Use of a Hand-carried Ultrasound Device by Critical Care Physicians for the Diagnosis of Pericardial Effusions, Decreased Cardiac Function, and Left Ventricular Enlargement in Pediatric Patients

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Prompt diagnosis of children with suggested cardiac disease in the acute care setting is critical for initiation of life-saving therapy. We hypothesized that pediatric critical care physicians could perform limited portable echocardiography in children. Portable hand-carried cardiac ultrasound units with 2.5-MHz phased-array transducers were used (Optigo, Philips Medical Systems, Andover, Mass). Noncardiologists were trained through a 1-hour introductory course and 2 hours of practical training. Portable echocardiography performed by noncardiologists was compared with a standard echocardiogram for diagnostic accuracy. In all, 23 patients (age 3 months-20 years) were screened during 18 months. The presence or absence of a pericardial effusion was correctly diagnosed in 21 of 23 patients (91%). Left ventricular size was correctly determined in 22 of 23 patients (96%). Left ventricular systolic function was correctly diagnosed in 22 of 23 patients (96%). These results show that, with appropriate instruction, pediatric critical care physicians are effective using limited portable echocardiography. (J Am Soc Echocardiogr 2005;18:313-9.)

The diagnosis of pericardial effusions, decreased cardiac function, and cardiac enlargement in patients who are critically ill is clinically imperative, but physical examination findings are often inconclusive. Echocardiography is usually required for a definitive answer. The current standard of care is to have a cardiologist with highly specialized training perform and interpret echocardiograms. However, this can delay diagnosis and potentially compromise patient care when a cardiologist is not at the bedside. If critical care physicians could use simplified bedside echocardiography to diagnose pericardial effusions, cardiac enlargement, and cardiac function more efficiently, then patient outcomes might be improved.

Previously, hand-carried cardiac ultrasound (HCU) devices showed no statistical difference in image quality when compared with standard echocardiography.[1] The devices identified moderate to severe cardiac pathology with a sensitivity of 97% and a specificity of 99%, and decreased the missed diagnosis rate of major cardiovascular findings in the physical examination from 43% to 21%.[1,2] HCU devices evaluated left ventricular (LV) ejection fractions in the inpatient setting with a sensitivity of 85% and a specificity of 90%. It diagnosed pericardial effusions in 28/33 cases (in 100% agreement with standard echocardiography) and found unexpected findings in 25% of the cases.[3] In another study, the Optigo device (Phillips Medical Systems, Andover, Mass) evaluated new patients referred to a cardiology outpatient clinic. The device answered the referral question in 75% of the patients and there was 98% agreement between the portable and the standard echocardiogram.[4] With a different HCU device, there was 100% correlation in diagnosing pericardial effusions and 93% correlation with decreased global LV function. One patient even had a pericardiocentesis performed under portable ultrasound guidance.[5] These studies show that portable ultrasound has results comparable with standard echocardiography and can be used as a rapid diagnostic tool in adult inpatient and outpatient settings.

Because of the technologic limitations of the initial portable devices, their use in the pediatric population was restricted. With the introduction of higher frequency imaging, Li et al[6] used portable echocardiography in the evaluation of known congenital heart disease. With pediatric cardiologists using the Sonoheart system (Sonosite Inc, Bothell, Wash) with a 4- to 7-MHz, miniaturized, curved,

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linear-array transducer, the authors showed that the portable system diagnosed 91% of the overall potential findings. The HCU missed only 3% of the structural disease and 6% of the valvular disease. Thus, with a higher frequency array, even congenital heart disease can be successfully imaged with HCU devices.

The expanding use of these machines, especially by noncardiologists, is developing quickly. Critical care and emergency department (ED) physicians are becoming increasingly skilled in using ultrasound as a diagnostic and therapeutic aid. The type and amount of training for noncardiologists is an important consideration in the use of HCU devices. We hypothesized that noncardiology critical care physicians could be trained to perform limited portable echocardiography to diagnose pericardial effusions, poor cardiac function, and LV enlargement in pediatric patients who were critically ill.

METHODS

All patients admitted to the pediatric intensive care department and the ED were eligible for this study. Critical care fellows and attending physicians completed 1 hour of focused instruction on the physical basis of ultrasound, applications, device configuration, and standard echocardiographic views (parasternal long, parasternal short, apical). The physicians used only 2-dimensional (2D) imaging and adjusted depth and gain. They also used the caliper function to make measurements. The physicians performed 2 hours of practical echocardiography training at the bedside under the supervision of a cardiologist. The physicians imaged with an ultrasound system (Optigo, Philips Medical Systems) that uses a 2.5-MHz phased-array transducer with a footprint size of 2.5 cm. The study was approved by our institutional review board. All patients or their parents gave informed written consent to participate in the study.

