Clin. Cardiol. 27, 241–245 (2004)

Rapid Screening of Cardiac Patients with a Miniaturized Hand-Held Ultrasound Imager—Comparisons with Physical Examination and Conventional Two-Dimensional Echocardiography

TIANRONG XIE, M.D., ANTONIO J. CHAMOUN, M.D., MARTI MCCULLOCH, RCDS, NICK TSIOURIS, M.D., YOCHAI BIRNBAUM, M.D., MASOOD AHMAD, M.D.

Division of Cardiology, The University of Texas Medical Branch in Galveston, Galveston, Texas, USA

Summary

Background: Rapid screening of cardiac patients with a hand-held ultrasound imager (SonoHeart™ [SH]) could provide valuable clinical information.

Hypothesis: Whether the use of this device yields additional information to a carefully conducted physical examination and comparable findings to those of conventional two-dimensional echocardiography (2-D) during inpatient rounds is not well established and is the subject of this study.

Methods: In all, 100 consecutive telemetry patients underwent rapid screening with 2-D and color Doppler SH during inpatient rounds. SonoHeart findings were compared with results from conventional 2-D and physical examination conducted by an attending cardiologist.

Results: All patients had interpretable images. Mean scanning time with SH was 5.0 ± 1.2 min; 2-D and SH findings were comparable. The parameters studied included chamber sizes, left ventricular (LV) systolic function, presence of LV hypertrophy (LVH), wall motion abnormalities (WMA), pericardial effusion (PE), and valvular regurgitations. Mild to moderate valvular regurgitation and LV systolic dysfunction were reliably diagnosed by SH in a number of patients whose symptoms were unrelated to the abnormalities detected.

Conclusions: Rapid screening with SH provides accurate and valuable information that would otherwise be undetected during physical examination. Its introduction into clinical practice may redefine the initial approach to patients with cardiovascular disease.

Key words: SonoHeart, screening, echocardiography, hand-held, physical examination

Introduction

During the last four decades, ultrasound imaging has become an integral part of cardiovascular diagnosis and is a cornerstone of current management algorithms.[1]

With its natural evolution from M-mode to two-dimensional echocardiography (2-D) and, more recently, three-dimensional echocardiography (3-D), the machines used became increasingly bulky and more cumbersome. It is not surprising that the advent of hand-held echocardiography has been met with great enthusiasm.[2–6] This interest has increased with a growing need for timely, sometimes life-saving medical decisions in various settings. Clinical decision making is frequently driven by echocardiographic findings such as left ventricular (LV) systolic function, wall motion abnormalities (WMA), significant pericardial effusions (PE), and severe valvular disorders. Gathering such information could be greatly optimized by the wide availability and accuracy of an ultraportable ultrasound machine such as the SonoHeart™ (SH) (SonoSite, Inc., Bothell, Wash., USA).

In the current era of cost containment, many physicians speculate about whether a good, old-fashioned physical examination could yield enough information to obviate the need for a portable, high-tech screening process. Another concern is whether this approach would minimize the use of conventional 2-D without jeopardizing quality of care.

As a preliminary step for an ultimate answer to these questions, we evaluated rapid screening with color Doppler SH

Address for reprints:

Masood Ahmad, M.D.
Division of Cardiology
University of Texas Medical Branch
301 University Blvd.
4.148 McCullough Building
Galveston, TX 77555-0766, USA
e-mail: mahmad@UTMB.edu

Received: December 12, 2002
Accepted with revision: May 5, 2003

during inpatient cardiology rounds and compared the results with conventional 2-D findings and those from an incisive cardiovascular physical examination.

Methods

Patient Population

All patients admitted to telemetry cardiology services at The University of Texas Medical Branch were eligible for enrollment into the study. In all, 100 consecutive patients (55 men, 45 women, mean age 59.1 ± 17.0 years) were enrolled.

