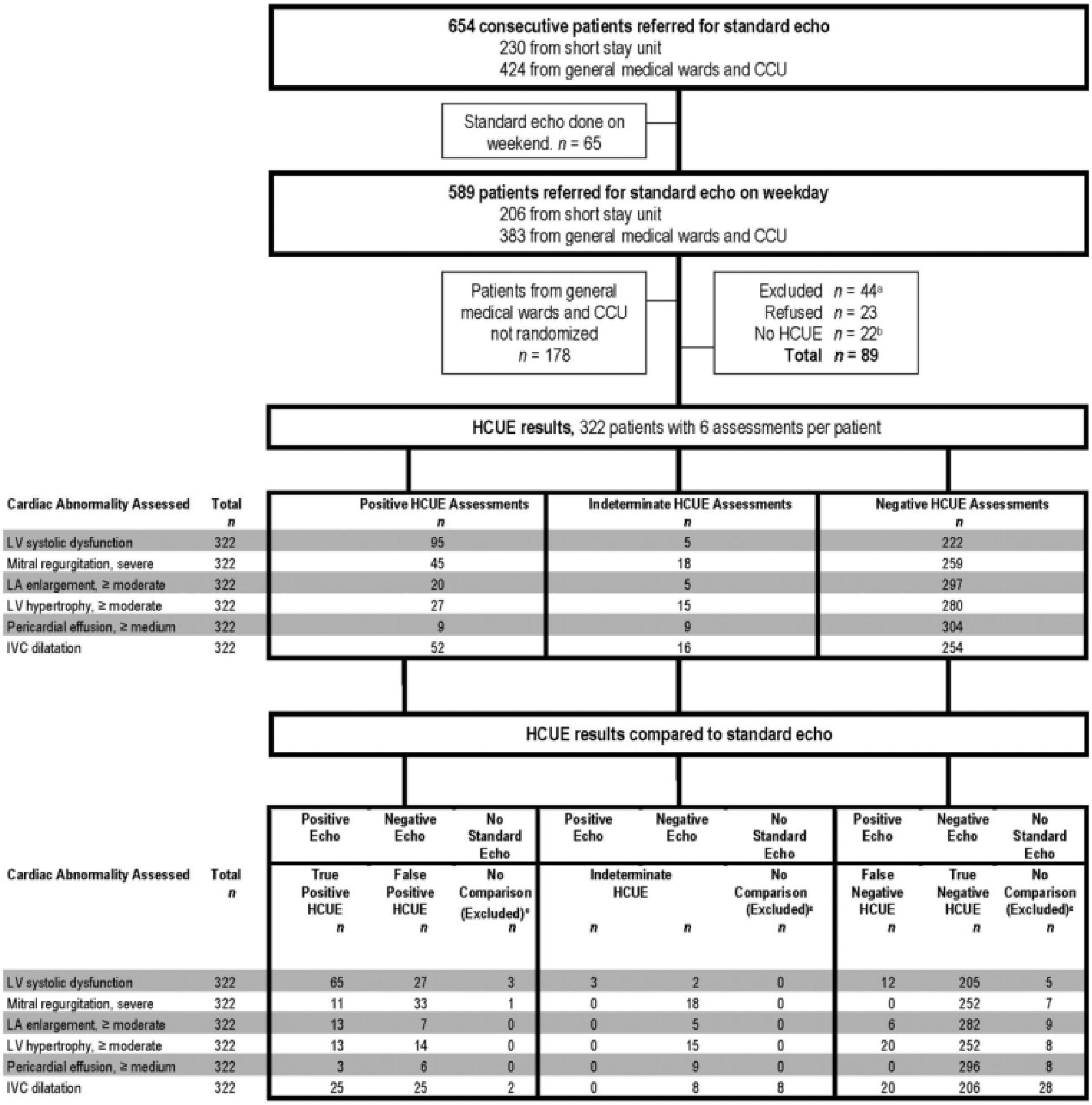

Cardiac Abnormality Assessed	Total n	Positive HCUE Assessments n	Indeterminate HCUE Assessments n	Negative HCUE Assessments n
LV systolic dysfunction	322	95	5	222
Mitral regurgitation, severe	322	45	18	259
LA enlargement, ≥ moderate	322	20	5	297
LV hypertrophy, ≥ moderate	322	27	15	280
Pericardial effusion, ≥ medium	322	9	9	304
IVC dilatation	322	52	16	254