Critical care physicians selected patients based on an initial assessment that included a physical examination and any laboratory work or radiographs that were clinically indicated. A limited bedside echocardiogram using the Optigo device (Philips Medical Systems) was completed in either the pediatric intensive care department or the ED. The study included 3 views: parasternal long, parasternal short, and apical. Results were reported as: (1) effusion–none, small, or large; (2) function–normal, mildly decreased, or severely decreased; (3) qualitative LV chamber size–normal or enlarged. When possible, the physician also measured the LV internal diameter during diastole using the parasternal short axis. A digital static image of each view was recorded onto a memory card for comparison with the standard echocardiographic images. Within 1 hour after the portable study, a cardiologist or sonographer performed a limited or complete standard echocardiogram using a Sonos 5500 device (Philips Medical Systems). The results of the standard echocardiogram, which were interpreted by a cardiologist blinded to the results of the portable study, were then compared with the critical care physician's interpretation recorded on a report form. Interventions were made only after the standard echocardiogram was officially read.

To determine that the results were not a result of chance, κ statistics were performed to evaluate agreement between HCU device and standard echocardiography diagnoses. For the measurement of LV end-diastolic diameter, a paired t test analysis compared the means of all the measurements from each of the two different modalities. Significance was defined by a P value $< .05$.

RESULTS

In all, 23 patients (13 male and 10 female) were enrolled in the study during an 18-month period. The average age was 7.5 years with an age range from 3 months to 20 years. In all, 15 studies were completed in the pediatric intensive care department and 8 in the ED. The most common indication for a portable echocardiogram was a suggested pericardial effusion based on cardiomegaly on chest radiograph (n = 14). Other indications for a pericardial effusion included prior diagnosis of pericarditis, possible rejection in a cardiac transplant, and chest pain after central line placement. Suggested ventricular dysfunction was an indication in 9 patients based on hemodynamic instability, tachycardia, and electrocardiographic changes (Table 1).

The presence or absence of pericardial effusions were correctly diagnosed in 21 of 23 patients (91%) ($\kappa = 0.62$), including a large effusion that required pericardiocentesis (Figure 1). In case 8, a small effusion was missed using portable echocardiography. This effusion was related to postpericardiotomy syndrome and did not require any intervention. In case 11, the critical care physician diagnosed a small effusion that was not present on the standard echocardiogram.

Ventricular size was correctly determined in 22 of 23 patients (96%) ($\kappa = 0.83$). Critical care physicians diagnosed LV hypertrophy (case 9) (Figure 2) and a mildly enlarged single ventricle (case 23). Case 21 was diagnosed with normal LV size by portable echocardiography, but standard echocardiography displayed a moderately dilated LV consistent with a cardiomyopathy (Figure 3).

In 13 of the cases, the critical care physicians measured the LV end-diastolic dimension in the parasternal short axis (Figure 4). These measurements are displayed in Table 2. The measurements were not taken until later in the study period to allow time for the physicians to familiarize themselves with the machine. Overall, there was no significant difference between the portable mea-

Table 1 Patient demographics and results of portable and standard echocardiography

