Comparison of Effectiveness of Hand-Carried Ultrasound to Bedside Cardiovascular Physical Examination

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This study compared the accuracy of cardiovascular diagnoses by medical students operating a small hand-carried ultrasound (HCU) device with that of board-certified cardiologists using standard physical examinations. Sixty-one patients (38% women; mean age 70 ± 19 years) with clinically significant cardiac disease had HCU studies performed by 1 of 2 medical students with 18 hours of training in cardiac ultrasound and physical examinations by 1 of 5 cardiologists. Diagnostic accuracy was determined by standard echocardiography. Two-hundred thirty-nine abnormal findings were detected by standard echocardiography. The students correctly identified 75% (180 of 239) of the pathologies, whereas cardiologists found 49% (116 of 239) ($p < 0.001$). The students' diagnostic specificity of 87% was also greater than cardiologists' specificity of 76% ($p < 0.001$). For nonvalvular pathologies (115 findings), students' sensitivity was 61%, compared with 47% for cardiologists ($p = 0.040$). There were 124 clinically significant valvular lesions (111 regurgitations, 13 stenoses). Students' and cardiologists' sensitivities for recognizing lesions that cause a systolic murmur were 93% and 62% ($p < 0.001$), respectively. Students' sensitivity for diagnosing lesions that produce a diastolic murmur was 75%; cardiologists recognized 16% of these lesions ($p < 0.001$). The diagnostic accuracy of medical students using an HCU device after brief echocardiographic training to detect valvular disease, left ventricular dysfunction, enlargement, and hypertrophy was superior to that of experienced cardiologists performing cardiac physical examinations. **(Am J Cardiol 2005;96:1002–1006)**

We hypothesized that medical students without clinical experience could be trained to make accurate cardiac diagnoses with a portable cardiac ultrasound device. Moreover, we compared the cardiovascular diagnostic accuracy of medical students using a hand-carried ultrasound (HCU) device with that of experienced cardiologists using conventional physical examinations.

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Sixty-one patients with ≥1 of the following major cardiac findings identified by standard cart-based transthoracic echocardiography participated in the study: left ventricular (LV) systolic dysfunction with an ejection fraction <50% or any valvulopathy of moderate or greater severity. The HCU studies were performed by 1 of 2 medical students trained in cardiac ultrasound, and the conventional cardiovascular examinations were conducted by 1 of 5 board-certified cardiologists for the assessment of a variety of clinically important cardiac findings that deserve treatment or regular follow-up. The inclusion criteria, namely, LV systolic dysfunction with an ejection fraction <50% or any valvulopathy of moderate or greater severity, were arbitrarily called major findings; the rest of the findings were called minor findings. These findings are listed in Table 1. The accuracy of students' and cardiologists' diagnoses were determined using standard echocardiography. Patients were studied in a consecutive fashion, and no patient was excluded because of poor echocardiographic image quality.

The patients were 70 ± 19 years of age. Thirty-eight percent were women, 33% were in intensive care units, 28% had atrial fibrillation, 11% had chronic lung disease, and 15% weighed ≥80 kg.

The Cedars-Sinai Medical Center Institutional Review Board approved this study, and all patients signed an informed consent form.

Before entry into the study, standard echocardiography (Sonos 5500, Philips Medical Systems, Andover, Massachusetts; or HDI 5000, ATL Ultrasound, Inc., Bothell, Washington) performed by cardiac sonographers was recorded on S-VHS tape and interpreted off-line by an echocardiologist for the presence of any of the findings listed in Table 1. Valvular regurgitation and stenosis and pericardial effusion were graded using a 4-point scale (none to severe). Severe LV dysfunction was defined as an ejection fraction ≤35%. An internal LV diameter at end-diastole ≥60 mm, LV wall thickness ≥14 mm, and systolic pulmonary artery

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Table 1
Cardiovascular evaluation

Finding	Standard Echocardiographic Criteria
LV systolic dysfunction	LV ejection fraction <50%
LV enlargement	LV end-diastolic diameter >56 mm
LV hypertrophy	Septal and posterior wall thickness ≥12 mm
Right ventricular enlargement	Right ventricular end-diastolic diameter ≥43 mm in 4-chamber view
Right atrial pressure high	Inferior vena cava diameter ≥20 mm without inspiratory collapse
Pulmonary hypertension	Systolic pulmonary artery pressure ≥40 mm Hg
Pericardial effusion	≥ Moderate
AR	≥ Mild
MR	≥ Moderate
TR	≥ Moderate
Aortic valve stenosis	Aortic valve area ≤1.5 cm^2
Mitral valve stenosis	Mitral valve area ≤2 cm^2

pressure ≥55 mm Hg were considered cut-off values to define LV dilation, LV hypertrophy, and pulmonary hypertension as severe. Each diagnosis was confirmed by 2 echocardiologists, each blinded to the other's diagnosis. In any case of discordance between the 2 readers, the final result was reached by consensus.