Cardiac Abnormality Assessed	Total n	Positive Echo: True Positive HCUE n	Negative Echo: False Positive HCUE n	No Standard Echo: No Comparison (Excluded)c n	Positive Echo: Indeterminate HCUE n	Negative Echo: Indeterminate HCUE n	No Standard Echo: No Comparison (Excluded)c n	Positive Echo: False Negative HCUE n	Negative Echo: True Negative HCUE n	No Standard Echo: No Comparison (Excluded)c n
LV systolic dysfunction	322	65	27	3	3	2	0	12	205	5
Mitral regurgitation, severe	322	11	33	1	0	18	0	0	252	7
LA enlargement, ≥ moderate	322	13	7	0	0	5	0	6	282	9
LV hypertrophy, ≥ moderate	322	13	14	0	0	15	0	20	252	8
Pericardial effusion, ≥ medium	322	3	6	0	0	9	0	0	296	8
IVC dilatation	322	25	25	2	0	8	8	20	206	28

FIGURE 1. Flow diagram of HCUE results. (a) Among those excluded, 23 patients were unable to consent due to language (n = 13), current imprisonment (n = 6), or altered mental status (n = 4). The remaining 21 patients were excluded because of a requirement for immobilization (n = 8), an intraaortic balloon pump (n = 4), an external pacemaker (n = 3), endotracheal intubation (n = 3), severe pain (n = 2), or ongoing thrombolytic therapy (n = 1). (b) Twenty-two patients were neither excluded nor refused but nevertheless had no HCUE. Among these patients, 15 were not available for hand-carried ultrasound echocardiograms because they were discharged home from the hospital (n = 10) or undergoing other procedures (n = 5); 7 patients were never approached by study investigators. (c) Among the 322 patients who received HCUE, 8 did not receive SE. In addition, SE was not interpretable due to poor image quality for LA enlargement in 1 patient and for IVC dilatation in 30 patients. **Abbreviations:** CCU, cardiac care unit; echo, standard transthoracic echocardiography; HCUE, hand-carried ultrasound echocardiography; IVC, inferior vena cava; LA, left atrium; LV, left ventricle.

enrolled patients within hours of SE. We limited the time interval between tests to minimize the effect that changes in physiologic variables, such as blood pressure and intravascular volume, have on the reliability of serial echocardiographic measurements.[16] Hospitalists performed HCUE with a MicroMaxx 3.4 hand-carried ultrasound machine equipped with a cardiology software package and a 1 to 5 MHz P17 cardiac transducer (Sonosite, Inc., Bothell, WA); simultaneous electrocardiographic recording, though available, was not used. While patients laid on their own standard hospital beds or on a standard hospital gurney in a room adjacent to the SE waiting room, hospitalists

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TABLE 1. Twenty-Seven-Hour Training Program in Hand-Carried Ultrasound Echocardiography

Six cardiac assessments learned using 2-dimensional gray scale and color Doppler imaging
Left ventricular systolic dysfunction
Mitral valve regurgitation
Left atrium enlargement
Left ventricular hypertrophy
Pericardial effusion
Inferior vena cava diameter
Lecture (2 hours)*
Basic principles of echocardiography
HCUE scanning protocol and helpful techniques to optimize image quality
Hands-on training with instructor
Orientation to machine and demonstration of scanning protocol (1 hour)
Sessions 1 through 3: HCUE performed on 1 patient per hour (6 patients in 6 hours)
Sessions 4 through 10: HCUE performed on 2 patients per hour (28 patients in 14 hours)
Feedback sessions on image quality and interpretation with cardiologist
After hands-on training session 3 (2 hours)
After hands-on training session 10 (2 hours)

Abbreviations: HCUE, hand-carried ultrasound echocardiography.