No.	Age (y)	Sex	Site	Diagnosis/indication	PE findings	Laboratory results
1	14	M	PICU	Status post repair of subaortic stenosis	Normal	Cardiomegaly, decreased voltages on ECG
2	11	M	PICU	Cardiomyopathy with respiratory distress	Inspiratory crackles	Cardiomegaly
3	0.5	M	PICU	Hemodynamic instability	Tachycardia, poor pulses	None
4	10	F	PICU	Chronic liver disease	Tachypnea	Cardiomegaly
5	15	M	ED	Hemodynamic instability	Bradycardia, hypothermia	Sinus bradycardia
6	6	M	PICU	Hemodynamic instability	Tachycardia, poor pulses	S-T segment elevation
7	16	M	PICU	Status post cardiac arrest	Tachycardia	S-T segment depression
8	0.5	M	PICU	Status post transitional atrioventricular septal defect repair	Fever, irritability	Cardiomegaly
9	20	F	ED	Status post cardiac transplantation, chest pain	Decreased heart sounds, swollen extremity	Decreased voltages on ECG
10	14	F	PICU	Hx of metastatic renal carcinoma, shortness of breath	Tachycardia, decreased heart sounds	Cardiomegaly
11	8	F	PICU	Renal failure status post central line placement, chest pain	Jugular venous distension	None
12	0.8	F	ED	Bronchiolitis, respiratory distress	Tachycardia	Cardiomegaly
13	12	F	ED	Syncope	Orthostatic Irregular heart rate	WPW PVCs
14	16	F	PICU	Retropharyngeal abscess with mediastinitis	Tachycardia	Wide mediastinum on CXR, CT suggestive of pericardial fluid
15	17	M	ED	Chest pain, previous diagnosis of pericarditis	Reproducible chest wall pain	Normal ECG
16	5	M	PICU	Head trauma, hemodynamic instability	Tachycardia	None
17	0.5	F	ED	Respiratory distress, Hx of ASD, PDA	Tachypnea, murmur	Cardiomegaly
18	0.25	M	ED	Viral symptoms	Tachycardia	Cardiomegaly
19	1.2	M	PICU	Hemodynamic instability	Tachycardia, poor pulses	Cardiomegaly
20	1	M	PICU	Head trauma, hemodynamic instability	Tachycardia, poor pulses	None
21	0.8	F	PICU	Tachypnea, hemodynamic instability	Tachycardia, poor pulses	Cardiomegaly
22	1.2	F	PICU	Respiratory failure secondary to bronchiolitis	Bradycardia	None
23	2	M	ED	Tricuspid atresia status post fontan procedure, shortness of breath	Decreased breath sounds at bases	Normal CXR

ASD, Atrial septal defect; *CT,* computed tomography; *CXR,* chest roentgenogram; *ECG,* electrocardiogram; *ED,* emergency department; *F,* female; *Hx,* history; *LV,* left ventricle; *LVH,* LV hypertrophy; *M,* male; *PDA,* patent ductus arteriosus; *PE,* physical examination; *PICU,* pediatric intensive care unit department; *PVC,* premature ventricular contraction; *RV,* right ventricle; *ULN,* upper limit of normal; *WPW,* Wolf-Parkinson-White syndrome.

surements and the standard studies (P = .06). However, two measurements appear to be made at end systole. In case 9, the portable end-diastolic measurement was 2.7 cm and the end-systolic

Table 1 Continued

Portable diagnosis	Standard echocardiogram diagnosis
No effusion, normal LV size, slightly decreased function	No effusion, normal LV size, slightly decreased function
No effusion, enlarged LV size, severely decreased function	No effusion, mildly dilated LV, severe posterior wall hypertrophy, moderate septal wall hypertrophy, moderately decreased function
No effusion, normal LV size, normal function	No effusion, normal LV size, normal function
Small effusion, normal LV size, mildly decreased function	Small effusion, normal LV size, mild hypertrophy, normal systolic function
No effusion, normal LV size, mildly decreased function	No effusion, normal LV size, normal function
No effusion, normal LV size, mildly decreased function	No effusion, normal LV size, mildly decreased function
No effusion, normal LV size, mildly decreased function	No effusion, normal LV size, thickness ULN, mildly decreased function
No effusion, normal LV size, normal function	Small effusion, normal LV size, normal function
No effusion, hypertrophic LV, mildly decreased function	No effusion, asymmetric LVH, mildly decreased function
Large effusion, normal LV size, normal function	Large effusion, normal LV size, mild RV collapse, normal function
Small effusion, normal LV size, normal function	No effusion, normal LV size, concentric LVH, normal function
No effusion, normal LV size, normal function	No effusion, normal LV size, normal function
No effusion, normal LV size, normal function	No effusion, LV size ULN, normal function
No effusion, normal LV size, normal function	No effusion, normal LV size, normal function, small right pleural effusion
No effusion, normal LV size, normal function	No effusion, normal LV size, normal function
No effusion, normal LV size, normal function	No effusion, normal LV size, hyperdynamic function
No effusion, normal LV size, normal function	No effusion, normal LV size, normal function, moderate ASD, small PDA, flattened septum consistent with RV pressure overload
No effusion, normal LV size, normal function	No effusion, normal LV size, normal function
No effusion, normal LV size, mildly decreased function	No effusion, normal LV size, normal function, moderate right pleural effusion
No effusion, normal LV size, severely decreased LV function	No effusion, normal LV size, severely decreased LV function
No effusion, normal LV size, normal function	No effusion, moderately dilated LV, moderately decreased LV function, moderate MV insufficiency
No effusion, normal LV size, normal function	No effusion, normal LV size, normal function
No effusion, mildly increased LV size, normal function	No effusion, mildly increased LV size, normal function

measurement by standard echocardiography was 2.7 cm. Case 19 had an end-diastolic measurement of 1.6 cm and an end-systolic measurement of 1.8 cm. This error is likely related to the lack of an electrocardiographic tracing on the portable studies.