Study Protocol

A board-certified cardiologist conducted a thorough cardiovascular history and physical examination during inpatient telemetry rounds. Findings were noted in the patients' medical records. A screening echocardiographic study by an echotechnologist using the hand-held SH machine followed physical examination. A conventional 2-D echocardiogram was obtained within 24 to 48 h from admission. The SH and 2-D studies were interpreted independently by echocardiologists blinded to the findings from physical examination.

Echocardiography

Hand-held echocardiography screening: Screening echocardiography was performed using the hand-held ultrasound device SH with a 2 to 4 MHz broad band transducer. The SH weighs 5.3 lbs (2.4 kg) and is powered by alternative current or a rechargeable lithium ion battery. The SH control panel settings are similar to those of conventional 2-D settings. The model we used had no pulsed or continuous-wave Doppler or M-mode capabilities. Long and short parasternal views and two- and four-chamber apical views were obtained in all patients. Subcostal views were obtained at the discretion of the echotechnologist. All valves were assessed by color-flow Doppler. Studies were recorded on a mini-portable Sony VHS tape recorder.

Two-dimensional conventional echocardiography: A Hewlett-Packard Sonos 2500 or 5500 ultrasound machine (Philips Medical Systems/Agilent Technologies, Andover, Mass., USA) equipped with a 2.5–3.5 MHz phased array transducer was used for the conventional echocardiographic study. All standard views were obtained, including long and short parasternal views and two- and four-chamber apical and subcostal views. Left ventricular end-diastolic dimension and septal thickness were obtained in parasternal long-axis views. Conventional pulsed and continuous-wave Doppler and color-flow Doppler assessments were used to analyze all valves. Studies were recorded on VHS tape for subsequent interpretation.

Echocardiographic interpretation: All interpretations were carried out by American Board Certified echocardiologists. An estimated LV ejection fraction (EF) < 50% was considered diagnostic of systolic dysfunction. Left ventricular wall motion analysis was based on the 16-segment model of the American Society of Echocardiography.[1] An LV end-diastolic size of ≥ 5.5 cm denoted enlargement. Left ventricular hypertrophy (LVH) was diagnosed when the end-diastolic septal wall thickness was ≥ 1.2 cm. A left atrial (LA) size > 4 cm measured on the long parasternal view was considered enlarged. Right ventricular (RV) size was compared with LV size using four-chamber apical views, and a midventricular end-diastolic dimension ≥ 2/3 of the LV was considered to be enlarged. Pericardial effusion (PE) was classified as significant or insignificant; a circumferential PE was considered significant. Severity of valvular regurgitation was graded as mild, moderate, and severe, using accepted standards set by American College of Cardiology/American Heart Association (ACC/AHA) guidelines.[1]

Statistical Analysis

Conventional 2-D findings were considered as the standard of reference. Agreement coefficients between SH, 2-D, and physical findings were calculated if applicable.

Results

All patients enrolled in the study had interpretable SH and 2-D echocardiographic images. The average time needed to perform the rapid SH screening examination was 5.04 ± 1.21 min.

Echocardiographic Findings

Chamber sizes and left ventricular hypertrophy: The LV end-diastolic dimension was 4.60 ± 0.89 cm with 2-D and 4.39 ± 0.89 with SH (p = NS). Enlargements of the left and right ventricles (LV, RV) and the left and right arteries were diagnosed by 2-D in 19, 19, 49, and 26 patients, respectively, and by SH in 18, 20, 44, and 24 patients, respectively. Of the latter patients, 17, 18, 39, and 23 had 2-D confirmation of the SH diagnosis.

Left ventricular hypertrophy was diagnosed in 41 patients using the 2-D approach; 37 patients had LVH diagnosed by SH. Of these, 33 had confirmation of the diagnosis by 2-D. The 12 discordant diagnoses were all mild LVH, including the eight patients diagnosed by 2-D and the four diagnosed by SH. Results and agreement coefficients are shown in Table I.

