Published in final edited form as:

Mayo Clin Proc. 2014 June ; 89(6): 790–798. doi:10.1016/j.mayocp.2013.12.016.

Diagnostic Capability of Comprehensive Handheld vs Transthoracic Echocardiography

Michael W. Cullen, MD, Lori A. Blauwet, MD, Ori M. Vatury, MD, Sharon L. Mulvagh, MD, Thomas R. Behrenbeck, MD, PhD, Christopher G. Scott, and Patricia A. Pellikka, MD

Division of Cardiovascular Diseases (Drs Cullen, Blauwet, Vatury, Mulvagh, Behrenbeck, and Pellikka) and Division of Biomedical Statistics and Informatics (Mr Scott), Mayo Clinic, Rochester, Minnesota

Abstract

Objective—To assess the diagnostic capability of handheld echocardiography (HHE) compared with transthoracic echocardiography (TTE) performed and evaluated by experienced sonographers and expert echocardiographers.

Patients and Methods—We conducted a prospective study of adult outpatients undergoing comprehensive TTE from July 9, 2012, through April 3, 2013. Experienced sonographers performed a detailed, standardized examination with a handheld ultrasound device (Vscan; GE Healthcare) that included 2-dimensional and color Doppler images from standard imaging windows. TTE and HHE images were independently interpreted by expert echocardiographers to whom the other study was masked. Agreement between the standard TTE and the HHE reports was analyzed.

Results—The study group contained 190 patients (mean [SD] age, 62 [17] years; 49% male). κ Values were 0.52 for left ventricular (LV) enlargement, 0.52 for right ventricular enlargement, 0.62 for regional wall motion abnormalities, 0.73 for aortic stenosis, and 0.61 for mitral regurgitation. Lin concordance correlation coefficients ranged from 0.89 for LV end-systolic diameter to 0.78 for LV end-diastolic diameter. In 51 patients (27%), echocardiographic findings were discordant between HHE and standard TTE. The most common discordant finding was the presence vs absence of any regional wall motion abnormalities. In discordant cases, HHE tended to underestimate, rather than overestimate, the severity of abnormal findings.

Conclusion—HHE in experienced hands shows moderate correlation with standard TTE, but discordant findings were present in 27% of patients. HHE, even when performed and interpreted by experienced operators, should not be used as a surrogate for standard TTE.

© 2014 Mayo Foundation for Medical Education and Research. Published by Elsevier Inc. All rights reserved.

Reprints: Patricia A. Pellikka, MD, Division of Cardiovascular Diseases, Mayo Clinic, 200 First St SW, Rochester, MN 55905 (pellikka.patricia@mayo.edu).

Conflict of interest: The authors have no financial conflicts of interest to report regarding this manuscript.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Keywords

focused cardiac ultrasound; hand-carried ultrasound; handheld echocardiography; portable cardiac ultrasound; transthoracic echocardiography

Introduction

Transthoracic echocardiography (TTE) represents an essential diagnostic tool in cardiovascular disease.¹ In the United States, echocardiography is commonly performed by qualified sonographers using large ultrasound systems and interpreted by cardiologists with specialized training.² Recently, the development of handheld ultrasound devices small enough to fit in the pocket of a physician's laboratory coat have raised new possibilities regarding the point-of-care applicability of echocardiography.^{3,4}

Studies of handheld and portable echocardiograms have found that they can be used to accurately assess gross cardiac structure and function and to augment information available from the physical examination.⁵⁻¹⁴ Inexperienced users can glean clinically useful information from portable echocardiography,¹⁵⁻¹⁸ but they can also misinterpret the findings.^{7,19} Studies assessing handheld devices have typically been small, have enrolled unselected patients, and have limited the scope of the handheld examination or diagnostic comparison.^{9-13,19} Despite these limitations, reports have suggested that handheld echocardiography (HHE) may substitute for TTE in particular clinical settings.^{20,21}

Critical assessment of HHE is crucial to its appropriate application and interpretation. Although previous studies have generally evaluated HHE favorably, they have not studied these devices as a surrogate for TTE under controlled clinical conditions. Therefore, we sought to assess the diagnostic capability of HHE in the hands of experienced sonographers and expert echocardiographers as a potential substitute for standard TTE. We hypothesized that HHE would show concordance with standard TTE for detection of clinically significant abnormal findings.

Methods

Patient Selection

We conducted a prospective study of adult outpatients referred to the Mayo Clinic Echocardiography Laboratory for a resting TTE. Patients were enrolled in the study from July 9, 2012, through April 3, 2013. Patients with established congenital heart disease, with left ventricular (LV) assist devices, or who received intravenous echocardiographic contrast agent with their standard TTE were excluded. The Mayo Clinic Institutional Review Board approved this study.

