

HAND-CARRIED ULTRASOUND FOR CARDIAC EVALUATION

A Technology Assessment

INTRODUCTION

The California Technology Assessment Forum is asked to review the scientific evidence for the use of hand carried ultrasound in the evaluation of cardiac disease.

BACKGROUND

Accurate diagnosis of cardiac pathology is based on a thorough history and physical exam and on the appropriate use of technology and diagnostic tests. Almost two centuries ago, Laennec introduced the stethoscope, a device that enabled physicians to expand their diagnostic armamentarium to include auscultation along with inspection, palpation and percussion. Flexible tubing was added to the stethoscope after 1850 and it has remained essentially unaltered for 150 years¹. While still an essential tool of the trade, the stethoscope and indeed the cardiac physical exam have significant limitations in the diagnosis of cardiac disease. These limitations have fueled the growth of cardiac imaging devices; chief among these for real time imaging of cardiac structure and function is the standard echocardiogram (SE).

One of the main reasons for requesting an echocardiogram in current clinical practice is for the evaluation of left ventricular (LV) function. Estimation of LV function can be done either qualitatively by visual inspection of global and regional function, or quantitatively. LV systolic dysfunction with symptoms of heart failure (HF) is a common clinical problem in the United States and other developed nations, occurring in at least two percent of the adult population and rising to three percent in those aged over 75 years². Symptomatic HF has a major impact on patients and healthcare systems. In addition to high mortality, patients with heart failure have morbidity from symptoms such as dyspnea and fatigue. Accurate, timely diagnosis is important since angiotensin converting enzyme inhibitors (ACE-I) and beta-blockers have been shown to improve morbidity and mortality in heart failure caused by left ventricular systolic dysfunction. Unfortunately, HF is difficult to diagnose accurately on clinical grounds and studies suggest that asymptomatic LV dysfunction is as prevalent as symptomatic HF in the general population. And while some research suggests

that treatment of patients with asymptomatic HF can slow progression of the disease and decrease HF related morbidity and mortality³, there is currently no consensus about the advisability of routine screening of asymptomatic patients for LV dysfunction with cardiac imaging.

Other important indications for echocardiography include detection and evaluation of valvular heart disease, pericardial disease and detection of pulmonary hypertension.

Hand-carried Ultrasound

Prototypical hand-carried ultrasound (HCU) devices for the heart were first described 30 years ago by Roelandt et al (1978) who used a 1.5 kg machine to obtain limited cardiac images⁴. The technology has continued to evolve with ever increasing technological sophistication and miniaturization. There are currently more than ten HCU devices manufactured by GE Medical Systems, SonoSite, ZONARE Medical Systems, Philips Technologies and others that have been FDA approved for a wide range of indications (SEE TABLE 1). In fact, a recent report projects that the HCU market is forecasted worldwide to see revenues in excess of \$1 billion by 2011 (<http://www.sonoworld.com/NewsStories/NewsStories.aspx?ID=450>). These devices range in weight from 1.0 kg up to 4.5 kg with features ranging from simple 2D mode and no storage capacity to 2D/M mode with color and spectral Doppler and the capacity for extensive storage of images. For example, the SonoHeart ELITE <http://india.sonosite.com/Elite/Elite.php>) touts: high resolution 2D imaging, tissue harmonic imaging (THI), continuous wave (CW) and pulsed wave (PW) Doppler, directional color power (DCPD) and color power Doppler and M-mode for adult, pediatric, neonatal and vascular imaging. It provides permanent documentation of studies and can be battery or AC powered. It weighs: 5.7 lb. (2.6 kg) with one transducer and battery attached.

Table 1 Commercial miniaturized, battery-operated ultrasound systems for cardiac or vascular applications

Device (manufacturer)	Features	Weight ^a	Cost
Tringa 50S, cardiac (Esaote)	2D/M	1.0 kg (2 lbs)	\$7,500
ilook 15, cardiac (SonoSite)	2D	1.5 kg (3 lbs)	\$12,500
ilook 25, vascular (SonoSite)	2D	1.5 kg (3 lbs)	\$15,500
SonoSite 180Plus, vascular (SonoSite)	2D/M, CD/SD	2.5 kg (6 lbs)	\$28,000
SonoHeart Elite, cardiac (SonoSite)	2D/M, CD/SD	2.5 kg (6 lbs)	\$28,000
OptiGo, cardiac (Philips Technologies)	2D, CD	3.0 kg (7 lbs)	\$16,000
Terason 2000, cardiac and vascular (Teratech)	2D/M, CD/SD	3.5 kg (8 lbs)	\$30,000
Mysono 201, cardiac and vascular (Medison)	2D/M	3.5 kg (8 lbs)	\$15,000
Titan, cardiac and vascular (SonoSite0)	2D/M, CD/SD	3.5 kg (8 lbs)	\$45,000
Vivid I, cardiac and vascular (GE Healthcare)	2D/M, CD/SD	4.5 kg (10 lbs)	\$80,000

^a Weights are given as gross estimates from industry data, rounded to the nearest 0.5 kg or 1 lb, 2D, two-dimensional ultrasound; CD, color Doppler; M, M-mode; SD, spectral Doppler.

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Hand carried ultrasound has been endorsed as an extension of the physical exam to detect disease in asymptomatic patients and to better identify patients who require more extensive testing⁵. It has been used for imaging of the carotid arteries to detect sub-clinical atherosclerosis⁵, to screen for abdominal aortic aneurysm⁶, to identify pleural effusions⁷, pulmonary edema⁸ to estimate right atrial pressure⁹, to evaluate venous disease¹⁰ and to rapidly assess critically ill patients¹¹, among other indications.

The focus of this review is on the use of HCU in the cardiac evaluation. Most of this research has emphasized its potential utility in this regard as a valuable adjunct to the physical exam for the detection of asymptomatic LV dysfunction. Specifically, some experts argue that: “The use of HCU to increase the accuracy of physical examination has the potential to detect cardiovascular disease at an earlier stage, improve triage and subspecialty referral, and to eliminate unnecessary testing generated by inaccurate auscultation.”⁵ The major advantage of HCU is that it can provide immediate, point of care information in the ambulatory or acute settings. It has the potential to enhance medical decision making and increase appropriate and decrease inappropriate referrals for standard echocardiography or other diagnostic tests. HCU is not meant to substitute for SE in the patient who needs full echocardiographic evaluation; few, if any, experts currently would recommend initiation of acute or chronic treatment on the basis of an HCU result alone.

TECHNOLOGY ASSESSMENT (TA)

TA Criterion 1: **The technology must have final approval from the appropriate government regulatory bodies.**

Several devices have received 510(k) approval from the FDA for use in cardiac evaluation.

TA Criterion 1 is met.

TA Criterion 2: **The scientific evidence must permit conclusions concerning the effectiveness of the technology regarding health outcomes.**

The Medline database, Cochrane clinical trials and reviews database and the Database of Abstracts of Reviews of Effects (DARE) were searched using the key words “hand-carried ultrasound”, “HCU”, “portable echocardiogram” and “cardiac examination” or “cardiovascular examination” from 1966 to December 2007. The bibliographies of systematic reviews and key articles were manually searched for additional references. Abstracts of citations were reviewed and all relevant articles reviewed in full.