The HCU device used in this study, OptiGo (Philips Medical Systems, Andover, Massachusetts), weighs 2.9 kg and with a 2.5-MHz phased-array transducer provides 2-dimensional imaging and conventional color-flow Doppler (CFD). OptiGo CFD allows aliasing for the identification of high-velocity jets. There are variable settings for the CFD sample location and color gain.

Two first-year medical students performed the HCU studies. The students received 18 hours of training in echocardiography in 3 weeks. Training included 4 hours of lecture and 14 hours of practical experience performing and interpreting studies.

HCU studies were performed at patients' bedsides <4 hours after the standard echocardiographic examinations. Students did not interview patients or receive any data on their history other than the main symptoms for referral to the standard echocardiographic studies. The 2-dimensional and CFD HCU images were obtained from the parasternal long- and short-axis, apical 4-, 3-, and 2-chamber, and subcostal views. All parameters were assessed categorically (present or absent), except for valvular regurgitation, which was evaluated as none, mild, moderate, or severe. Valvular regurgitation was considered for comparison between HCU and physical examination if aortic regurgitation (AR) was greater than or equal to mild and mitral regurgitation (MR) and tricuspid regurgitation (TR) was greater than or equal to moderate by standard echocardiography.

Because the HCU device used in our study is not provided with spectral Doppler, the diagnosis of pulmonary hypertension and valvular stenosis was inferred from 2-dimensional and CFD signs. At the end of the HCU examinations, students completed a data sheet of the echocardiographic findings.

One of 5 board certified cardiologists, unaware of the HCU results, evaluated the same findings assessed by the students (Table 1). The cardiologists were provided with the reasons for referral to the standard echocardiographic studies. The examinations were performed in patients' rooms according to the cardiologists' usual methods of physical examination after the students' HCU studies. At the end of the examinations, the cardiologists completed the same diagnostic questionnaire as that completed by the students.

The sensitivity, specificity, and accuracy of students' and cardiologists' diagnoses were analyzed using the standard echocardiographic examinations as the gold standard. Because the study was conducted in patients referred for cardiac echocardiography, true normal patients were not included. Differences between students and cardiologists in agreement percentages for the same characteristics were assessed by McNemar's test for related proportions. Differences in agreement percentages between independent groups were assessed by Fisher's exact test. p Values are given for all significance tests. Calculations were performed using the statistical software package SAS version 8.2 (SAS Institute Inc., Cary, North Carolina).

Of 61 patients, 19 had 1 major finding on standard echocardiography, 25 had 2 major findings, and 17 had 3 major findings. The most common referral symptoms provided to students and cardiologists were shortness of breath (36%), chest pain (22%), and fever (10%); less common reasons for referrals were syncope, stroke, and hypotension.

Of the 239 abnormal findings identified by standard echocardiography, students recognized 75% (180 of 239) and cardiologists identified 49% (116 of 239) ($p < 0.001$). The specificities were 87% and 76% ($p < 0.001$) for students and cardiologists, respectively. Even when considering the most severe cases of LV dysfunction (LV ejection fraction ≤35%) and severe valvular lesions, cardiologists' diagnostic rate was suboptimal (68%) compared with that of the students (96%) ($p < 0.001$).

The examiners' sensitivity and specificity for specific cardiac findings are listed in Table 2. The students had statistically significant greater sensitivity and specificity for the identification of nonvalvular lesions. As shown in Figure 1, the general accuracy of students for the assessment of LV size and function, LV thickness, right ventricular size, right atrial pressure, and pulmonary hypertension was 77%, significantly superior to cardiologists' accuracy of 62% ($p < 0.001$).

Students' sensitivity was superior to cardiologists' sensitivity, precisely, when evaluating the most severe cases of LV dysfunction, LV enlargement, and LV hypertrophy, as demonstrated in Table 3. Students' and cardiologists' sensitivities for the severe findings were 73% (30 of 41) and 51% (21 of 41) ($p = 0.049$), respectively. Students' and cardiologists' sensitivities for the nonsevere group were 52% (23 of 44) and 36% (16 of 44) ($p = 0.210$), respectively.