Sonographic Equipment

This study used the Vscan handheld ultrasound device (GE Healthcare) for the HHE examination and the iE33 (Phillips) or Vivid E9 (GE Healthcare) for the TTE examination. The Vscan weighs 13.8 ounces and obtains 2-dimensional (2D) grayscale and color Doppler

ultrasound images. It does not contain zoom functions, spectral Doppler, the capability for velocity or time measurements, or an electrocardiography interface. The Vscan analyzes the cycle length of ultrasound images to detect and store clips that are 1 cardiac cycle in length. If the device cannot detect the cardiac cycle length, it stores 2-second clips. The US Food and Drug Administration has approved the Vscan for abdominal, cardiac, and obstetrical imaging.²²

HHE Examination

Eligible patients were approached for enrollment while they waited in the examination room during review of their clinical TTE. If patients provided informed consent, 1 of 6 experienced research sonographers performed the HHE examination without knowledge of the clinically indicated TTE results. The HHE examination included acquisition of 27 protocolized 2D and color Doppler images from the parasternal, apical, and subcostal windows. Sonographers imaged all cardiac chambers and valves plus extracardiac structures such as the aorta and inferior vena cava. Table 1 outlines the specific imaging windows and views that the sonographers obtained. Sonographers adjusted the gain and depth of the Vscan to optimize image quality. They obtained additional images to clarify unclear or unexpected findings. No time limits existed on the sonographer examination.

Images from the HHE examination were uploaded to a secure server for offline viewing through the Vscan Gateway software program (GE Healthcare). The sonographers recorded the HHE study findings in an electronic report formatted identically to the report of the clinical TTE. All HHE reports included measurements of LV systolic and diastolic diameters from the parasternal long-axis position at the level of the mitral valve leaflet tips.¹ When findings appeared qualitatively abnormal, sonographers were instructed to measure ventricular wall thickness or aortic dimensions. Volumetric measurements of atrial and ventricular size were not part of the HHE examination.

HHE Interpretation

One of 5 expert echocardiographers reviewed the HHE images and completed the report as he or she would a clinical TTE report. The clinicians reviewing the HHE image had access to the patient's medical record and the indication for the study, but the clinical TTE was blinded to them.

The clinicians interpreting the HHE study evaluated LV size qualitatively and quantitatively with 2D measurements in end-diastole and end-systole at the level of the mitral valve leaflet tips, in accordance with published recommendations.¹ LV wall thickness was evaluated qualitatively for all studies and quantitatively at the discretion of the interpreting physician. LV ejection fraction was calculated from LV systolic and diastolic diameters using the Quinones method.²³ When ventricular dimensions were technically not feasible, LV ejection fraction was estimated visually. Resting LV regional wall motion and wall motion score index were assessed on the basis of the 16-segment model.²⁴ Right ventricular size, right ventricular function, left atrial size, and right atrial size were assessed qualitatively on the basis of recommended criteria.¹ Measurement functions on the Vscan Gateway software program were available to the reviewing clinicians if the measurements would augment their

interpretation of the HHE images. Valvular heart disease, including valvular morphology, stenotic lesions, and regurgitant lesions, were assessed qualitatively on the basis of 2D and color Doppler images. Effusions were classified as present or absent, and their size was assessed qualitatively. Aorta and inferior vena cava size were assessed qualitatively and quantitatively according to standard criteria.¹ Abnormalities were graded on a 6-level ordinal scale of increasing severity that included trivial, mild, mild-to-moderate, moderate, moderate-to-severe, and severe classifications.

TTE Examination and Interpretation

In accordance with the usual clinical practice, patients were scheduled for clinical TTE studies at 75-minute intervals, which include time for patient preparation, the echocardiographic examination, online measurements, study review, and examination room turnover between patients. The TTEs were obtained and interpreted in accordance with the American Society of Echocardiography's recommendations for a complete transthoracic echocardiographic examination.²⁵ TTEs included 2D, color Doppler, and pulsed and continuous wave Doppler imaging. Reports included qualitative and quantitative assessment of chamber dimensions, ventricular function, atrial size, LV wall thickness, aortic diameter, the severity of valvular lesions, and extracardiac findings.