Left ventricular systolic dysfunction and wall motion abnormalities: The mean estimated left ventricular ejection fraction (LVEF) was 49.6 ± 14.9% by 2-D and 49.9 ± 14.5% (p = NS) by SH.

There was perfect agreement in the diagnosis of LV systolic dysfunction, with 30 patients having LV systolic dysfunction diagnosed by both 2-D and SH imaging. Segmental wall motion abnormalities (WMA) were detected in 36 patients, 35 of whom were diagnosed with these abnormalities using SH. One patient was believed to have WMA revealed by SH but not by 2D (Table II).

Pericardial effusion: Nineteen patients had PE using 2-D imaging. SonoHeart studies showed that 17 patients had PE, which was positively confirmed in 15 patients in 2-D studies. None of these patients demonstrated significant signs of cardiac compression, and no significant PE was found in the four patients with negative SH findings. These results along with agreement coefficients are shown in Table III.

Valvular disorders: Mitral, aortic, tricuspid, and pulmonic regurgitations were diagnosed in 45, 25, 53, and 18 patients, respectively, using 2-D, and in 46, 27, 52, and 26 patients, respectively, using SH. Two-dimensional echocardiography confirmed this diagnosis in 39, 23, 47, and 16 of these patients, respectively. Results and the agreement coefficients are summarized in Table IV. All regurgitations missed by SH were classified as mild when 2-D imaging was performed.

In addition, aortic stenosis was diagnosed in four patients by 2-D. Based on Doppler information, two patients had mild disease, one patient had mild to moderate aortic stenosis, and one patient had moderate aortic stenosis. Mitral stenosis was diagnosed in one patient by 2-D. Of those five patients, mitral stenosis and aortic stenosis were detected in one and two patients, respectively, on the basis of valve thickening and decreased leaflet excursion visualized by SH. Two patients with mild aortic stenosis (not classified as stenotic by SH) were noted to have a thickened aortic valve when SH was used.

Physical Examination

Congestive heart failure versus left ventricular systolic dysfunction: Of 10 patients who had a physical examination suggestive of congestive heart failure (CHF [jugular venous pressure higher than 4 cm above the sternal angle or S3 gallop]), 9 had systolic dysfunction shown by both SH and 2-D. One patient with LVEF estimated at 60 to 65% using both 2-D and SH approaches had mild LVH with normal diastolic function visualized on 2-D. However, of 90 patients with unsuspected systolic dysfunction on physical examination, 21 had LV dysfunction, including 13 patients in whom it was severe (EF < 35%) as revealed by SH. The 2-D results confirmed the SH results in 20 of the 21 patients with LV dysfunction. In addition,

TABLE I Left ventricular hypertrophy and chamber enlargement: 2-D versus SH

	SH		Agreement	
2-D	Present	Absent	%	Kappa
LVH				
Present	33	8		
Absent	4	55	88	0.75
LV enlargement				
Present	17	2		
Absent	1	80	97	0.90
RV enlargement				
Present	18	1		
Absent	2	79	97	0.90
LA enlargement				
Present	39	9		
Absent	5	47	86	0.72
RA enlargement				
Present	23	3		
Absent	1	73	96	0.89

Abbreviations: 2-D = two-dimensional echocardiography, SH = SonoHeart, LVH = left ventricular hypertrophy, RV = right ventricular, LA = left artery, RA = right artery.

TABLE II Left ventricular systolic dysfunction and wall motion abnormalities: 2-D versus SH

	SH		Agreement	
2-D	Present	Absent	%	Kappa
LVEF < 50 %				
Present	30	3		
Absent	1	66	96	0.91
WMA				
Present	35	1		
Absent	1	63	98	0.96

Abbreviations: LVEF = left ventricular ejection fraction, WMA = wall motion abnormality. Other abbreviations as in Table I.

TABLE III Pericardial effusion: 2-D versus SH

	SH		Agreement	
2-D	Present	Absent	%	Kappa
PE				
Present	15	4		
Absent	2	79	94	0.80

Abbreviation: PE = pericardial effusion. Other abbreviations as in Table I.