The peer-reviewed literature consists primarily of level five prospective, comparative case series conducted at one site. Outcomes assessed in this research include: operating characteristics of the HCU device such as time of image acquisition and adequacy of images; the sensitivity, specificity and positive and negative predictive value of the HCU examination compared with the ‘gold standard’ full echocardiogram to identify cardiac pathology; and the accuracy of physical exam findings compared with HCU. Other outcomes have focused on the training aspects of HCU; for example, can non-cardiology trained physicians (and students) and other health professionals learn to use the HCU with acceptable accuracy and reproducibility. A few papers have conducted a cost-effectiveness analysis to examine if the use of HCU can reduce the number of inappropriate referrals for SE and therefore lead to cost savings (e.g. Greaves et al., 2005 and Trambaiolo et al., 2006).

It is not possible to conclude from the current research whether HCU improves health outcomes for

patients beyond the current standard of care consisting of physical exam and standard echocardiogram when appropriate. Future research should consider collecting data on patient centered outcomes such as satisfaction with medical care, symptoms, physical functioning, quality of life, morbidity and mortality. The research would also benefit from a more in-depth analysis of the utility of the HCU in medical decision-making, more attention paid to consistent blinding of examiners and more research conducted in “point of care” settings such as outpatient clinics and the emergency department where use of the HCU has more potential to influence care. Most of the outpatient studies to date have been conducted in specialty cardiology settings. While the literature notes that HCU performs better than well-trained cardiologists in detecting cardiac pathology, for the HCU to impact important health outcomes it would be more helpful to study patients with cardiac risk factors or disease not already being followed in subspecialty settings.

While evidence from level 1 studies are the preferred basis for deciding whether CTAF criterion are met, in the absence of Level 1 studies, technologies may meet criteria if, overall, level 2-4 studies indicate that: 1) The technology provides substantial benefits to important health outcomes, and 2) the new technology has been shown to be *safer or more beneficial* than existing technologies. The current literature on HCU and the cardiac examination does not meet these criteria.

Forty-six additional references were reviewed, but did not meet criteria for inclusion in the write-up. (References 44-90).

Level of Evidence: 3, 5

TA Criterion 2 is not met

TA Criterion 3: The technology must improve net health outcomes.

For diagnostic tests, there is evidence that use of the test would result in improved medical management in a way that will benefit the patient.

Case Series

Outpatient Referral Population

Trambaiolo et al (2007) report on 222 consecutive patients referred to an outpatient cardiology clinic to examine the potential use and cost effectiveness of HCU in reducing the need for SE.¹²

Eight echo trained cardiologists performed a physical exam (PE) and electrocardiogram (EKG) on every patient; when SE was indicated and HCU was performed first (OptiGo) and based on this information the cardiologist confirmed or canceled the SE request. Overall, an SE was requested in 50% of patients and HCU was performed in 108; the need for SE was confirmed in 74 patients and allowed for SE to be cancelled in 34 patients (31%). Agreement between the two devices was 73% ($k=0.4$). HCU missed ten major abnormalities in nine patients including left ventricular hypertrophy (LVH) and a pericardial effusion. Most inconclusive exams with the HCU were related to the limited Doppler capability of the device. While supportive of the potential cost savings implications of HCU, the authors caution that: *“Portable fully equipped systems require more experience and training, both in performing the examinations and interpreting the data, and we should be cautious in suggesting the widespread use of these systems in a clinical setting where immediate decision making is required.”*

Ippisch and Kimball (2007) compared the diagnostic accuracy of pediatric cardiac PE versus the PE plus two different HCU devices¹³. Thirty patients (three months to 19 years) were seen by a single cardiologist and evaluated for cardiac shunts, valvular insufficiency and valvular anatomy with PE, HCU with device 1 (18 patients) and device 2 (12 patients) and then all underwent SE. HCU device 2 had more transducer choices and a wider variety of applications. They found that PE plus HCU device 1 did not improve accuracy over PE alone, but it was improved with the more technologically sophisticated device 2.

Ghani et al (2006) examined whether HCU could be used in a pacemaker clinic to screen for LV dysfunction¹⁴. HCU Screening was done by an internist who had 20 hours of didactic training and 20 practice examinations. SE by blinded echocardiographer was used as the gold standard. Of 80 patients screened, HCU images were obtainable in 91% and required approximately four minutes to obtain. Prevalence of LV dysfunction (LVEF < 40%) was 17/80 (21%). The sensitivity, specificity, negative predictive value (npv) and positive predictive value (ppv) was 75%, 91%, 71% and 88% respectively. Accuracy increased over the course of the study.

Kobal et al (2005) compared the accuracy of cardiac diagnosis of medical students with an HCU (OptiGo) compared with board certified cardiologists using standard PE¹⁵. Sixty-one patients with

cardiac disease confirmed by SE had HCU studies by one of two first year medical students (trained for 18 hrs). They correctly identified 75% of cardiac pathology compared with 49% detected by PE alone by the cardiologists ($p < 0.001$). Students identified 86% of LV dysfunction (LV $< 50\%$) compared with 45% by the cardiologists, and 89% of valvular lesions compared with 50% by the cardiologists. The student's performance was lower in diagnosing LVH (65%) and right ventricular (RV) enlargement (62%) and correctly assessed the severity of regurgitant jets 50% of the time. Overall, medical students with limited training in HCU had better diagnostic accuracy of cardiac pathology than did board certified cardiologists with standard PE (not including EKG) alone.

Vourvouri et al (2005) determined the diagnostic potential of an HCU device (OptiGo, Philips Medical Systems) in a cardiology outpatient clinic compared with the HCU diagnosis with the clinical diagnosis and diagnosis with a full-featured SE system¹⁶. 300 consecutive patients took part in the study. The HCU examination was performed by an experienced echocardiographer before patients visited the cardiologist. The echocardiographer noted whether the HCU device was able to confirm or reject the referral diagnosis, which abnormality was detected, and whether SE investigation was necessary. Physical examination by a cardiologist followed and thereafter, whenever required, a complete study with an SE was carried out. The HCU data were compared with the clinical diagnosis of the cardiologist and the SE diagnosis in a blinded manner. The cardiologist referred 203 of 300 patients for an SE study and 13 patients for transoesophageal echocardiography. In 84 patients no further examination was considered necessary. HCU echocardiography was able to confirm or reject the suspected clinical diagnosis in 159 of 203 (78%) patients. In 44 of 203 (22%) patients SE Doppler was needed. Agreement between the HCU device and the SE system for the detection of major abnormalities was excellent (98%). The HCU device missed four percent of the major findings. Among the 84 patients not referred for an SE, the HCU device detected unsuspected major abnormalities missed with the physical examination in 14 (17%).