Discordant Findings

The clinical TTE and HHE reports were compared to identify discordant findings between the 2 studies. The interpretation of standard TTE was considered the gold standard. We defined a discordant finding as greater than mild regurgitant valvular heart disease, ventricular enlargement, or ventricular dysfunction detected on either HHE or standard TTE if no abnormalities for that parameter were detected on the other study. A classification of severity of more than 2 levels different (ie, mild vs moderate-to-severe) also constituted a discordant finding. Stenotic valvular lesions were classified as discordant if any degree of stenosis was detected on 1 study while the other study was considered normal. Regional wall motion assessment was considered discordant if regional wall motion abnormalities in any segment were present on HHE or TTE and no segments were abnormal on the other study. Aortic size was considered discordant if any degree of dilation was detected on 1 study and the other study was considered normal or if a classification of severity more than 2 levels different between HHE and TTE was present. Finally, we considered discordant any HHE reports that excluded findings from the standard TTE or included findings not reported on the standard TTE that potentially altered therapeutic decisions or led to additional testing. We classified each discordant finding into 1 of 8 categories: LV size, right ventricular size and function, LV regional wall motion, valvular heart disease, aortic dimensions, intracardiac masses or devices, congenital heart disease, and pleural/pericardial/abdominal conditions.

Data Analysis and Statistical Methods

Continuous variables are reported as mean (SD); categorical variables are reported as number (%) of the total group. Categorical variables from the TTE or HHE report were grouped into 2 or 3 levels on the basis of the clinical significance of the distinctions between degrees of severity. Agreement was defined by a simple κ statistic for categorical variables

with 2 levels and a weighted κ statistic for categorical variables with 3 levels. κ Statistics of 0.41 to 0.60 were considered as moderate agreement, 0.61 to 0.80 as good agreement, and 0.81 or greater as excellent agreement.²⁶ Continuous variables were assessed with Lin concordance correlation coefficient to summarize correlation along the line of identity. Concordance correlation coefficients of 0.51 to 0.70 were considered moderate positive correlation, 0.71 to 0.90 were good positive correlation, and 0.91 or greater were excellent positive correlation.²⁷ If a parameter was not available from either the TTE or HHE report for a participant, that participant was excluded from the calculation of the correlation coefficients or agreement statistics for that particular parameter.

Results

Patient Characteristics

This study enrolled 200 patients. Ten patients were excluded (5 for incomplete images, 4 for contrast agent administration, and 1 for withdrawal of consent), leaving a final study group of 190 patients. Mean (SD) age was 62 (17) years, and 93 patients (49%) were male. Table 2 shows the primary referral indications for the standard TTE. The most common indications included cardiovascular symptoms, heart rhythm disorders, and valvular heart disease.

Echocardiography Examinations

The HHE study was completed without interruption in 182 (96%) of the 190 patients. The mean duration of the uninterrupted HHE studies was 8 minutes, 12 seconds. The mean (SD) number of stored images in the 190 HHE studies was 34 (7) vs 102 (23) for the standard TTE studies.

Agreement Among Reports

Table 3 displays the mean values and correlation coefficients for continuous variables on the standard TTE and the HHE reports. Mean LV dimensions and ejection fractions showed good correlation. The wall motion score index correlation was good at 0.80 for all patients with regional wall motion interpreted on both HHE and TTE. Among 14 patients with a wall motion score index of greater than 1 on both HHE and TTE, the wall motion score index correlation was slightly better, at 0.88. Aortic diameter showed excellent correlation between the clinical TTE and HHE.

Table 3 also displays the agreement statistics for categorical parameters between the standard TTE and HHE. κ Statistics ranged from 0.47 for inferior vena cava dilation to 0.73 for the presence of aortic stenosis.

Discordant Findings

TTE and HHE detected 61 discordant findings in 51 of the 190 patients (27%). Two patients had 3 discordant findings, 6 patients had 2 discordant findings, and 42 patients had a single discordant finding between TTE and HHE. Table 4 displays the characteristics of the specific discordant findings.

The most common discordance was regional wall motion assessment, accounting for 15 (25%) of the 61 discordant findings. Of these 15 cases of discordant regional wall motion assessment, 6 patients had regional wall motion abnormalities detected on TTE but not HHE and 9 had regional wall motion abnormalities detected on HHE but not TTE. Other examples of undetected findings on HHE included pleural effusions (n=5), a pericardial cyst (n=1), a previously placed atrial septal defect closure device (n=1), an enlarged coronary sinus related to an undiagnosed persistent left superior vena cava (n=1), and a malignant right atrioventricular groove mass (n=1). With the exception of regional wall motion analysis, discordant findings more commonly occurred when HHE underestimated the degree of pathologic factors compared with TTE.