*Slides from this lecture and additional images of normal and abnormal findings were provided on a digital video disc.

positioned them without assistance from nursing staff and recorded 7 best-quality images per patient. Patients were first positioned in a partial (30–45 degrees) left lateral decubitus position to record 4 grayscale images of the short-axis and long-axis parasternal and 2-chamber and 4-chamber apical views; 2 color Doppler images of the mitral inflow were also recorded from the long-axis parasternal and the 4-chamber apical views. Patients were then positioned supine to record 1 grayscale image of the inferior vena cava (IVC) from the transhepatic view. Hospitalists did not perform a history or physical exam on enrolled patients, nor did they review patients' medical records.

Immediately following the HCUE, hospitalists replayed the recorded images as often as needed and entered final interpretations on data collection forms. Linear measurements were made manually with a caliper held directly to the hand-carried ultrasound monitor. These measurements were then translated into qualitative assessments based on standard values used by our hospital's echocardiographers (Table 2).[17] When a hospitalist could not confidently assess a cardiac abnormality, the final HCUE assessment was recorded as indeterminate. Hospitalists also recorded the time to perform each HCUE, which included the time to record 7 best-quality images, to interpret the findings, and to fill out the data collection form.

Data Analysis

We based our sample size calculations on earlier reports of HCUE by noncardiologist trainees for assessment of left ventricular (LV) systolic function.[7,10] From these reports, we estimated a negative likelihood ratio of 0.3. In addition, we expected about a quarter of our patients to have LV systolic dysfunction (B.M., personal communication). Therefore, to achieve 95% confidence intervals (CIs) around the point estimate of a negative likelihood ratio that excluded 0.50, our upper bound for a clinically meaningful result, we needed a sample size of approximately 300 patients.[18]

We defined threshold levels of ordinal severity for the 6 cardiac abnormalities under study based on their clinical pertinence to hospitalists (Table 2). Here, we reasoned that abnormalities at or above these levels would likely lead to important changes in hospitalists' management of inpatients; abnormalities below these levels rarely represent cardiac disease that is worthy of an immediate change in management. Since even mild degrees of LV dysfunction have important diagnostic and therapeutic implications for most general medicine inpatients, particularly those presenting with heart failure,[19] we set our threshold for LV dysfunction at mild or greater. In contrast, since neither mild nor moderate mitral regurgitation (MR) has immediate implications for medical or surgical therapy even if symptoms or LV dysfunction are present,[20] we set our threshold for MR at severe. Similarly, though mild LA enlargement[21] and mild LV hypertrophy[22] have clear prognostic implications for patients' chronic medical conditions, we reasoned that only moderate or severe versions likely reflect underlying abnormalities that affect hospitalists' point-of-care decision-making. Since cardiac tamponade is rarely both subclinical[23] and due to a small pericardial effusion,[24] we set our threshold for pericardial effusion size at moderate or large. Finally, we set our threshold IVC diameter, a marker of central venous volume status,[25] at dilated, because volume overload is an important consideration in hospitalized cardiac patients.

Using these thresholds, investigators dichotomized echocardiographers' SE readings as normal or abnormal for each of the 6 cardiac abnormalities under study to serve as the reference standards. Hospitalists' HCUE results were then compared to the reference standards in 2 different ways. We first analyzed HCUE results as dichotomous values to calculate conventional sensitivity, specificity, and positive and negative likelihood ratios. Here we considered indeterminate HCUE results positive in a clinically conservative tradeoff that neither ignores indeterminate results nor risks falsely classifying them as negative.[26] We then analyzed hospitalists' HCUE results as ordinal values for receiver operating characteristic (ROC) curve analysis. Here we considered an indeterminate result as 1 possible test result.[27]

To examine interobserver variability of HCUE, we first chose from the 6 possible assessments only those with a mean number of abnormal patients per hospitalist greater than 5. We reasoned that variability among assessments with lower prevalence would be predictably wide and inconclusive. We then expressed variability as standard deviations (SDs) around mean sensitivity and specificity for the 8 hospitalists.