Giannotti et al (2005) studied 87 consecutive patients referred to cardiology who underwent HCU (OptiGo) followed by SE. Operators were trained echocardiographers¹⁷. Mean examination time was 6.7 minutes for HCU and 13.6 minutes for SE. Of the 74 patients (85%) for whom HCU exam

was satisfactory, the diagnosis was concordant with SE in 62 cases (83.8% agreement). Overall, a correct diagnosis was made by HCU in 71.3% of the study population.

Borges et al (2004) report on results from a study of 315 patients referred to their cardiology clinic for pre-operative assessment before non-cardiac surgery¹⁸. SE and HCU were performed by experienced cardiologists in a blinded manner. Overall, 138 (43%) of patients had cardiac pathology identified by SE. HCU had overall agreement of 94.8% ($k = 0.89$) in detection of the main echocardiographic finding. Global LV function was assessed correctly in 85.6% of cases, pericardial effusion in 91% and HCU detected valve disease with an agreement of 96.7% with SE. The authors attribute the impressive results to the fact that the study was “performed only by experienced cardiologists under ideal conditions” with devices with Doppler and harmonic imaging capabilities.

Alexander et al (2004) compared the accuracy of HCU (OptiGo) with SE in patients scheduled to have a SE¹⁹. Medical house staff conducted the HCU after receiving one three hour training session to learn to assess four common diagnoses (LVEF, mitral regurgitation-MR, aortic valve thickening and pericardial effusion). They found that agreement (kappa) between HCU and SE was acceptable for diagnosis of LVEF ($k=0.51$) and large pericardial effusion ($k=0.51$) but not for the valvular disease. They conclude that with minimal training clinicians can learn to assess LV function and pericardial effusion, though with less accuracy than with SE.

Vourvouri et al (2003) report on a study to test the screening potential of HCU for LV dysfunction compared with SE and plasma brain natriuretic peptide (BNP)²⁰. Eighty-eight consecutive patients referred for SE underwent the SE followed by HCU with either SonoHeart or OptiGo portable devices. Of the 82 patients included in the analysis, 19 had an EF < 40%; the HCU devices (no comparison between the two devices is presented) detected 17 of 19 patients for sensitivity, and specificity of 89% and 98% respectively.

Rugolotto et al (2001) compared image quality and accuracy of the OptiGo HCU compared with SE²¹. They enrolled 121 consecutive patients referred for SE at Stanford University Hospital. Two experienced cardiologists read the studies; the HCU reader was blinded to the results of the SE.

Scanning time with the HCU averaged 9.5 minutes compared with 40-45 minutes for SE. They conclude that overall image quality of the HCU is adequate and clinical accuracy “acceptable” compared with SE when performed by an echocardiographer with level II training. The HCU was most limited in estimation of LV end-diastolic volume and estimation of valvular regurgitation. The authors conclude that future studies are needed to understand the appropriate application of HCU in clinical practice.

Spencer et al (2001) compared the results of physical exams conducted by board certified cardiologists compared with those obtained with a HCU by the same examiners in 36 cardiology clinic patients. All patients underwent SE as the “gold standard”²². Compared with SE, physical exam alone missed 43% of “major” cardiovascular abnormalities versus 21% miss rate for HCU. PE identified a small number of important clinical findings missed by HCU. The authors argue that HCU can be a useful adjunct to but not replacement for the PE.

Outpatient Screening Population

Croft et al (2006) report on a pilot study designed to study the impact of HCU on clinical decision making of medical residents²³. Nine residents underwent 15 hours of training and five hours or supervised use of an HCU (Phillips OptiGo) and then performed an HCU exam (under the observation of a “passive and mute” echocardiographer) on consenting patients who attended the outpatient medical clinic as part of routine care. The patients then immediately underwent a second HCU conducted by the trained echocardiographer. Compared with the trained echocardiographer, the residents acquired accurate images in 94% of 72 patients and interpreted them correctly in 93%; they correctly identified “major” HCU findings in 92% of patients and “minor” findings in 75%. (An example of a major finding would be severe LVH or moderate/severe LV dysfunction). Compared with PE alone, the authors found that the use of HCU led to an “appropriate” change in patient management in 40% of patients; for example, they ordered five additional SE, five stress tests and eliminated 13 SE. It is important to remember that the gold standard upon which appropriateness was measured was the comparison HCU performed by the trained echocardiographer and not SE. No clinical outcomes were reported.

Kirkpatrick et al (2005) report that nurses trained in the use of HCU correctly identified three out of 63 patients from an outpatient diabetes clinic as having occult LV systolic dysfunction (LVF < 40%) when compared with SE²⁴.

Senior et al (2003) compare the accuracy of a hand held ultrasound device (OptiGo, Sonos 4500, Philips, Eindhoven, Netherlands) with SE in 189 patients diagnosed with hypertension who attended a community based screening program in England. Each patient underwent consecutive studies performed and analyzed by one of the investigators (a cardiology registrar who had “an intensive” six month training program)²⁵. The main outcome measure was detection of LVH (defined as left ventricular mass index (LVMI) exceeding 134 gm²/m² and 110 gm²/m² for men and women respectively). Overall they detected LVH in 46 (26%) of patients of the 179 patients analyzed. There was agreement of 86% (k=0.63, 95% confidence interval, 0.50-0.70) between the two devices. The sensitivity and positive and negative predictive value for the prediction of LVH by the HCU was 72%, 73% and 90% compared with SE. The authors conclude that HCU accurately assessed LVH and may be used for community-based screening in targeted patients with hypertension.

Galasko et al (2003) report on results of 562 consecutive patients (45% of patients were selected from a general clinic population and the rest were considered ‘high risk’ secondary to history of vascular disease, DM, hypertension (HTN) or heavy alcohol use) attending a community-based heart failure screening program who underwent same day HCU and SE²⁶. An estimate of LVEF using the HCU was possible in 97% of cases using an “eyeball estimate” with a sensitivity, specificity and negative predictive value in diagnosing LV dysfunction (EF<50%) of 96%, 98% and 99.6% respectively. No blinding of investigators is reported and only one investigator was used to conduct all of the HCU; he had undergone six months of intensive training prior to the study.

Vourvouri et al (2002) studied 100 consecutive patients with hypertension and screened them for LVH with HCU and SE²⁷. LVH was defined as an increase in LV mass > 134g.m⁻² for men and > 110g.m⁻² for women. Sixty-five men and 35 women were studied. The anterior septum and posterior wall were visualized in all patients with both devices. The SE identified LVH by body surface area in 18 patients and by height in 26 patients. Agreement between the SE and the HCU

for assessment of LVH was 93%, $k=0.77$ (LV mass/body surface area) and 90%, $k=0.76$ (LV mass/height).