Discussion

The present study sought to compare the capabilities of HHE as a surrogate for standard TTE in outpatients undergoing comprehensive TTE. Given the notion in some reports that HHE could substitute for standard TTE in certain clinical environments,^{20,21} we believed that assessing HHE in this manner addressed an important question regarding application of HHE technology. In our study, experienced sonographers obtained the HHE images without restrictions on imaging windows or the duration of examination. Expert echocardiographers reviewed the HHE images and prepared a report analogous to standard practice. Essentially, we sought to assess HHE under the circumstances most similar to those in which we perform standard clinical TTE.

We found a good-to-excellent correlation between HHE and TTE with regard to standardized measurements and a moderate-to-good correlation with regard to severity classification of common echocardiographic parameters. However, despite the experience of the operators coupled with the echocardiography laboratory environment, HHE was discordant with TTE in 27% of cases. In cases of discrepant findings, HHE tended to underestimate, rather than overestimate, the severity of pathological findings.

These findings are important because they demonstrate that, although HHE may augment a bedside clinical evaluation, it cannot substitute for comprehensive TTE. Given the technological limitations of HHE and the comprehensive nature of our HHE examination, these results are not necessarily unexpected. The live and offline viewing windows for HHE are smaller than standard TTE. HHE does not yet contain several basic capabilities, such as frequency adjustment, an electrocardiography interface, zoom features, or pulsed and continuous wave Doppler imaging. It also lacks more sophisticated diagnostic features, such as capabilities for echocardiographic contrast agent use, strain measurements, and 3-dimensional imaging. All of these factors likely contribute to the high rate of discordant findings in our study. These findings carry relevance not only for experienced sonographers and echocardiographers, but also for other users of HHE, such as hospitalists, general internists, emergency room physicians, critical care specialists, and those applying HHE to populations in developing countries.²⁸⁻³⁰

The findings from other studies regarding portable cardiac ultrasound techniques and HHE support the results of this study. Prior work with a Vscan device in experienced hands also

found good correlation with standard TTE for basic assessment of cardiac structure and function.^{9-12,14,19} Our work builds on these investigations by replicating, to the extent possible, an ideal clinical echocardiography environment.

Despite the environment in which we conducted our study, the high rate of discordance differs from the good correlation that prior studies have demonstrated. However, these studies have limited the scope of the HHE examination or depth of diagnostic comparison. For example, a study by Liebo et al¹² placed time limits on image acquisition for the HHE examination, did not use color Doppler imaging in the HHE study, and did not assess right-sided cardiac structures or aortic dimensions with the HHE device. Prinz and Voigt¹⁰ did not compare right ventricular, aortic, or other extracardiac findings between TTE and HHE. Other studies have enrolled fewer than 50 patients and had only a single imager complete the HHE examinations.^{9,19} In contrast, our study assessed HHE under circumstances that mimicked clinical practice as closely as possible, with experienced sonographers and expert physicians completing the images and reports, respectively. These characteristics are important because prior work has showed that accuracy of HHE depends directly on the experience of the interpreting clinician.^{12,31,32} Therefore, our findings add to the existing HHE literature by demonstrating that suboptimal HHE performance under ideal conditions may contribute to decreased accuracy in the hands of less experienced operators or in less controlled environments.

We defined the criteria for discordant findings on the basis of clinical relevance of discrepancies in severity classification for the parameters in our analysis. For example, we only considered ventricular size and regurgitant valvular lesions discordant when a difference of more than a full 1 level of severity existed between the HHE and TTE reports. We considered stenotic valvular lesions discrepant when 1 modality failed to identify them because of the implications that even mild undiagnosed mitral or aortic stenosis could have for long-term clinical surveillance. We used similar criteria for ascending aortic enlargement and regional wall motion abnormalities. Any degree of aortic dilation implies the need for additional surveillance. A single segment of wall motion abnormality can identify coronary artery disease and change the trajectory of a patient's clinical evaluation. Thus, we are confident that the discordant findings in our study carry relevance for the clinical care of these patients.

Limitations

This was a single-institution study conducted in a large echocardiography laboratory with a diverse patient population. Nevertheless, the spectrum of indications for TTE mimics a typical clinical practice, suggestive that our patient population reflects those of other TTE laboratories.

Although we attempted to perform as comprehensive an HHE examination as possible, the mean number of clips in our study was 34 compared with 102 clips for the standard TTE examination. The mean duration of the HHE examinations was 8 minutes, 12 seconds. The exact duration of the standard TTE studies was not available for this study but is considerably longer than the HHE examination. Some of the discrepancy in clip number could be explained by lack of spectral Doppler, tissue Doppler, or other advanced imaging

modalities available on the HHE devices. Despite these differences in clip number and study duration, the good correlation between HHE and TTE suggests that image quality was sufficient for interpretation of typical echocardiographic parameters. The high rate of discordant findings, in turn, may be related to less sophisticated imaging capabilities or limited viewing windows on the HHE devices.