The CIs for likelihood ratios were constructed using the likelihood-based approach to binomial proportions of

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TABLE 2. Definitions of Hand-Carried Ultrasound Echocardiography Results

Cardiac Abnormality by Standard Echocardiography	Hand-Carried Ultrasound Echocardiography Operator's Method of Assessment	Hand-Carried Ultrasound Echocardiography Results: Positive		Hand-Carried Ultrasound Echocardiography Results: Negative	
Left ventricle systolic dysfunction, mild or greater	Grade degree of abnormal wall movement and thickening during systole	Severe	Mild or moderate	Normal	Vigorous
Mitral valve regurgitation, severe	Classify regurgitant jet as central or eccentric, then measure as percentage of left atrium area				
	Central jet	$\geq$20%		<20%	
	Eccentric jet	$\geq$20%		indeterminate 20%	
Left atrium enlargement, moderate or severe	Measure left atrium in 3 dimensions at end diastole, then use the most abnormal dimension	Extreme	Borderline		
	Anteroposterior or mediolateral (cm)	$\geq$5.1	4.5–5.0	$\leq$4.4	
	Superior-inferior (cm)	$\geq$7.1	6.1–7.0	$\leq$6.0	
Left ventricle hypertrophy, moderate or severe	Measure thickest dimension of posterior or septal wall at end diastole	Extreme: $\geq$1.4 cm	Borderline: 1.2–1.3 cm	$\leq$1.1 cm	
Pericardial effusion, medium or large	Measure largest dimension in any view at end diastole	$\geq$1 cm		<1 cm	
Inferior vena cava dilatation	Measure largest respirophasic diameter within 2 cm of right atrium	$\geq$2.1 cm		Normal: 1 to 2 cm	Contracted: $\leq$0.9 cm

Abbreviation: cm, centimeters.

Koopman.[28] The areas under ROC curves were computed using the trapezoidal rule, and the CIs for these areas were constructed using the algorithm described by DeLong et al.[29] All analyses were conducted with Stata Statistical Software, Release 10 (StataCorp, College Station, TX).

Results

During the 3 month study period, 654 patients were referred for SE from the 3 participating patient care units (Figure 1). Among these, 65 patients were ineligible because their SE was performed on the weekend and 178 other patients were not randomized from the general medical wards and CCU. From the remaining eligible patients, 322 underwent HCUE and 314 (98% of 322) underwent both SE and HCUE. Individual SE assessments were not interpretable (and therefore excluded) due to poor image quality for LA enlargement in 1 patient and IVC dilatation in 30 patients. Eighty-three percent of patients who underwent SE (260/314) were referred to assess LV function (Table 3). The prevalence of the 6 clinically pertinent cardiac abnormalities under study ranged from 1% for moderate or large pericardial effusion to 25% for LV systolic dysfunction. Overall, 40% of patients had at least 1 out of 6 cardiac abnormalities.

Each hospitalist performed a similar total number of HCUE examinations (range, 34–47). The median time difference between performance of SE and HCUE was 2.8 hours (25th–75th percentiles, 1.4–5.1). Despite the high prevalence of chronic obstructive pulmonary disease and obesity, hospitalists considered HCUE assessments indeterminate in only 2% to 6% of the 6 assessments made for each patient (Table 4). Among the 38 patients (12% of 322) with any indeterminate HCUE assessment, 24 patients had only 1 out of 6 possible. Hospitalists completed HCUE in a median time of 28 minutes (25th-75th percentiles, 20–35), which included the time to record 7 best-quality moving images and to fill out the research data collection form.

When HCUE results were analyzed as dichotomous values, positive likelihood ratios ranged from 2.5 to 21, and negative likelihood ratios ranged from 0 to 0.4 (Table 5). Positive and negative likelihood ratios were both sufficiency high and low to respectively increase and decrease by 5-fold the prior odds of 3 out of 6 cardiac abnormalities: LV systolic dysfunction, moderate or severe MR regurgitation, and

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moderate or large pericardial effusion. Considering HCUE results as ordinal values for ROC analysis yielded additional diagnostic information (Figure 2). For example, the likelihood ratio of 1.0 (95% CI, 0.4–2.0) for borderline positive moderate or severe LA enlargement increased to 29 (range, 13–62) for extreme positive results. Areas under the ROC curves were ≥0.9 for 4 out of 6 cardiac abnormalities.