Hospitalized (non-critical care) Patients

Martin et al (2007) report on a study in which ten hospitalist physicians were trained in the use of HCU (SonoSite Elite) (each completed an average of 35 training HCUs) and their subsequent results were compared with gold standard SE in hospitalized patients referred for SE and with results obtained on the HCU by trained technicians²⁸. They conclude that after training, hospitalists cannot perform HCU at the same level as echocardiography technicians—and that it remains unknown whether the skills acquired by the hospitalists would lead to a net benefit for patients. In another study conducted at the same institution, Hellman et al (2005) conclude that medical residents with minimal training can learn how to perform some basic functions of HCU. No clinical or comparative outcomes were collected.²⁹

Greaves et al (2005) tested the diagnostic potential and the impact on costs of HCU in the detection of a normal echocardiogram for patients referred for SE in the inpatient setting.³⁰ The comparator was the use of standard departmental echocardiograms (SDE; Sonos 5500, Philips, Eindhoven), which was considered the 'gold' standard for the analysis. This was a single-centered, prospective, within-group, comparison diagnostic study. All patients underwent HCU and subsequently SE. There was no loss to follow-up. No blinding method was reported. They report a sensitivity, specificity, and positive and negative predictive value of HCU predicting a completely normal SE as 74%, 96%, 94% and 81%, and conclude that if either all inpatients or those with requests for LV function assessment underwent HCU initially, and only those with abnormal scans underwent further SE, there would be a 29% and 22% reduction in department workload. The assessments of the different tests were independent, but the authors did not state whether any methods were used to blind the second test to the results of the previous test. No power calculations were reported, thus it was not possible to ascertain whether the results obtained were due to the intervention or to chance.

Tsutsui et al (2004) studied 44 consecutive hospitalized patients who underwent bedside SE and HCU (OptiGo) performed by level 2 trained cardiologists.³¹ The agreement between HCU and SE for the detection of wall motion abnormalities was 83% ($\kappa = 0.58$). There was good agreement in determination of valvular regurgitation with κ ranging from 0.74 to 0.85. Evaluation of pulmonary hypertension by HCU was not possible due to technical limitations. The authors recommend that HCU be performed by cardiologists with at least level 2 training.

DeCara et al (2003) performed SE on 300 adult inpatients referred for imaging.³² The patients then had HCU (OptiGo) performed by three internal medicine residents (trained with 20 hrs of didactics and 20 observed studies) or by level-3 cardiology fellows. For clinically important findings, sensitivity was slightly but significantly higher for the cardiologist performed scans. Clinically important findings missed by the residents included regional wall motion abnormalities, significant pericardial effusions and RV dysfunction. In addition, there were significant differences in overall positive predictive value (75% vs. 67%) between the internist and cardiology trained echocardiographer. The authors conclude that “standardized training, competency testing, and quality assurance guidelines need to be established before these devices can be utilized for clinical decision making by physicians without formal training in echocardiography.”

CRITICAL CARE PATIENTS

Goodkin et al (2001) report on results from 80 acutely ill patients in intensive care units, step down units, post-operative recovery rooms and the emergency department.³³ Each patient was studied separately by operators blinded to the others results. They found that the HCU (SonoHeart) did not detect the clinical findings related to the reason for the referral in 31% of the patients and missed a clinically important finding independent of the reason for referral in 19% of patients when compared with SE. The authors’ explanation for the missed findings include technical limitations of the HCU (such as lack of spectral Doppler capability that may be addressed with newer HCU models) and inherent difficulties in imaging acutely ill patients with portable devices. They conclude that HCU “falls far short” to SE in the evaluation of critically ill patients.

Vignon et al (2004) evaluated the diagnostic capability of HCU (with Doppler capability) in critically ill patients compared to SE.³⁴ They studied 55 consecutive patients over two months in a medical-surgical ICU; 40 patients were being mechanically ventilated at the time of the study. While the 2D imaging quality allowed for accurate (though inferior) assessment of LV dysfunction and wall motion abnormality compared with SE, they found that the overall diagnostic accuracy of HCU was lower than SE for important clinical questions such as the presence of valvular disease and pulmonary HTN.

Vignon et al (2003) compared HCU (OptiGo) with SE in 103 ventilated patients. Operators were intensivists with level 3 training in cardiology.³⁵ Compared with SE, HCU had lower overall diagnostic capacity (defined as significantly fewer clinical questions solved) which they mainly attributed to its lack of spectral Doppler capacity.

Overall, performance of HCU in critical care settings has been disappointing. As Beaulieu (2007) notes, this is an ideal setting in which focused, point of care echocardiographic studies by non-cardiology medical professionals could be most useful.³⁶ However, they also point out that significant challenges must be overcome in medical education and “politics” (i.e. improved cooperation among the professional societies) before HCU can be successfully integrated into critical care units.

HCU in Developing Countries

Kobal et al (2004) evaluated the use of HCU in 126 patients referred to a cardiology clinic in rural Mexico.³⁷ They concluded that the HCU identified 86 cardiac findings and obviated the need for further SE evaluation in 90% of patients. While further research is needed, these findings suggest a potential application for HCU in regions where access to specialized medical care is poor. Further research is needed.

Patient Safety

HCU is considered a safe procedure with no reported significant adverse effects.

In sum, it is not possible to conclude from the research to date that use of HCU as an adjunct to the cardiac physical exam improves patient outcomes. Therefore, TA criteria 3 is not met. There are several methodological shortcomings of the current research. Most of the studies are small, single site trials that are not designed or powered to examine important clinical outcomes or other relevant patient health outcomes such as patient satisfaction or quality of life. Several studies neglect to adequately describe whether HCU and SE operators were blinded (a potential source of bias), do not fully describe recruitment procedures and do not report p values. In addition, there is variability across the studies in the devices used and in the definition of relevant outcomes (e.g. the definition of LV dysfunction) that make it impossible to generalize findings. While some studies have found that the accuracy of HCU compares favorably with SE, there is also significant variation in outcomes across studies that may be due to differences in HCU specific training, patient population, setting (echo lab vs. critical care unit, for example), physician background and device used. While in general, accuracy of HCU seems to be improving with successive generations of devices, the two studies published in the past year (Trambaiolo et al, 2007; Martin et al, 2007) both report disappointing results. It is possible that as devices become increasingly sophisticated they will also become increasingly complicated to operate. The literature is not consistent in answering the question as to who should be trained to use the HCU and how much training is necessary to achieve acceptable accuracy.

A larger conceptual issue that remains unresolved, and that must be addressed before use of HCU can be endorsed, is whether any screening tool designed to detect asymptomatic LV dysfunction improves patient outcomes. Until this clinical research question is resolved it will be difficult to show that the HCU will improve patient health outcomes in any meaningful way, even if the other methodological issues discussed above are addressed.

In sum, while some of these early results demonstrate that the HCU shows promise, the evidence to date does not support the conclusion that use of the HCU device in the cardiac examination improves health outcomes according to CTAF criterion # 3.

TA Criterion 3 is not met.

TA Criterion 4: The technology must be as beneficial as any established alternatives.

Alternative technologies to the use of HCU for the detection of cardiac disease and specifically LV dysfunction include the PE with stethoscope, the EKG, brain natriuretic peptide (BNP) and SE. History and PE of the patient, including visual inspection, palpation and auscultation, are the standard initial approach to evaluate patients with suspected or known cardiac disease. Unfortunately, HF is difficult to diagnose accurately on clinical grounds and several studies have pointed out the deficiencies of the PE for the detection of cardiac disease in general, and specifically for identifying patients with HF^{2, 38, 39}. Only 26% of patients with suspected heart failure referred to a rapid access clinic for echocardiography had the diagnosis confirmed after investigation, and clinical diagnosis by hospital physicians is just as poor².