Some of the disagreement between standard TTE and HHE may reflect interobserver variability. However, it is unlikely that interobserver variability explains all the discordance. For instance, previous data from our laboratory demonstrated agreement in resting regional wall motion assessment in 96% of segments examined in patients undergoing dobutamine echocardiography.³³ Data from this study suggest good agreement when assessing quantitative parameters such as LV dimensions. In contrast, the high rate of discordant findings on HHE is more likely related to the technical limitations of HHE for detecting subtle findings rather than interobserver variability in the interpretation of those findings.

An independent gold standard was not available to reconcile discordant findings between the TTE and HHE studies. Additionally, our study was not designed to assess the clinical impact these discordant findings have on a patient's care or clinical outcomes. Future studies must examine the accuracy of standard TTE vs HHE against an independent gold standard and assess the clinical impact of HHE on subsequent patient care.

Conclusions

In summary, our study found moderate-to-good agreement and correlation between standard TTE and HHE in outpatients undergoing a comprehensive echocardiographic evaluation in experienced hands. Despite this agreement, HHE and TTE detected a high rate of discordant findings. These results suggest that, although HHE can accurately assess basic cardiac structure and function, it does not have the technical capabilities to substitute for standard clinical TTE. Further dissemination of HHE technology to less experienced users or less controlled settings should occur with caution.

Acknowledgments

This study was made possible by Center for Translational Science Activities Grant Number UL1 TR000135 from the National Center for Advancing Translational Sciences, a component of the National Institutes of Health. Its contents are solely the responsibility of the authors and do not necessarily represent the official view of the National Institutes of Health.

Funding: This project received funding for statistical support from the Mayo Clinic Division of Cardiovascular Diseases.

References

1. Lang RM, Bierig M, Devereux RB, et al. Chamber Quantification Writing Group; American Society of Echocardiography's Guidelines and Standards Committee; European Association of Echocardiography. Recommendations for chamber quantification: a report from the American Society of Echocardiography's Guidelines and Standards Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. *J Am Soc Echocardiogr*. 2005; 18(12):1440–1463. [PubMed: 16376782]