Table 2
Students' and cardiologists' (MD) diagnoses of nonvalvular lesions

Finding	Cases	Sensitivity (%)			Specificity (%)		
		Students	MD	p Value	Students	MD	p Value
LV ejection fraction <50%	22	86	45	0.002	82	69	0.302
LV end-diastolic diameter >56 mm	12	67	75	1.000	94	63	<0.001
LV hypertrophy	23	65	43	0.227	71	63	0.581
Pulmonary hypertension	28	39	36	1.000	88	70	0.109
Elevated right atrial pressure	14	50	57	1.000	83	70	0.263
Right ventricular enlargement	16	63	44	0.508	95	82	0.109
Total	115	61	47	0.040	84	68	<0.001

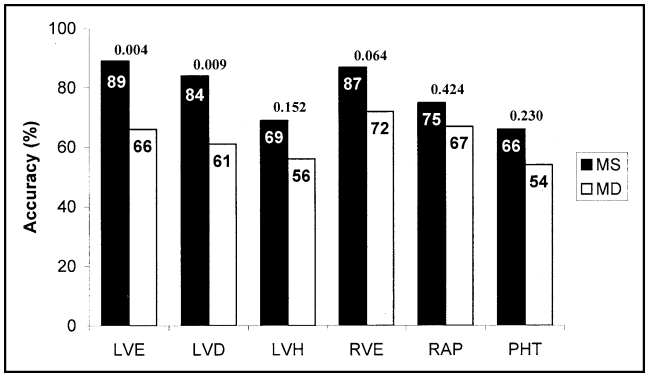

Figure 1. Medical students' (MS) and cardiologists' (MD) diagnostic accuracy for nonvalvular lesions. Students were more accurate than board-certified cardiologists in diagnosing nonvalvular lesions. The most significant difference between groups was observed for diagnosing LV size and function. LVD = LV dysfunction; LVE = LV enlargement; LVH = LV hypertrophy; RAP = elevated right atrial pressure; RVE = right ventricular enlargement; PHT = pulmonary hypertension.

Standard echocardiography identified 111 clinically significant valvular regurgitant lesions and 13 stenotic lesions: 27 greater than or equal to mild AR, 45 greater than or equal to moderate MR, 39 greater than or equal to moderate TR, 8 aortic valve stenoses (valve area $\leq$1.5 cm^2), and 5 mitral valve stenoses (valve area $\leq$2 cm^2). Students had significantly greater sensitivity (89%) than cardiologists (50%) for the diagnosis of valvular lesions ($p < 0.001$). As demonstrated in Figure 2, for students and cardiologists, the lesions that cause a systolic murmur (84 MR and TR and 8 aortic stenoses) were more frequently diagnosed than the lesions that produce a diastolic murmur (27 AR and 5 mitral stenoses).

Students were superior to cardiologists in identifying and correctly assessing the grade of regurgitation, regardless of the severity of the regurgitant lesion. Of the 36 cases of severe valvular regurgitation (1 AR, 19 MR, and 16 TR), 57 cases of moderate valvular regurgitation (8 AR, 26 MR, and 23 TR), and 18 cases of mild AR, students recognized regurgitant jets of at least mild severity in 92% (102 of 111) of the valvular regurgitations, and cardiologists identified the corresponding murmurs in 49% (55 of 111) ($p < 0.001$). Students' and cardiologists' specificities for the same findings were 78% and 81%, respectively (p = NS). Students correctly assessed the severity in 50% (55 of 111) of the valvular regurgitant lesions, whereas cardiologists correctly diagnosed 18% (22 of 111) of the cases ($p < 0.001$).

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The most important finding in our study is that the diagnostic accuracy of first-year medical students using bedside cardiac ultrasound examinations was significantly superior to that of board-certified cardiologists performing cardiac physical examinations for the detection and evaluation of selected valvular and nonvalvular cardiac abnormalities. Students' overall diagnostic sensitivity was 75% compared with 49% for cardiologists, and students' specificity was 87% compared with 76% for cardiologists. Specifically, students identified 86% of LV dysfunction and 89% of significant valvular lesions, whereas cardiologists diagnosed only 45% and 50%, respectively.

These wide differences in diagnostic accuracy are consistent with previous reports on the accuracy of physicians' physical examination.[1–10] Mangione et al[11] found that only 56% of cardiology fellows and 39% of medical residents were proficient in cardiac auscultation. This inaccuracy extends to board-certified cardiologists, who missed 59% of the cardiovascular findings in their physical examinations.[12] The diagnostic ability of our board-certified cardiologists compared favorably with that demonstrated in these reports. Our cardiologists identified 62% of the systolic murmurs, a finding similar to those of previous studies.[2,5,6,8,11–13] The sensitivity of our cardiologists for the recognition of diastolic murmurs was 16%, which is similar to previous studies that found accuracies of 1% to 26%.[2,8,11–16] Our study population had an average of 3.9 findings per patient. This fact could have affected the sensitivity of cardiologists to identify multiple precordial murmurs instead of an isolated murmur and biased the accuracy analysis toward ultrasound techniques. The presence of several cardiac findings is common in the clinical practice and increases with patient age. This clinical confounder can be overcome by HCU, because ultrasound techniques do not mask multiple pathologies. Clearly, these differences do not imply deficiency on the part of cardiologists but rather the great inherent difficulty involved in evaluating the function of many organs by use of palpation, percussion, and auscultation.