Likewise, while a completely normal electrocardiogram usually excludes LV dysfunction⁴⁰, an abnormal EKG does not reliably identify patients with LV dysfunction and is not recommended as a routine screening tool for asymptomatic patients. Further, EKG changes indicating cardiac disease may be subtle, and primary care physicians may lack the specific skills required in interpreting EKGs and referral for specialist opinion often will still be required. Data on the validity of BNP for screening are conflicting.

The SE consists of a two dimensional (2D) echocardiography that allows for visualization of the heart and related vessels structures using ultrasonic waves and a three dimensional (3D) view with improved accuracy and reproducibility in which echocardiographic images are generated by integration of information from multiple 2D imaging planes. The SE is non-invasive, does not entail exposure to radiation and can reliably and reproducibly evaluate systolic and diastolic dysfunction, wall motion abnormalities, and other cardiac anatomy including valves. HCU offers some potential advantages over SE. While bedside SE is feasible and is commonly done, the device is not easily portable and has limitations when used as a point of service screening tool in most circumstances. It requires an experienced operator with a minimum of level 2 training and image acquisition takes two to three times longer than with HCU. The diagnostic value of echocardiography, particularly

hand carried echocardiography, is limited in patients with poor acoustic windows or in patients who cannot achieve proper positioning.

In spite of the limitations of the cardiac PE, the research to date does not support the conclusion that cardiac PE with HCU is as beneficial as the current standard of care of PE with SE when indicated.

TA Criterion 4 is not met

TA Criterion 5: The improvement must be attainable outside of the investigational setting.

Hand-carried ultrasound devices currently approved by the FDA for cardiac evaluation have not been shown to improve health outcomes in the investigational setting, so improvement is not possible outside of this setting. The American Society of Echocardiography recommends a minimum of level 1 training (level 1 training requires the user to have personally performed 75 examinations and personally interpreted 150 examinations) for independent performance or interpretation of HCU⁴¹. The minimum level of experience required for the independent practice of standard echocardiography is defined by level-2 requirement, which, according to the American and Canadian Societies of Echocardiography, is a minimum of six months of training in echocardiography and includes the performance of 150 echocardiograms and the interpretation of 300 echocardiograms⁴². It is of critical importance to standardize training and identify core skills and competences before the HCU can be endorsed for use outside of investigational settings.

TA Criterion 5 is not met.

CONCLUSION

A number of hand-held ultrasound devices have received FDA approval for point of care cardiac examination. Several small, prospective case series have shown over 90% accuracy when compared with SE for detection of LVH and LV dysfunction. Hand-carried Ultrasound correlation

with SE is less impressive for evaluation of other cardiac abnormalities and results have been disappointing in the few studies from critical care units. Several of these case series have concluded that use of these devices in conjunction with a PE can increase diagnostic yield of some cardiac abnormalities in asymptomatic patients or in those with HTN and other cardiac risk factors. Cost effectiveness studies have concluded that results from the HCU can be used to decrease inappropriate referrals for more costly and time intensive SE. Methodological inconsistencies and shortcomings discussed above call into question some of these findings, yet overall the literature seems to suggest that HCU can be used to detect cardiac abnormalities with an inferior but acceptable level of accuracy compared with SE.

However, in spite of these promising results, HCU is still an evolving technology in search of a useful, evidence-based niche. While its proponents foresee a future in which every physician may replace his/her stethoscope with a more accurate and user friendly HCU (what some have called "tomorrow's stethoscope"⁴³), the evidence to date does not yet support the abandonment of the trusty symbol of the profession.

The barriers to the rational incorporation of HCU into medical practice face challenges that go well beyond the technical limitation of the device itself. Questions that will need to be addressed in future research include:

- How much training is necessary for accurate and consistent use of these devices? Is training on one device transferable to other HCU devices? Who should be the operators—all physicians?; board certified cardiologists?; critical care physicians?; ICU nurses and other allied health professionals?; echo technicians?; all of the above? What is the minimum level of use required to maintain competency? Should periodic recertification be required?
- How will the incorporation of these devices into point of care clinical encounters impact patient flow? While the actual time of image acquisition is generally less than 5 minutes, this does not include the additional time needed to explain the study to the patient and review the findings with them at the conclusion of the study. Considering that the average primary care encounter is less than 15 minutes, this adds a considerable burden to the

system and requires that other elements of the history and/or PE be eliminated in order to accommodate the new technology. Will patients (and health systems) tolerate the extra time needed to perform HCU in otherwise healthy patients? None of the research to date addresses this very practical limitation.

- In non-urgent cardiac evaluations how good does HCU need to be to be good enough? Is 90% agreement high enough to avoid a sending the patient for a second study? 95%? Will patients, doctors, health plans tolerate lower accuracy than the gold standard SE when the gold standard itself is non-invasive, safe and accurate? In this context, is the primary argument in favor of HCU one of potential cost saving (how many unnecessary tests can be avoided) rather than a device that will improve clinical outcomes? In fact, one trial of open access echocardiography found that only 12% of referrals by primary care physicians were felt to be "inappropriate"⁴⁰.
- Can HCU image quality obtained primarily in controlled settings be replicated in busy, acute and critical care settings? HCU use in the critical care setting has the potential to improve outcomes with earlier recognition and treatment of patients with life threatening cardiac pathology--- but research in this setting has demonstrated that HCU results are not acceptable there. Sub-optimal lighting and poor positioning of the patient, to name two challenges, may limit image acquisition in the acute care setting and limit HCU use. For HCU to improve clinical outcomes for patients in acute and critical care settings residents, fellows and attending physicians in these settings will have to undergo extensive training in the appropriate use of the technology and some of the current technical limitations of the devices will need to be resolved.¹¹
- And finally, does use of HCU truly improve diagnostic yield (in non-experimental settings) and lead to enhanced, evidence-based treatment? Can it be successfully integrated into clinical practice such that its use decreases cardiac related symptoms and hospitalizations and improve overall patient quality of life and ultimately reduce mortality? Heart failure is an increasing problem, accounting for significant morbidity, mortality and health care costs in the United States. It is frequently undetected because the clinical symptoms are often

non-specific and the easily available screening tools (PE and EKG) are relatively insensitive. To positively establish a diagnosis of HF, patients must be referred for cardiac imaging. However, to date, evidence is weak that screening asymptomatic patients for HF improves clinical outcomes, and no major cardiac professional organization has endorsed such widespread screening. It is only in a subset of asymptomatic patients, those with an LVEF of 35-40%, for whom treatment has been shown to improve outcomes³. Until more evidence accumulates, the wisdom of universal screening for HF and other cardiac abnormalities through any means remains in question.