2. Beller GA, Bonow RO, Fuster V. American College of Cardiology Foundation; American Heart Association; American College of Physicians Task Force on Clinical Competence and Training. ACCF 2008 recommendations for training in adult cardiovascular medicine core cardiology training (COCATS 3) (revision of the 2002 COCATS Training Statement). *J Am Coll Cardiol*. 2008; 51(3): 335–338. [PubMed: 18206749]
3. Kaul S, Miller JG, Grayburn PA, et al. A suggested roadmap for cardiovascular ultrasound research for the future. *J Am Soc Echocardiogr*. 2011; 24(4):455–464. [PubMed: 21440216]
4. Spencer KT, Kimura BJ, Korcarz CE, Pellicka PA, Rahko PS, Siegel RJ. Focused cardiac ultrasound: recommendations from the American Society of Echocardiography. *J Am Soc Echocardiogr*. 2013; 26(6):567–581. [PubMed: 23711341]
5. Bruce CJ, Montgomery SC, Bailey KR, Tajik J, Seward JB. Utility of hand-carried ultrasound devices used by cardiologists with and without significant echocardiographic experience in the cardiology inpatient and outpatient settings. *Am J Cardiol*. 2002; 90(11):1273–1275. [PubMed: 12450617]
6. Kobal SL, Trento L, Baharami S, et al. Comparison of effectiveness of hand-carried ultrasound to bedside cardiovascular physical examination. *Am J Cardiol*. 2005; 96(7):1002–1006. [PubMed: 16188532]
7. Martin LD, Howell EE, Ziegelstein RC, et al. Hand-carried ultrasound performed by hospitalists: does it improve the cardiac physical examination? *Am J Med*. 2009; 122(1):35–41. [PubMed: 19114170]
8. Spencer KT, Anderson AS, Bhargava A, et al. Physician-performed point-of-care echocardiography using a laptop platform compared with physical examination in the cardiovascular patient. *J Am Coll Cardiol*. 2001; 37(8):2013–2018. [PubMed: 11419879]
9. Egan M, Ionescu A. The pocket echocardiograph: a useful new tool? *Eur J Echocardiogr*. 2008; 9(6):721–725. [PubMed: 18579497]
10. Prinz C, Voigt JU. Diagnostic accuracy of a hand-held ultrasound scanner in routine patients referred for echocardiography. *J Am Soc Echocardiogr*. 2011; 24(2):111–116. [PubMed: 21126857]
11. Fukuda S, Shimada K, Kawasaki T, et al. Pocket-sized transthoracic echocardiography device for the measurement of cardiac chamber size and function. *Circ J*. 2009; 73(6):1092–1096. [PubMed: 19372623]
12. Liebo MJ, Israel RL, Lillie EO, Smith MR, Rubenson DS, Topol EJ. Is pocket mobile echocardiography the next-generation stethoscope? A cross-sectional comparison of rapidly acquired images with standard transthoracic echocardiography. *Ann Intern Med*. 2011; 155(1):33–38. [PubMed: 21727291]
13. Cardim N, Fernandez Golfín C, Ferreira D, et al. Usefulness of a new miniaturized echocardiographic system in outpatient cardiology consultations as an extension of physical examination. *J Am Soc Echocardiogr*. 2011; 24(2):117–124. [PubMed: 21074362]
14. Andersen GN, Haugen BO, Graven T, Salvesen O, Mjølstad OC, Dalen H. Feasibility and reliability of point-of-care pocket-sized echocardiography. *Eur J Echocardiogr*. 2011; 12(9):665–670. [PubMed: 21810825]
15. Brennan JM, Blair JE, Goonewardena S, et al. A comparison by medicine residents of physical examination versus hand-carried ultrasound for estimation of right atrial pressure. *Am J Cardiol*. 2007; 99(11):1614–1616. [PubMed: 17531592]
16. Brennan JM, Ronan A, Goonewardena S, et al. Handcarried ultrasound measurement of the inferior vena cava for assessment of intravascular volume status in the outpatient hemodialysis clinic. *Clin J Am Soc Nephrol*. 2006; 1(4):749–753. [PubMed: 17699282]
17. DeCara JM, Lang RM, Spencer KT. The hand-carried echocardiographic device as an aid to the physical examination. *Echocardiography*. 2003; 20(5):477–485. [PubMed: 12848871]
18. Razi R, Estrada JR, Doll J, Spencer KT. Bedside hand-carried ultrasound by internal medicine residents versus traditional clinical assessment for the identification of systolic dysfunction in patients admitted with decompensated heart failure. *J Am Soc Echocardiogr*. 2011; 24(12):1319–1324. [PubMed: 21885245]

19. Culp BC, Mock JD, Chiles CD, Culp WC Jr. The pocket echocardiograph: validation and feasibility. *Echocardiography*. 2010; 27(7):759–764. [PubMed: 20412264]
20. Frederiksen CA, Juhl-Olsen P, Larsen UT, Nielsen DG, Eika B, Sloth E. New pocket echocardiography device is interchangeable with high-end portable system when performed by experienced examiners. *Acta Anaesthesiol Scand*. 2010; 54(10):1217–1223. [PubMed: 21039344]
21. Gianstefani S, Catibog N, Whittaker AR, et al. Pocket-size imaging device: effectiveness for ward-based transthoracic studies. *Eur Heart J Cardiovasc Imaging*. 2013 May 24. Epub ahead of print.
22. Food and Drug Administration, Department of Health & Human Services. [September 28, 2013] Traditional 510(k) premarket notification: GE Vscan – compact diagnostic ultrasound system. Jul 14. 2009 http://www.accessdata.fda.gov/cdrh_docs/pdf9/K092756.pdf
23. Quinones MA, Waggoner AD, Reduto LA, et al. A new, simplified and accurate method for determining ejection fraction with two-dimensional echocardiography. *Circulation*. 1981; 64(4): 744–753. [PubMed: 7273375]
24. Pellikka PA, Nagueh SF, Elhendy AA, Kuehl CA, Sawada SG. American Society of Echocardiography. American Society of Echocardiography recommendations for performance, interpretation, and application of stress echocardiography. *J Am Soc Echocardiogr*. 2007; 20(9): 1021–1041. [PubMed: 17765820]
25. Picard MH, Adams D, Bierig SM, et al. American Society of Echocardiography. American Society of Echocardiography recommendations for quality echocardiography laboratory operations. *J Am Soc Echocardiogr*. 2011; 24(1):1–10. [PubMed: 21172594]
26. Viera AJ, Garrett JM. Understanding interobserver agreement: the kappa statistic. *Fam Med*. 2005; 37(5):360–363. [PubMed: 15883903]
27. Hinkle, DE.; Wiersma, W.; Jurs, SG. *Applied Statistics for the Behavioral Sciences*. 5. Vol. 784. Independence, KY: Cengage Learning; 2002.
28. Singh S, Bansal M, Maheshwari P, et al. ASE-REWARD Study Investigators. American Society of Echocardiography. Remote Echocardiography with Web-Based Assessments for Referrals at a Distance (ASE-REWARD) Study. *J Am Soc Echocardiogr*. 2013; 26(3):221–233. [PubMed: 23439071]
29. Labovitz AJ, Noble VE, Bierig M, et al. Focused cardiac ultrasound in the emergent setting: a consensus statement of the American Society of Echocardiography and American College of Emergency Physicians. *J Am Soc Echocardiogr*. 2010; 23(12):1225–1230. [PubMed: 21111923]
30. Kimura BJ, Amundson SA, Shaw DJ. Hospitalist use of hand-carried ultrasound: preparing for battle. *J Hosp Med*. 2010; 5(3):163–167. [PubMed: 20235285]
31. Prinz C, Dohrmann J, van Buuren F, et al. The importance of training in echocardiography: a validation study using pocket echocardiography. *J Cardiovasc Med (Hagerstown)*. 2012; 13(11): 700–707. [PubMed: 22929564]
32. Michalski B, Kasprzak JD, Szymczyk E, Lipiec P. Diagnostic utility and clinical usefulness of the pocket echocardiographic device. *Echocardiography*. 2012; 29(1):1–6. [PubMed: 22044766]
33. Chuah SC, Pellikka PA, Roger VL, McCully RB, Seward JB. Role of dobutamine stress echocardiography in predicting outcome in 860 patients with known or suspected coronary artery disease. *Circulation*. 1998; 97(15):1474–1480. [PubMed: 9576428]