LV systolic dysfunction and IVC dilatation were both prevalent enough to meet our criterion to examine interobserver variability; the mean number of abnormal patients per hospitalist was 10 patients for LV systolic dysfunction and 6 patients for IVC dilatation. For LV systolic dysfunction, SDs around mean sensitivity (84%) and specificity (87%) were 12% and 6%, respectively. For IVC dilatation, SDs around mean sensitivity (58%) and specificity (86%) were 24% and 7%, respectively.

TABLE 3. Patients Who Underwent Both Standard Echocardiography and Hand-Carried Ultrasound Echocardiography

Characteristic	
Age, year ± SD (25th to 75th percentiles)	56 ± 13 (48 to 64)
Women	146 (47)
Chronic obstructive pulmonary disease	47 (15)
Body mass index	
24.9 or less: underweight or normal	74 (24)
25 to 29.9: overweight	94 (30)
30 to 34.9: mild obesity	75 (24)
35 or greater: moderate or severe obesity	71 (23)
Patient care unit	
Short-stay unit	175 (56)
General medical wards	89 (28)
Cardiac care unit	50 (16)
Indication for standard echocardiography*	
Left ventricular function	260 (83)
Valvular function	56 (18)
Wall motion abnormality	29 (9)
Valvular vegetations	22 (7)
Any structural heart disease	20 (6)
Right ventricular function	18 (6)
Other†	38 (12)
Standard echocardiography findings‡	
Left ventricular systolic dysfunction ≥ mild	80 (25)
Inferior vena cava dilated	45 (14)
Left ventricular wall thickness ≥ moderate	33 (11)
Left atrium enlargement ≥ moderate	19 (6)
Mitral valve regurgitation ≥ severe	11 (4)
Pericardial effusion ≥ moderate	3 (1)
At least 1 of the above findings	127 (40)
Time difference between HCUE and standard echocardiogram, median hours (25th to 75th percentiles)	2.8 (1.4 to 5.1)
Time to complete HCUE, median minutes (25th to 75th percentiles)§	28 (20 to 35)

NOTE: Values are n (%) unless otherwise indicated. Total number of patients is 322.

Abbreviations: HCUE, hand-carried ultrasound echocardiography; SD, standard deviation.

* Ordering physicians listed 2 indications for 103 patients, 3 indications for 10 patients, and 4 indications for 2 patients; therefore, the total number of indications (n = 443) is greater than the total number of patients (n = 314).

† Other indications include mural thrombus (n = 13), left ventricular hypertrophy (n = 10), pericardial disease (n = 6), intracardiac shunt (n = 4), cardiomegaly (n = 4), and follow-up of known atrial septal aneurysm (n = 1).

‡ Standard echocardiography demonstrated 2 abnormal findings in 23 patients, 3 abnormal findings in 13 patients, and 4 abnormal findings in 5 patients; therefore, the total number of abnormal findings (n = 191) is greater than the total number of patients who had at least 1 abnormal finding (n = 127).

§ Includes time to record 7 best-quality images and fill out data collection forms.

TABLE 4. Indeterminate Findings from Hand-Carried Ultrasound Echocardiography

	n (%)*
Number of indeterminate findings per patient	
0	284 (88)
1	24 (7)
2	4 (1)
3 or more	10 (3)
Indeterminate findings by cardiac assessment	
Mitral valve regurgitation	18 (6)
Inferior vena cava diameter	16 (5)
Left ventricular hypertrophy	15 (5)
Pericardial effusion	9 (3)
Left atrium size	5 (2)
Left ventricle systolic function	5 (2)

* n = 322.

Discussion

We found that, after a 27-hour training program, hospitalists performed HCUE with moderate to excellent diagnostic accuracy for 6 important cardiac abnormalities. For example, hospitalists' assessments of LV systolic function yielded positive and negative likelihood ratios of 6.9 (95% CI, 4.9–9.8) and 0.2 (95% CI, 0.1–0.3), respectively. At the bedsides of patients with acute heart failure, therefore, hospitalists could use HCUE to lower or raise the 50:50 chance of LV systolic dysfunction[30] to 15% or 85%, respectively. Whether or not these posttest likelihoods are extreme enough to cross important thresholds will depend on the clinical context. Yet these findings demonstrate how HCUE has the potential to provide hospitalists with valuable point-of-care data that are otherwise unavailable—either because routine clinical assessments are unreliable[31] or because echocardiographic services are not immediately accessible.[1]