DRAFT RECOMMENDATION

It is recommended that use of HCU for cardiac evaluation does not meet CTAF criteria 2-5 for safety, efficacy and improvement in health outcomes

March 5, 2008

RECOMMENDATIONS OF OTHERS

BLUE CROSS AND BLUE SHIELD ASSOCIATION (BCBSA)

The BCBSA Technology Evaluation Center has not conducted a review of this device.

CENTERS FOR MEDICARE AND MEDICAID SERVICES (CMS)

CMS does not have language specific to the use of hand-carried ultrasound.

AMERICAN SOCIETY OF ECHOCARDIOGRAPHY (ASE)

ASE has been invited to have a representative at the meeting. The American Society of Echocardiography Position Statement on Hand Carried Ultrasound (HCU), March 2003 is available at: <http://www.asecho.org/freepdf/HCUPositionStatement.pdf>.

CALIFORNIA CHAPTER OF THE AMERICAN COLLEGE OF CARDIOLOGY (CA ACC)

The CA ACC has been invited to provide a position/opinion statement regarding this technology and representation at the meeting.

CALIFORNIA RADIOLOGICAL SOCIETY (CRS)

The CRS has been invited to provide a position/opinion statement regarding this technology and representation at the meeting.

ABBREVIATIONS USED IN THIS REVIEW

SE	Standard echocardiogram
LV	Left ventricular
HF	Heart failure
ACE-I	Angiotensin converting enzyme inhibitors
HCU	Hand-carried ultrasound
THI	Tissue harmonic imaging
CW	Continuous wave
PW	Pulsed wave
DCPD	Directional color power
DARE	Database of Abstracts of Reviews of Effects
LVH	Left ventricular hypertrophy
RV	Right ventricular
HTN	Hypertension
LVMi	Left ventricular mass index
npv	Negative predictive value
ppv	Positive predictive value
BNP	Brain natriuretic peptide
PE	Physical exam
EKG	Electrocardiogram
2D	Two dimensional
3D	Three dimensional

REFERENCES

1. Gorcsan J. Utility of hand-carried ultrasound for consultative cardiology. *Echocardiography*. Jul 2003;20(5):463-469.
2. Hobbs R. Can heart failure be diagnosed in primary care? *Bmj*. Jul 22 2000;321(7255):188-189.
3. Effect of enalapril on mortality and the development of heart failure in asymptomatic patients with reduced left ventricular ejection fractions. The SOLVD Investigators. *N Engl J Med*. Sep 3 1992;327(10):685-691.
4. Roelandt J, Wladimiroff JW, Baars AM. Ultrasonic real time imaging with a hand-held-scanner. Part II--initial clinical experience. *Ultrasound Med Biol*. 1978;4(2):93-97.
5. Kimura BJ, DeMaria AN. Technology insight: hand-carried ultrasound cardiac assessment--evolution, not revolution. *Nat Clin Pract Cardiovasc Med*. Apr 2005;2(4):217-223; quiz 224.
6. Vourvouri EC, Poldermans D, Schinkel AF, et al. Abdominal aortic aneurysm screening using a hand-held ultrasound device. "A pilot study". *Eur J Vasc Endovasc Surg*. Oct 2001;22(4):352-354.
7. Beckh S, Bolcskei PL, Lessnau KD. Real-time chest ultrasonography: a comprehensive review for the pulmonologist. *Chest*. Nov 2002;122(5):1759-1773.
8. Jambrik Z, Monti S, Coppola V, et al. Usefulness of ultrasound lung comets as a nonradiologic sign of extravascular lung water. *Am J Cardiol*. May 15 2004;93(10):1265-1270.
9. 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*. Jun 1 2007;99(11):1614-1616.
10. Frazee BW, Snoey ER, Levitt A. Emergency Department compression ultrasound to diagnose proximal deep vein thrombosis. *J Emerg Med*. Feb 2001;20(2):107-112.
11. Spevack DM, Spevack DM, Tunick PA, Kronzon I. Hand carried echocardiography in the critical care setting. *Echocardiography*. Jul 2003;20(5):455-461.
12. Trambaiolo P, Papetti F, Posteraro A, et al. A hand-carried cardiac ultrasound device in the outpatient cardiology clinic reduces the need for standard echocardiography. *Heart*. Apr 2007;93(4):470-475.

13. Ippisch HM, Kimball TR. The Impact of Evolving Hand-carried Echocardiographic Technology on Outpatient Physical Examination Accuracy in Pediatric Cardiology. *Congenital Heart Disease*. 2007;2(3):170-178.
14. Ghani SN, Kirkpatrick JN, Spencer KT, et al. Rapid assessment of left ventricular systolic function in a pacemaker clinic using a hand-carried ultrasound device. *J Interv Card Electrophysiol*. Jun 2006;16(1):39-43.
15. Kobal SL, Trento L, Baharami S, et al. Comparison of effectiveness of hand-carried ultrasound to bedside cardiovascular physical examination. *Am J Cardiol*. Oct 1 2005;96(7):1002-1006.
16. Vourvouri EC, Poldermans D, Deckers JW, Parharidis GE, Roelandt JR. Evaluation of a hand carried cardiac ultrasound device in an outpatient cardiology clinic. *Heart*. Feb 2005;91(2):171-176.
17. Giannotti G, Mondillo S, Galderisi M, et al. Hand-held echocardiography: added value in clinical cardiological assessment. *Cardiovasc Ultrasound*. 2005;3:7.
18. Borges AC, Knebel F, Walde T, Sanad W, Baumann G. Diagnostic accuracy of new handheld echocardiography with Doppler and harmonic imaging properties. *J Am Soc Echocardiogr*. Mar 2004;17(3):234-238.
19. Alexander JH, Peterson ED, Chen AY, Harding TM, Adams DB, Kisslo JA, Jr. Feasibility of point-of-care echocardiography by internal medicine house staff. *Am Heart J*. Mar 2004;147(3):476-481.
20. Vourvouri EC, Schinkel AF, Roelandt JR, et al. Screening for left ventricular dysfunction using a hand-carried cardiac ultrasound device. *Eur J Heart Fail*. Dec 2003;5(6):767-774.
21. Rugolotto M, Hu BS, Liang DH, Schnittger I. Rapid assessment of cardiac anatomy and function with a new hand-carried ultrasound device (OptiGo): a comparison with standard echocardiography. *Eur J Echocardiogr*. Dec 2001;2(4):262-269.
22. 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*. Jun 15 2001;37(8):2013-2018.
23. Croft LB, Duvall WL, Goldman ME. A pilot study of the clinical impact of hand-carried cardiac ultrasound in the medical clinic. *Echocardiography*. Jul 2006;23(6):439-446.
24. Kirkpatrick JN, Belka V, Furlong K, et al. Effectiveness of echocardiographic imaging by nurses to identify left ventricular systolic dysfunction in high-risk patients. *Am J Cardiol*. May 15 2005;95(10):1271-1272.