Abbreviations

HHE	handheld echocardiography
LV	left ventricular
TTE	transthoracic echocardiography
2D	2-dimensional

Table 1**Imaging Windows and Views in the Protocolled Handheld Echocardiography Examination**

Imaging Window	View
Parasternal long axis	2D
	MV color-flow
	AV color-flow
	Ascending aorta, 2D
Right ventricular inflow	2D
	Tricuspid valve color-flow
Parasternal short axis	AV level, 2D
	AV level, tricuspid valve color-flow
	AV level, AV color-flow
	AV level, pulmonary valve color-flow
	Basal left ventricular level, 2D
	Middle left ventricular level, 2D
	Apical left ventricular level, 2D
Apical 4-chamber	Increased depth for biatrial view, 2D
	Decreased depth for wall motion assessment, 2D
	MV color-flow
	Tricuspid valve color-flow
Apical long axis	Increased depth for biatrial view, 2D
	Decreased depth for wall motion assessment, 2D
	MV color-flow
	AV color-flow
Apical 2-chamber	Increased depth for biatrial view, 2D
	Decreased depth for wall motion assessment, 2D
	MV color-flow
Subcostal long axis	2D
Subcostal short axis	Inferior vena cava, 2D
	Inferior vena cava with inspiration, 2D

Abbreviations: AV, aortic valve; MV, mitral valve; 2D, 2-dimensional.

Table 2

Indications for Transthoracic Echocardiography

Indication	No. (%)
Cardiovascular symptoms	33 (17.4)
Heart rhythm disorders	27 (14.2)
Valvular heart disease	26 (13.7)
Heart failure	23 (12.1)
Other ^a	22 (11.6)
Cardiac function assessment without known heart disease ^b	17 (8.9)
Coronary artery disease	17 (8.9)
Prechemotherapy	14 (7.4)
Murmur	11 (5.8)
Total	190 (100.0)

^aIncludes aortic conditions, hypertrophic cardiomyopathy, cardiac masses, cardiac transplantation, pericardial disease, and pulmonary disorders.

^bIncludes assessment of cardiac function in the clinical setting of a systemic disease with potential cardiac involvement, screening of cardiac conditions in patients with a family history of heart disease, and evaluation of candidacy for solid organ donation.