TABLE IV Valvular regurgitation: 2-D versus SH

	SH		Agreement	
2-D	Present	Absent	%	Kappa
Mitral regurgitation				
Present	39	6		
Absent	7	48	87	0.74
Aortic insufficiency				
Present	23	2		
Absent	4	71	94	0.84
Tricuspid regurgitation				
Present	47	6		
Absent	5	42	89	0.78
Pulmonic insufficiency				
Present	16	2		
Absent	10	72	88	0.65

Abbreviations as in Table I.

four patients, who had no physical signs suggestive of systolic dysfunction and who were believed to have preserved LV systolic function by SH, were diagnosed with mild LV systolic function (EF estimated at 40 to 50%) with 2-D. These results are summarized in Table V.

Murmurs versus valvular disorders: Of 48 patients with normal physical examinations, 16 had mild mitral regurgitation (MR), and 3 had moderate MR shown by SH. With the exception of 2 of 16 patients with mild MR, the SH results were confirmed by 2-D. Another patient had mild MR diagnosed by 2-D but not by SH. Using SH, mild aortic insufficiency (AI) was found in seven patients, and eight were diagnosed with mild pulmonic insufficiency (PI).These results were confirmed by 2-D in six patients with AI and in five patients with PI. Two-dimensional echocardiography did not identify any additional patients with AI or PI. Mild tricuspid regurgitation (TR) was found in 17 and moderate TR in 7 patients, while 1 had severe TR as diagnosed by SH. These findings were confirmed by 2-D, except for mild TR in 4 of the 17 patients with mild TR. An additional three patients had mild TR diagnosed by 2-D but not by SH.

Of 100 patients studied, physical examination detected murmurs in 40, which included 39 patients with systolic and 2 with diastolic murmurs. Of the 39 patients with systolic murmurs, 13 demonstrated no detectable lesions when SH was used. Results by 2-D confirmed these data (except in one case of mild MR that was only seen when 2-D was used). Both 2-D and SH diagnosed AI in the two patients with diastolic murmurs, whereas SH additionally detected mild PI in one of these patients. These findings are summarized in Table VI.

TABLE V Congestive heart failure on physical examination versus left ventricular systolic dysfunction on 2-D/SH

2-D/SH	Physical examination suggestive of CHF: Present	Physical examination suggestive of CHF: Absent	Agreement %	Kappa
LVEF < 50%	9/9	21/24		
LVEF ≥ 50%	1/1	69/66	78/75	0.35/0.31

Abbreviation: CHF = congestive heart failure. Other abbreviations as in Tables I and II.

TABLE VI Murmurs on physical examination versus valvular regurgitation on 2-D/SH

2-D/SH	Normal physical examination n = 48
Mitral regurgitation	
Present	20/19
Absent	28 /29
Aortic insufficiency	
Present	6/7
Absent	42/41
Tricuspid regurgitation	
Present	24/25
Absent	24/23
Pulmonic insufficiency	
Present	5/8
Absent	43/40

Abbreviations as in Table I.

Discussion

Our study demonstrates that a screening echocardiographic study using the SH device is feasible, rapid, and provides valuable information beyond that found during a well-conducted cardiovascular examination, especially pertaining to asymptomatic LV dysfunction, WMA, and presence of PE. This "5-minute" test could be even shorter if the rounding physician is the actual operator focusing the examination on a single parameter, such as level of LV systolic function, presence of significant WMA, severe valvular regurgitation, or cardiac compression secondary to a significant PE.