In fact, recent data from the Joint Commission on Accreditation of Healthcare Organizations shows how inaccessible SE may be. Approximately one-quarter of hospitals in the United States send home about 10% of patients with acute heart failure without echocardiographic assessment of LV systolic function before, during, or immediately after hospitalization.[32] In doing so, these hospitals leave unmet the 2002 National Quality Improvement Goal of universal assessment of LV systolic function for all heart failure patients. Hospitalists could close this quality gap with routine, 10-minute HCUE assessments in all patients admitted with acute heart failure. (Our research HCUE protocol

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TABLE 5. Diagnostic Test Characteristics of Hand-Carried Ultrasound Echocardiography for Detecting Cardiac Abnormalities

Clinically Pertinent Cardiac Abnormality by Standard Echocardiography	Prevalence n/total n	Sensitivity* % (95% CI)	Specificity* % (95% CI)	$LR_{positive}$*,† (95% CI)	$LR_{negative}$*,† (95% CI)
Left ventricular systolic dysfunction	80/314	85 (75–92)	88 (83–92)	6.9 (4.9–9.8)	0.2 (0.1–0.3)
Mitral valve regurgitation, severe	11/314	100 (72–100)	83 (79–87)	5.9 (3.9–7.4)	0 (0–0.3)
Left atrium enlargement, moderate or severe	19/313	90 (67–99)	74 (68–79)	3.4 (2.5–4.3)	0.1 (0.04–0.4)
Left ventricular hypertrophy, moderate or severe	33/314	70 (51–84)	73 (67–78)	2.5 (1.8–3.3)	0.4 (0.2–0.7)
Pericardial effusion, moderate or large	3/314	100 (29–100)	95 (92–97)	21 (6.7–31)	0 (0–0.6)
Inferior vena cava, dilated	45/284	56 (40–70)	86 (81–90)	4.0 (2.6–6.0)	0.5 (0.4–0.7)

NOTE: Includes all 314 patients who underwent both standard echocardiography and hand-carried ultrasound echocardiography, although standard echocardiography was not interpretable (and therefore excluded) due to poor image quality for LA enlargement in 1 patient and for IVC dilatation in 30 patients.

*Indeterminate results from hand-carried ultrasound echocardiography (which occurred in 2% to 6% of assessments) were considered positive test results in calculating the test characteristics.

† LR_x is the conventional likelihood ratio of test result *x*, which is equal to the probability of test result *x* in patients with the abnormality divided by probability of test result *x* in patients without the abnormality; *x* is positive or negative.

required a median time of 28 minutes, but this included time to assess 5 other cardiac abnormalities and collect data for research purposes). Until the clinical consequences of introducing hospitalist-performed HCUE are studied, potential benefits like this are tentative. But our findings suggest that training hospitalists to accurately perform HCUE can be successfully accomplished in just 27 hours.

Other studies of HCUE training programs for noncardiologists have also challenged the opinion that learning to perform HCUE requires more than 100 hours of training.[2,7–11] Yet only 1 prior study has examined an HCUE training program for hospitalists.[5] In this study by Martin et al.,[5] hospitalists completed 5 supervised HCUE examinations and 6 hours of interpretation training before investigators scored their image acquisition and interpretation skills from 30 unsupervised HCUE examinations. To estimate their final skill levels at the completion of all 35 examinations by accounting for an initially steep learning curve, investigators then adjusted these scores with regression models. Despite these upward adjustments, hospitalists' image acquisition and interpretation scores were low in comparison to echocardiographic technicians and cardiology fellows. Besides these adjusted measurements of hospitalists' skills, however, Martin et al.[5] unfortunately did not also report standard measures of diagnostic accuracy, like those proposed by the Standards for Reporting of Diagnostic Accuracy (STARD) initiative.[33] Therefore, direct comparisons to the present study are difficult. Nevertheless, their findings suggest that a training program limited to 5 supervised HCUE examinations may be inadequate for hospitalists. In fact, the same group's earlier study of medical trainees suggested a minimum of 30 supervised HCUE examinations.[9] We chose to design our hospitalist training program based on this minimum, though they surprisingly did not.[5] As others continue to refine the components of hospitalist HCUE training programs, such as the optimal number of supervised examinations, our program could serve as a reasonable comparative example: more rigorous than the program designed by Martin et al.[5] but more feasible than ASE level 1 training.