Table 3

Agreement Between Standard Transthoracic and Handheld Echocardiography for Categorical Variables

Variable	No. of Patients	Standard Transthoracic Echocardiography, Mean (SD)	Handheld Echocardiography, Mean (SD)	Agreement (95% CI) ^a
LV end-diastolic diameter, mm	179	50 (6)	50 (6)	0.78 (0.72-0.84)
LV end-systolic diameter, mm	163	33 (7)	33 (7)	0.89 (0.85-0.92)
LV ejection fraction, %	187	60 (11)	60 (11)	0.87 (0.83-0.90)
Wall motion score index	185	1.1 (0.3)	1.1 (0.3)	0.80 (0.75-0.85)
Wall motion score index ^b	14	2.0 (0.6)	2.0 (0.5)	0.88 (0.67-0.96)
Aortic diameter, mm	56	35 (6)	36 (6)	0.91 (0.86-0.95)
LV size (normal vs mild vs >mild enlargement)	187	NA	NA	0.52 (0.35-0.68)
Increased LV wall thickness (present vs absent)	160	NA	NA	0.51 (0.28-0.74)
Regional wall motion abnormalities (present vs absent)	186	NA	NA	0.62 (0.45-0.80)
Right ventricular size (normal vs mild enlargement)	185	NA	NA	0.52 (0.32-0.71)
Right ventricular function (normal vs decreased)	185	NA	NA	0.65 (0.46-0.84)
Left atrial size (normal vs enlarged)	181	NA	NA	0.55 (0.42-0.68)
Right atrial size (normal vs enlarged)	180	NA	NA	0.49 (0.37-0.62)
Aortic stenosis (present vs absent)	190	NA	NA	0.73 (0.55-0.91)
Mitral regurgitation (trivial vs mild vs >mild regurgitation)	187	NA	NA	0.61 (0.51-0.72)
Tricuspid regurgitation (trivial vs mild vs >mild regurgitation)	176	NA	NA	0.61 (0.51-0.71)
Pericardial effusion (present vs absent)	190	NA	NA	0.51 (0.28-0.74)
Inferior vena cava size (normal vs dilated)	167	NA	NA	0.47 (0.27-0.67)
Aortic enlargement (present vs absent)	99	NA	NA	0.59 (0.30-0.89)

Abbreviations: LV, left ventricular; NA, not applicable.

^a Agreement statistics are presented as simple κ statistics for dichotomous variables, weighted κ statistics for multilevel variables, and Lin concordance correlation coefficients for continuous variables.^b Presented for 14 patients who had regional wall motion abnormalities identified on both standard transthoracic echocardiography and handheld echocardiography.

Table 4Characteristics of 61 Discordant Findings^a

Category	Value ^b
Regional wall motion, No. (%) ^c	15 (25)
Abnormalities detected on HHE but not TTE	9
Abnormalities detected on TTE but not HHE	6
Valvular heart disease, No. (%) ^d	11 (18)
Mild aortic stenosis undetected on HHE	3
Bicuspid AV undetected on HHE	2
Flail septal leaflet of tricuspid valve undetected on HHE	1
Systolic anterior motion of MV undetected on HHE	1
Degenerative strands on MV and AV leading to TEE undetected on HHE	1
Tricuspid regurgitation underestimated on HHE	1
Prosthetic AV undetected on HHE	1
MV prolapse undetected on HHE	1
MV vegetations on standard TTE identified as flail MV leaflet on HHE	1
Aortic dilation, No. (%)	11 (18)
Aortic dilation underestimated on HHE	9
Aortic dilation overestimated on HHE	2
Pleural/pericardial/abdominal findings, No. (%)	8 (13)
Pleural effusion undetected on HHE	5
Pericardial cyst undetected on HHE	1
Ascites undetected on HHE	1
Inferior vena cava narrowing undetected on HHE	1
LV size and function, No. (%)	5 (8)
LV size underestimated on HHE	4
LV size overestimated on HHE	1
RV size and function, No. (%) ^e	5 (8)
RV size underestimated on HHE	4
RV dysfunction overestimated on HHE	1
RV dysfunction underestimated on HHE	1
Masses, No. (%)	3 (5)
Right atrioventricular groove mass undetected on HHE	1
Right atrial mass undetected on HHE	1
Right atrial device lead mass undetected on HHE	1
Congenital findings, No. (%)	3 (5)
Atrial septal defect closure device undetected on HHE	1
Dilated coronary sinus and persistent left superior vena cava undetected on HHE	1
Linear right atrial membrane undetected on HHE	1

Abbreviations: AV, aortic valve; HHE, handheld echocardiography; LV, left ventricular; MV, mitral valve; RV, right ventricular; TEE, transesophageal echocardiography; TTE, transthoracic echocardiography.

^a We found 61 discordant diagnoses in 51 of 190 patients. This table details these discordant diagnoses between standard TTE and HHE in each category.

^b Values are presented as number of findings unless specified as number and percentage, in which case the percentage is reported in terms of the 61 discordant findings.

^c After review of all the data, it was believed that wall motion by TTE represented the correct assessment in each of these cases.

^d One patient had both a bicuspid AV and mild aortic stenosis not detected on HHE.

^e One HHE study did not detect both increased RV size and decreased RV function vs standard TTE.