Table 3
Students' and cardiologists' (MD) sensitivities by severity

Finding	Sensitivity		
	Cases	Students	Cardiologists
LV ejection fraction ≤35%	10	100% (10/10)	60% (6/10)
35% >LV ejection fraction <50%	12	75% (9/12)	33% (4/12)
LV end-diastolic diameter ≥60 mm	7	100% (7/7)	71% (5/7)
56 mm >LV end-diastolic diameter <60 mm	5	20% (1/5)	40% (2/5)
LV hypertrophy ≥14 mm	11	73% (8/11)	36% (4/11)
12 mm ≥LV hypertrophy <14 mm	12	58% (7/12)	50% (6/12)
Pulmonary hypertension ≥55 mm Hg	13	38% (5/13)	46% (6/13)
40 mm Hg ≥pulmonary hypertension <55 mm Hg	15	40% (6/15)	27% (4/15)

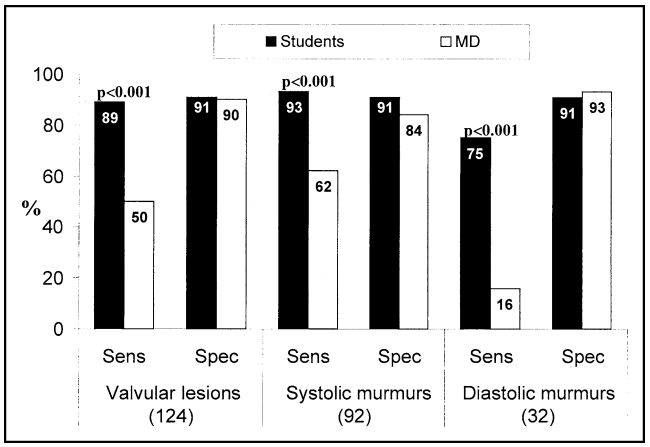

Figure 2. Medical students' and cardiologists' (MD) diagnostic sensitivity (sens) and specificity (spec) for valvular lesions. The sensitivity of students to recognize valvular lesions (111 valvular regurgitations and 13 valvular stenoses) was significantly superior to that of board-certified cardiologists for those that cause a systolic murmur (n = 92) as well as a diastolic murmur (n = 32). Students' and cardiologists' specificities were similar.

Students' performance illustrates how bedside cardiac examination can be improved by diagnostic imaging, even when experience in imaging acquisition and knowledge of pathologic anatomy is limited. Students were remarkably accurate in some diagnoses and only good in others. Our students had high sensitivity in identifying LV dysfunction (86%) and lower sensitivity in diagnosing LV enlargement (67%), LV hypertrophy (65%), and right ventricular enlargement (62%). Similarly, students recognized regurgitant jets in 92% (102 of 111) of the clinically significant valvular regurgitations, and they correctly assessed their severity in 50% (55 of 111) of the cases. Trained cardiologists using HCU devices performed better: the levels of diagnostic accuracy for LV dysfunction,[17–20] LV hypertrophy,[18,21,22] and valvular dysfunction[21,23] increased to as much as 96%. Thus, our data also illustrate that HCU diagnostic accuracy varies with the parameter evaluated and the level of echocardiographic training.

HCU diagnostic accuracy is also influenced by device characteristics.[24] The HCU device chosen for this study (OptiGo) has 2-dimensional and CFD capabilities. To some extent, our students' performance was limited by the absence of spectral Doppler capability. We estimate that 17% (41 of 244) of the cardiac findings were not detected because of the lack of spectral Doppler. Thus, students performed less well in the assessment of pulmonary hypertension, which is best assessed by spectral Doppler. Even so, by using right ventricular hypertrophy to infer diagnoses, students' sensitivity was comparable with that of cardiologists (39% vs 36%). Although the precise echocardiographic Doppler assessment of mitral and aortic stenosis severity generally uses spectral Doppler, students were able to accurately identify 8 of 13 of clinically significant valvular stenoses using 2-dimensional and CFD signs, similar to cardiologists (6 of 13 cases).

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