The number and complexity of assessments taught in HCUE training programs will determine their duration. With ongoing advancements in HCUE technology, there is a growing list of potential assessments to choose from. Although HCUE training programs ought to include assessments with proven clinical applications, there are no trials of HCUE-directed care to inform such decisions. In their absence, therefore, we chose 6 assessments based on the following 3 criteria. First, our assessments were otherwise not reliably available from routine clinical data, such as the physical examination. Second, our assessments were straightforward: easy to learn and simple to perform. Here, we based our reasoning on an expectation that the value of HCUE lies not in highly complex, state-of-the-art assessments—which are best left to echocardiographers equipped with SE—but in simple, routine assessments made with highly portable machines that grant noncardiologists newfound access to point-of-care data.[34] Third, our assessments were clinically pertinent and, where appropriate, defined by cut-points at levels of severity that often lead to changes in management. We suspect that setting high cut-points has the salutary effects of making assessments easier to learn and more accurate, because distinguishing mild abnormalities is likely the most challenging aspect of echocardiographic interpretation.[35] Whether or not our choices of assessments, and their cut-points, are optimal has yet to be determined by future research designed to study how they

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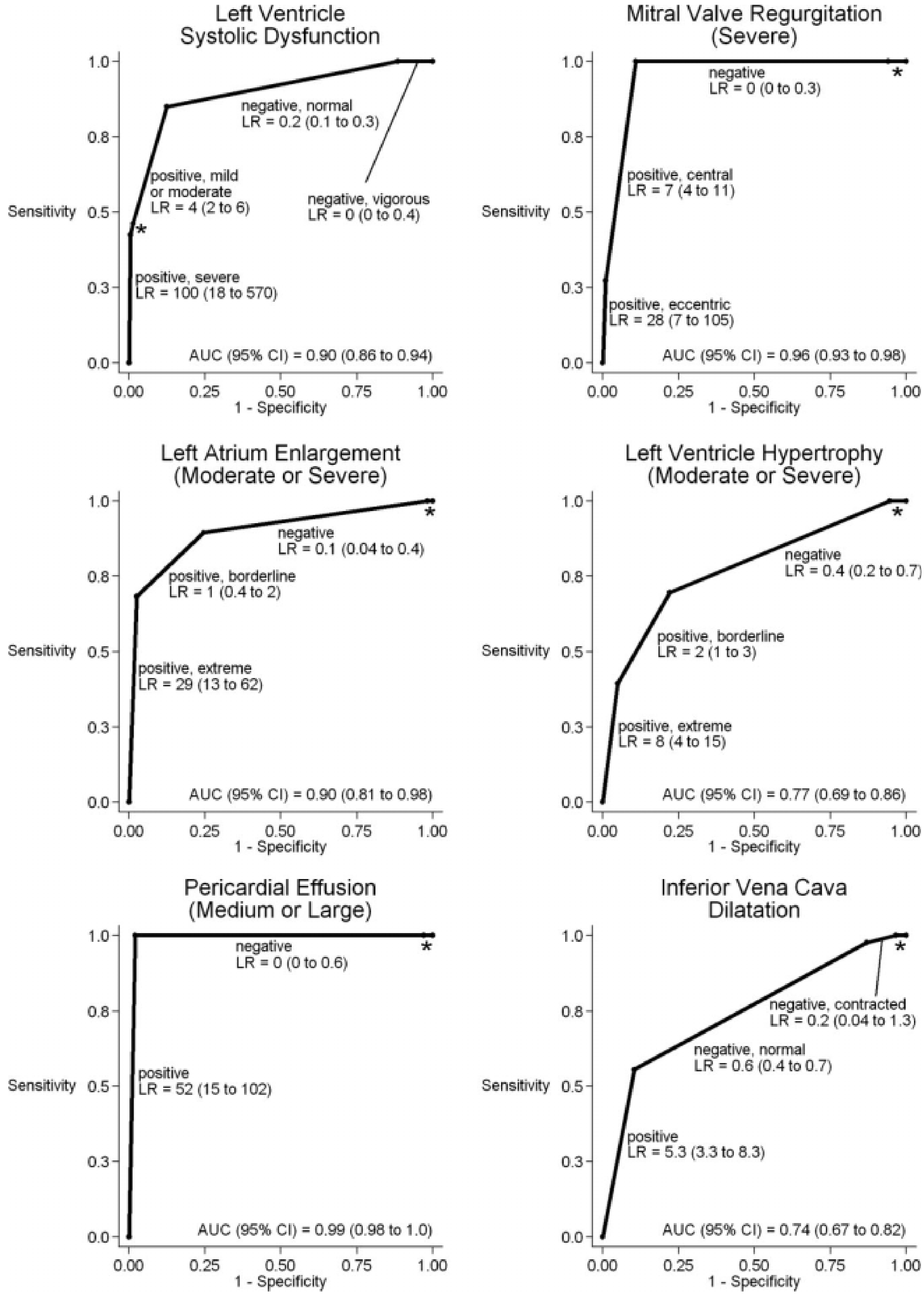