A noticeable yet unsurprising finding was that SH and conventional 2-D agreed perfectly on estimated LV systolic function, segmental WMA, presence of LVH, and enlargement of chambers. Visual estimation of LVEF by experienced observers correlates highly with objective measures such as radionuclide ventriculography.[7] In addition to being able to assign a patient to a New York Heart Association functional class, early knowledge of systolic function from SH may have additional prognostic value that could be used to improve and expedite treatment plans. Furthermore, patients presenting with unequivocal signs or symptoms of heart failure with normal systolic function, demonstrated by echocardiography, presumably have diastolic dysfunction, a condition that may require different management approaches. The importance of early detection of LV systolic dysfunction is highlighted by the results of a 2-year follow-up study of patients evaluated in the emergency room for cardiac-related symptoms. Early adverse events (occurring within 48 h of presentation) in patients with LV systolic dysfunction were more than eight-fold higher than in patients who had no evidence of LV systolic dysfunction (26.9 vs. 3.3%, $p < 0.01$). Early detection of this condition could potentially improve clinical decision making.[8] When conventional 2-D was used, LV systolic dysfunction was the only finding associated with early and late adverse events after controlling for other risk factors.[8] The ability of SH to detect asymptomatic systolic dysfunction rapidly provides a very important prognosticator whose presence requires implementation of specific treatment and early management plans.[8] Furthermore, the rapid detection of early segmental WMA may have an invaluable impact on managing patients presenting with chest pain, particularly those who have unremarkable electrocardiograms and negative cardiac marker findings. Sabia *et al.* demonstrated that regional WMA found in patients presenting to the emergency room with chest pain is more sensitive than are electrocardiographic changes for detecting acute myocardial infarction, and its rapid discovery by SH may improve decision making.[9]

Significant PE was also very reliably detected with SH. As described by Reddy *et al.*, cardiac tamponade has three phases, but often only the third phase is readily diagnosed clinically by classical signs.[10] Detecting PE during its earlier phases using SH could significantly impact fluid management and anticoagulation decisions.

Two-dimensional echocardiography and SH identified valvular regurgitation equally well. Findings by SH were also suggestive of severe aortic or mitral stenosis, with detection of severe valvular thickening and reduced leaflet excursion. Almost one-half of our patients had normal cardiovascular examinations, although echocardiograms showed mild to moderate degrees of valvular regurgitation with good correlation between 2-D and SH findings. Whereas theoretically none of these patients would require an aggressive early intervention, our findings highlight the limited sensitivity of physical examination for detecting less than severe regurgitation. Coupled with its ability to reveal enlargement of chambers equally as well as 2-D, examination with SH may become the technique of choice for rapid screening, particularly for cardiology outpatient referrals.

Our findings are in agreement with the report by Spencer *et al.*[5] demonstrating improvement in detection of important cardiovascular pathology by SH when compared with physical examination. Goodkin *et al.*[6] found SH inferior to conventional 2-D in assessment of critically ill patients, which may be due to the lack of spectral Doppler capability needed in the assessment of several of their patients with prosthetic valves and diastolic dysfunction. Our study focused on examination of relatively stable patients in whom the major clinical questions could be answered without the use of spectral Doppler.

Study Limitations

The major limitation of our study is our use of an early model of the SH, which did not include pulsed Doppler, continuous-wave Doppler, and M-mode. If these parameters had been available, an even greater systematic comparison between SH and conventional 2-D approaches would have been possible. The role of pulsed and continuous-wave Doppler for assessing pressure gradients, severity of valvular disorders, and diastolic filling patterns has been well established.[11–16] The most recent versions of hand-held echocardiographs are available with Doppler and M-mode features, which should overcome some of the limitations observed in our study.

Conclusions

Screening cardiac patients with SH is a rapid and feasible technique that can be easily used during cardiology inpatient rounds and augments findings from physical examination. The use of this approach could obviate the need for a conventional 2-D echocardiogram in patients with completely normal or mildly abnormal screening studies. Our findings raise intriguing questions that will require further investigation. For example, how would SH screening studies alter our current management approaches? Will these approaches prove to be as efficacious and safe as our current practices, especially if the use of hand-held echocardiography by noncardiologists becomes widespread? Finally, will we actually be able to contain hospital costs and length of stay with the use of this technology? These answers await future developments in the use of hand-held echocardiography.