25. Senior R, Galasko G, McMurray JV, Mayet J. Screening for left ventricular dysfunction in the community: role of hand held echocardiography and brain natriuretic peptides. *Heart*. Nov 2003;89 Suppl 3:iii24-28.
26. Galasko GI, Lahiri A, Senior R. Portable echocardiography: an innovative tool in screening for cardiac abnormalities in the community. *Eur J Echocardiogr*. Jun 2003;4(2):119-127.
27. Vourvouri EC, Poldermans D, Schinkel AF, et al. Left ventricular hypertrophy screening using a hand-held ultrasound device. *Eur Heart J*. Oct 2002;23(19):1516-1521.
28. Martin LD, Howell EE, Ziegelstein RC, Martire C, Shapiro EP, Hellmann DB. Hospitalist performance of cardiac hand-carried ultrasound after focused training. *Am J Med*. Nov 2007;120(11):1000-1004.
29. Hellmann DB, Whiting-O'Keefe Q, Shapiro EP, Martin LD, Martire C, Ziegelstein RC. The rate at which residents learn to use hand-held echocardiography at the bedside. *Am J Med*. Sep 2005;118(9):1010-1018.
30. Greaves K, Jeetley P, Hickman M, et al. The use of hand-carried ultrasound in the hospital setting--a cost-effective analysis. *J Am Soc Echocardiogr*. Jun 2005;18(6):620-625.
31. Tsutsui JM, Maciel RR, Costa JM, Andrade JL, Ramires JF, Mathias W, Jr. Hand-carried ultrasound performed at bedside in cardiology inpatient setting - a comparative study with comprehensive echocardiography. *Cardiovasc Ultrasound*. 2004;2:24.
32. DeCara JM, Lang RM, Koch R, Bala R, Penzotti J, Spencer KT. The use of small personal ultrasound devices by internists without formal training in echocardiography. *Eur J Echocardiogr*. Jun 2003;4(2):141-147.
33. Goodkin GM, Spevack DM, Tunick PA, Kronzon I. How useful is hand-carried bedside echocardiography in critically ill patients? *J Am Coll Cardiol*. Jun 15 2001;37(8):2019-2022.
34. Vignon P, Frank MB, Lesage J, et al. Hand-held echocardiography with Doppler capability for the assessment of critically-ill patients: is it reliable? *Intensive Care Med*. Apr 2004;30(4):718-723.
35. Vignon P, Chastagner C, Francois B, et al. Diagnostic ability of hand-held echocardiography in ventilated critically ill patients. *Crit Care*. Oct 2003;7(5):R84-91.
36. Beaulieu Y. Specific skill set and goals of focused echocardiography for critical care clinicians. *Crit Care Med*. May 2007;35(5 Suppl):S144-149.

37. Kobal SL, Lee SS, Willner R, et al. Hand-carried cardiac ultrasound enhances healthcare delivery in developing countries. *Am J Cardiol.* Aug 15 2004;94(4):539-541.
38. Remes J, Miettinen H, Reunanen A, Pyorala K. Validity of clinical diagnosis of heart failure in primary health care. *Eur Heart J.* Mar 1991;12(3):315-321.
39. Senior R, Galasko G. Cost-effective strategies to screen for left ventricular systolic dysfunction in the community--a concept. *Congest Heart Fail.* Jul-Aug 2005;11(4):194-198, 211.
40. Davie AP, Francis CM, Love MP, et al. Value of the electrocardiogram in identifying heart failure due to left ventricular systolic dysfunction. *Bmj.* Jan 27 1996;312(7025):222.
41. Seward JB, Douglas PS, Erbel R, et al. Hand-carried cardiac ultrasound (HCU) device: recommendations regarding new technology. A report from the Echocardiography Task Force on New Technology of the Nomenclature and Standards Committee of the American Society of Echocardiography. *J Am Soc Echocardiogr.* Apr 2002;15(4):369-373.
42. Nair P, Siu SC, Sloggett CE, Bicular L, Sidhu RS, Yu EH. The assessment of technical and interpretative proficiency in echocardiography. *J Am Soc Echocardiogr.* Jul 2006;19(7):924-931.
43. Bryan CS. Tomorrow's stethoscope: the hand-held ultrasound device? *J S C Med Assoc.* Dec 2006;102(10):345.
44. *American Society of Echocardiography Position Statement on Hand Carried Ultrasound*; American Society of Echocardiography; March 2003
45. Arnett DK, Skelton TN, Liebson PR, Benjamin E, Hutchinson RG. Comparison of m-mode echocardiographic left ventricular mass measured using digital and strip chart readings: the Atherosclerosis Risk in Communities (ARIC) study. *Cardiovasc Ultrasound.* 2003;1:8.
46. Bedetti G, Gargani L, Corbisiero A, Frassi F, Poggianti E, Mottola G. Evaluation of ultrasound lung comets by hand-held echocardiography. *Cardiovasc Ultrasound.* 2006;4:34.
47. Branger B, Dauzat M, Zabadani B, Vecina F, Lefranc JY. Pulsed Doppler sonography for the guidance of vein puncture: a prospective study. *Artif Organs.* Sep 1995;19(9):933-938.
48. Breikreutz R, Walcher F, Seeger FH. Focused echocardiographic evaluation in resuscitation management: concept of an advanced life support-conformed algorithm. *Crit Care Med.* May 2007;35(5 Suppl):S150-161.

49. Brennan JM, Blair JE, Hampole C, et al. Radial artery pulse pressure variation correlates with brachial artery peak velocity variation in ventilated subjects when measured by internal medicine residents using hand-carried ultrasound devices. *Chest*. May 2007;131(5):1301-1307.
50. 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*. Jul 2006;1(4):749-753.
51. Campbell B. Clinical and hand-held Doppler examination of primary varicose veins. *Ann R Coll Surg Engl*. Jul 2001;83(4):287-288.
52. Campbell WB, Niblett PG, Peters AS, et al. The clinical effectiveness of hand held Doppler examination for diagnosis of reflux in patients with varicose veins. *Eur J Vasc Endovasc Surg*. Dec 2005;30(6):664-669.
53. Cohen TJ, Tucker KJ, Lurie KG, et al. Active compression-decompression. A new method of cardiopulmonary resuscitation. Cardiopulmonary Resuscitation Working Group. *Jama*. Jun 3 1992;267(21):2916-2923.
54. Decara JM, Kirkpatrick JN, Spencer KT, et al. Use of hand-carried ultrasound devices to augment the accuracy of medical student bedside cardiac diagnoses. *J Am Soc Echocardiogr*. Mar 2005;18(3):257-263.
55. DeCara JM, Lang RM, Spencer KT. The hand-carried echocardiographic device as an aid to the physical examination. *Echocardiography*. Jul 2003;20(5):477-485.
56. Duvall WL, Croft LB, Goldman ME. Can hand-carried ultrasound devices be extended for use by the noncardiology medical community? *Echocardiography*. Jul 2003;20(5):471-476.
57. Fine RE, Boyd BA, Whitworth PW, Kim JA, Harness JK, Burak WE. Percutaneous removal of benign breast masses using a vacuum-assisted hand-held device with ultrasound guidance. *Am J Surg*. Oct 2002;184(4):332-336.
58. Firstenberg MS, Cardon L, Jones P. Initial clinical experience with an ultra-portable echocardiograph for the rapid diagnosis and evaluation of critically ill patients. *J Am Soc Echocardiogr*. 2000 2000;13:489.
59. Francis CM, Caruana L, Kearney P, et al. Open access echocardiography in management of heart failure in the community. *Bmj*. Mar 11 1995;310(6980):634-636.
60. Galasko GI, Barnes SC, Collinson P, Lahiri A, Senior R. What is the most cost-effective strategy to screen for left ventricular systolic dysfunction: natriuretic peptides, the electrocardiogram, hand-held echocardiography, traditional echocardiography, or their combination? *Eur Heart J*. Jan 2006;27(2):193-200.