FIGURE 2. ROC curves of hand-carried ultrasound echocardiography (HCUE) results. Includes all 314 patients who underwent both SE and HCUE, although SE was not interpretable (and therefore excluded) due to poor image quality for LA enlargement in 1 patient and for IVC dilatation in 30 patients. Conventional likelihood ratios are presented with 95% CI for each test result. Each likelihood ratio is calculated by dividing the probability of the test result in patients with the abnormality by the probability of the test result in patients without the abnormality. In addition, the likelihood ratios are equivalent to the slopes of the corresponding segments of the curves. An "indeterminate" HCUE result was considered 1 of the possible test results (*); likelihood ratios for these indeterminate HCUE results, which occurred in 2% to 6% of assessments, were not presented because the CIs widely spanned above and below 1. **Abbreviations:** AUC, area under receiver-operating characteristic curve; LR, conventional likelihood ratio.

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affect patient outcomes. Given our hospitalists' performance in the present study, these assessments seem worthy of such future research.

Our study had several limitations. We studied physicians and patients from only 1 hospital; similar studies performed in different settings, particularly among patients with different proportions and manifestations of disease, may find different results. Nevertheless, our sampling method of prospectively enrolling consecutive patients strengthens our findings. Some echocardiographic measurement methods used by our hospitalists differed in subtle ways from echocardiography guideline recommendations.[35] We chose our methods (Table 2) for 2 reasons. First, whenever possible, we chose methods of interpretation that coincided with our local cardiologists'. Second, we chose simplicity over precision. For example, the biplane method of disks, or modified Simpson's rule, is the preferred volumetric method of calculating LA size.[35] This method requires tracing the contours of the LA in 2 planes and then dividing the LA volume into stacked oval disks for calculation. We chose instead to train our hospitalists in a simpler method based on 2 linear measurements. Any loss of precision, however, was balanced by a large gain in simplicity. Regardless, minor variations in LA size are not likely to affect hospitalists' bedside evaluations. Finally, we did not validate the results of our reference standard (SE) by documenting interobserver reliability. Yet, because SE is generally accurate for the 6 cardiac abnormalities under study, the effect of this bias should be small.

These limitations can be addressed best by controlled trials of HCUE-directed care. These trials will determine the clinical impact of hospitalist-performed HCUE and, in turn, inform our design of HCUE training programs. As the current study shows, training hospitalists to participate in such trials is feasible: like other groups of noncardiologists, hospitalists can accurately perform HCUE after a brief training program. Whether or not hospitalists should perform HCUE requires further study.

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Address for correspondence and reprint requests:
Brian P. Lucas, MD, MS, 1900 West Polk Street, Room 520,
Chicago, IL 60612; Telephone: (312) 864-4503; Fax: (312) 864-9948;
E-mail: brian_lucas@rush.edu Received 29 February 2008;
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