References

1. Cheitlin MD, Alpert JS, Armstrong WF, Aurigemma GP, Beller GA, Bierman FZ, Davidson TW, Davis JL, Douglas PS, Gillam LD: ACC/AHA Guidelines for the Clinical Application of Echocardiography. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Clinical Application of Echocardiography). Developed in collaboration with the American Society of Echocardiography. *Circulation* 1997;95:1686–1744
2. Schwarz KQ, Meltzer RS: Experience rounding with a hand-held two-dimensional cardiac ultrasound device. *Am J Cardiol* 1988;62:157–159
3. Schiller NB: Hand-held echocardiography: Revolution or hassle? *J Am Coll Cardiol* 2001;37:2023–2024
4. Roelandt JR: A personal ultrasound imager (ultrasound stethoscope). A revolution in the physical cardiac diagnosis! *Eur Heart J* 2002;23:523–527
5. Spencer KT, Anderson AS, Bhargava A, Bales AC, Sorrentino M, Furlong K, Lang RM: Physician-performed point of care echocardiography using a laptop platform compared with physical examination in the cardiovascular patient. *J Am Coll Cardiol* 2001;37:2013–2018
6. Goodkin GM, Spevack DM, Tunick PA, Kronzon I: How useful is hand-carried bedside echocardiography in critically ill patients? *J Am Coll Cardiol* 2001;37:2019–2022
7. Amico AF, Lichtenberg GS, Reisner SA, Stone CK, Schwartz RG, Meltzer RS: Superiority of visual versus computerized echocardiographic estimation of radionuclide ejection fraction. *Am Heart J* 1989;118:1259–1265
8. Sabia P, Abbott RD, Afrookteh A, Keller MW, Touchstone DA, Kaul S: Importance of two-dimensional echocardiographic assessment of left ventricular systolic function in patients presenting to the emergency room with cardiac-related symptoms. *Circulation* 1991;84:1615–1624
9. Sabia P, Afrookteh A, Touchstone DA, Keller MW, Esquivel L, Kaul S: Value of regional wall motion abnormality in the emergency room diagnosis of acute myocardial infarction. A prospective study using two-dimensional echocardiography. *Circulation* 1991;84:I85–I92
10. Reddy PS, Curtiss EI, O'Toole JD, Shaver JA: Cardiac tamponade: Hemodynamic observations in man. *Circulation* 1978:58:265–272
11. Nishimura RA, Tajik AJ: Determination of left-sided pressure gradients by utilizing Doppler aortic and mitral regurgitant signals: Validation by simultaneous dual catheter and Doppler studies. *J Am Coll Cardiol* 1988;11: 317–321
12. Nishimura RA, Tajik AJ: Quantitative hemodynamics by Doppler echocardiography: A noninvasive alternative to cardiac catheterization. *Prog Cardiovasc Dis* 1994;36:309–342
13. Nishimura RA, Appleton CP, Redfield MM, Ilstrup DM, Holmes DR Jr, Tajik AJ: Noninvasive Doppler echocardiographic evaluation of left ventricular filling pressures in patients with cardiomyopathies: A simultaneous Doppler echocardiographic and cardiac catheterization study. *J Am Coll Cardiol* 1996;28:1226–1233
14. Nishimura RA, Tajik AJ: Evaluation of diastolic filling of left ventricle in health and disease: Doppler echocardiography is the clinician's Rosetta Stone. *J Am Coll Cardiol* 1997;30:8–18
15. Oh JK, Appleton CP, Hatle LK, Nishimura RA, Seward JB, Tajik AJ: The noninvasive assessment of left ventricular diastolic function with two-dimensional and Doppler echocardiography. *J Am Soc Echocardiogr* 1997; 10:246–270
16. Ommen SR, Nishimura RA, Hurrell DG, Klarich KW: Assessment of right atrial pressure with 2-dimensional and Doppler echocardiography: A simultaneous catheterization and echocardiographic study. *Mayo Clin Proc* 2000; 75:24–29