61. Hailey D, Topfer LA. Hand-carried ultrasound units for point-of-care cardiac examinations. *Issues Emerg Health Technol.* Oct 2002(41):1-4.
62. Hunt SA. ACC/AHA 2005 guideline update for the diagnosis and management of chronic heart failure in the adult: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing Committee to Update the 2001 Guidelines for the Evaluation and Management of Heart Failure). *J Am Coll Cardiol.* Sep 20 2005;46(6):e1-82.
63. Kerber RE. Transthoracic cardioversion of atrial fibrillation and flutter: standard techniques and new advances. *Am J Cardiol.* Oct 17 1996;78(8A):22-26.
64. Khan NA, Rahim SA, Anand SS, Simel DL, Panju A. Does the clinical examination predict lower extremity peripheral arterial disease? *Jama.* Feb 1 2006;295(5):536-546.
65. Kirkpatrick JN, Ghani SN, Spencer KT. Hand carried echocardiography screening for LV systolic dysfunction in a pulmonary function laboratory. *Eur J Echocardiogr.* Aug 11 2007.
66. Kock HJ, Jurgens C, Hirche H, Hanke J, Schmit-Neuerburg KP. Standardized ultrasound examination for evaluation of instability of the acromioclavicular joint. *Arch Orthop Trauma Surg.* 1996;115(3-4):136-140.
67. Langer SG, Carter SJ, Haynor DR, et al. Image acquisition: ultrasound, computed tomography, and magnetic resonance imaging. *World J Surg.* Nov 2001;25(11):1428-1437.
68. Lee DS, Wang TJ, Vasan RS. Screening for ventricular remodeling. *Curr Heart Fail Rep.* Apr 2006;3(1):5-13.
69. Liang D, Schnittger I. Accuracy of hand-carried ultrasound. *Echocardiography.* Jul 2003;20(5):487-490.
70. Macpherson CN, Bartholomot B, Frider B. Application of ultrasound in diagnosis, treatment, epidemiology, public health and control of *Echinococcus granulosus* and *E. multilocularis*. *Parasitology.* 2003;127 Suppl:S21-35.
71. MacRae K. Hand-held Dopplers in central catheter insertion. *Prof Nurse.* Nov 1998;14(2):99-102.
72. Mahomed K, Nyoni R, Mlambo T, Jacobus E, Kasule J. Intrapartum foetal heart rate monitoring--continuous electronic versus intermittent Doppler--a randomised controlled trial. *Cent Afr J Med.* Dec 1992;38(12):458-462.
73. Mondillo S, Giannotti G, Innelli P, Ballo PC, Galderisi M. Hand-held echocardiography: its use and usefulness. *Int J Cardiol.* Jul 28 2006;111(1):1-5.
74. Mor-Avi V, Lang RM. Three-dimensional echocardiographic evaluation of myocardial perfusion. *Cardiol Clin.* May 2007;25(2):273-282.

75. Pandian NG, Ramasamy S, Martin P, Banerjee A. Ultrasound stethoscope as an extension of clinical examination during hospital patient rounds: preliminary experience with hand-held miniaturized echocardiography instrument (abstr). *J Am Soc Echocardiogr.* 2000;13:486.
76. Porembka DT. Importance of transesophageal echocardiography in the critically ill and injured patient. *Crit Care Med.* Aug 2007;35(8 Suppl):S414-430.
77. Pritchett AM, Bruce CJ, Bailey KR, Tajik AJ, Seward JB. Personal ultrasound imager: extension of the cardiovascular physical examination (abstr). *J Am Soc Echocardiogr.* 2000;13:485.
78. Quiles J, Garcia-Fernandez MA, Almeida PB, et al. Portable spectral Doppler echocardiographic device: overcoming limitations. *Heart.* Sep 2003;89(9):1014-1018.
79. Roelandt JR. Ultrasound stethoscopy: a renaissance of the physical examination? *Heart.* Sep 2003;89(9):971-973.
80. Ronan A, Schmidt GA, Justin S, Spencer KT. A 58-year-old man with episodically widened pulse pressure. *Chest.* Jan 2007;131(1):313-316.
81. Schiller NB. Hand-held echocardiography: revolution or hassle? *J Am Coll Cardiol.* Jun 15 2001;37(8):2023-2024.
82. Scholten C, Rosenhek R, Binder T, Zehetgruber M, Maurer G, Baumgartner H. Hand-held miniaturized cardiac ultrasound instruments for rapid and effective bedside diagnosis and patient screening. *J Eval Clin Pract.* Feb 2005;11(1):67-72.
83. Senior RM, Galasko G, Hickman M, Jeetley P, Lahiri A. Community screening for left ventricular hypertrophy in patients with hypertension using hand-held echocardiography. *Journal of the American Society of Echocardiography.* 2004;17(1):56-61.
84. Smith JJ, Brown L, Greenhalgh RM, Davies AH. Randomised trial of pre-operative colour duplex marking in primary varicose vein surgery: outcome is not improved. *Eur J Vasc Endovasc Surg.* Apr 2002;23(4):336-343.
85. Turnbull TJ, Dymowski JJ. Emergency department use of hand-held Doppler ultrasonography. *Am J Emerg Med.* Mar 1989;7(2):209-215.
86. Vowden KR, Goulding V, Vowden P. Hand-held doppler assessment for peripheral arterial disease. *J Wound Care.* Mar 1996;5(3):125-128.
87. Weston P, Alexander JH, Patel MR, Maynard C, Crawford L, Wagner GS. Hand-held echocardiographic examination of patients with symptoms of acute coronary syndromes in the emergency department: the 30-day outcome

associated with normal left ventricular wall motion. *Am Heart J.* Dec 2004;148(6):1096-1101.

88. White H, Venkatesh B. Applications of transcranial Doppler in the ICU: a review. *Intensive Care Med.* Jul 2006;32(7):981-994.
89. White PM, Wardlaw JM, Teasdale E, Sloss S, Cannon J, Easton V. Power transcranial Doppler ultrasound in the detection of intracranial aneurysms. *Stroke.* Jun 2001;32(6):1291-1297.
90. Whiteley MS, Fox AD, Horrocks M. Photoplethysmography can replace hand-held Doppler in the measurement of ankle/brachial indices. *Ann R Coll Surg Engl.* Mar 1998;80(2):96-98.