Systolic function was accurately assessed in 22 of 23 patients (96%) ($\kappa = 0.89$). A clinically significant

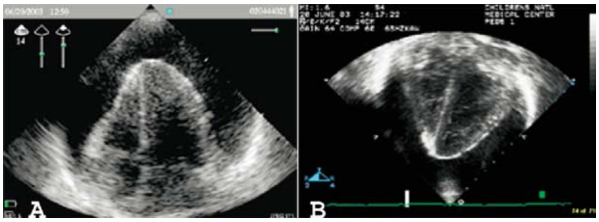

Figure 1 Apical 4-chamber image of significant pericardial effusion. Hand-carried cardiac ultrasound device (**A**) and standard echocardiographic (**B**) images.

Figure 2 Parasternal long-axis image of left ventricular hypertrophy for patient posttransplant. Hand-carried cardiac ultrasound device (**A**) and standard echocardiographic (**B**) images.

Figure 3 Apical 4-chamber view of dilated left ventricle secondary to idiopathic cardiomyopathy. Hand-carried cardiac ultrasound device (**A**) and standard echocardiographic (**B**) images.

Figure 4 Parasternal short-axis images at end diastole with measurement calipers showing. Hand-carried cardiac ultrasound device (**A**) and standard echocardiographic (**B**) images. Measured left ventricular end-diastolic dimensions are 4.6 cm (**A**) and 4.5 mm (**B**).

Table 2 Measurements of left ventricular end-diastolic dimension in the parasternal short axis by portable and standard echocardiography

Case No.	Portable (cm)	Standard (cm)
9	2.7	3.8
10	3.1	3.2
11	2.4	2.7
12	4.0	2.7
13	4.6	5.5
14	4.6	4.8
15	4.1	4.7
16	2.5	3.1
17	1.8	2.0
18	1.6	2.0
19	1.6	2.9
21	2.4	4.1

missed diagnosis occurred in one patient (case 21) where the critical care physician interpreted the portable study as normal systolic function. This patient, the same in whom the ventricular enlargement was missed, had moderately decreased function and inotropic support was started immediately. The critical care physicians correctly identified normal function in 12 of 15 patients, calling 3 patients mildly decreased. No interventions were planned based on these diagnoses. Four patients were correctly diagnosed as having mildly decreased function. One patient with severe head trauma was correctly diagnosed with severely decreased ventricular function by portable echocardiography (case 20). In other cases, severely decreased function was read as moderately decreased and normal function was thought to be hyperdynamic after the standard echocardiogram was read by a cardiologist.

DISCUSSION

We studied the use of HCU device echocardiography by critical care physicians in an acute setting. These results show that with limited training, these physicians are capable of diagnosing significant pericardial effusions, decreased LV systolic function, and LV enlargement. Portable echocardiography can be used by noncardiologists with limited training in an acute setting, but in a defined limited manner.

In 2001, Goodkin et al[7] performed a study of HCU use in patients who were critically ill. Of the 84 questions that the HCU was technically capable of evaluating, the device answered only 72 (86%). Additionally, the standard echocardiogram found 17 clinically significant diagnoses that the HCU did not (or could not) find. The HCU missed a significant finding in 36 patients who were critically ill (45%).[7] In another study, medical students underwent a 2-week tutorial and performed limited echocardiography in the ED and intensive care department. In the acute setting, the limited echocardiography was technically diagnostic in 96% of the cases and the medical students interpreted the echocardiographic findings correctly in 80% of the cases.[8]

Our study limited the HCU use to 2D echocardiography only. By limiting the clinical questions to only 3 per study (effusion, function, size), our results were improved compared with those of Goodkin et al.[7] We found 91% agreement in relation to effusions. There were differences in LV function because of the subjective nature of the evaluation, although only one missed case was clinically significant. This case demonstrates the significance of potential missed diagnoses. The patient had a cardiomyopathy that required the immediate initiation of inotropic support. Had this intervention been delayed further because of an incorrectly interpreted portable echocardiogram, the patient may have had a worse outcome. This case supports the opinion that all portable echocardiograms by noncardiologist must be repeated by a cardiologist within hours to screen for missed diagnoses.

As the applications of the HCU devices broaden, the question of appropriate training becomes a major issue, especially in regard to noncardiologists. Kimura et al[9] looked at the usefulness of a HCU device for bedside assessment of LV function. Internal medicine residents underwent a 1-hour training session that focused on the parasternal long-axis view with videotapes of normal and abnormal LV function. The use of the bedside echocardiography with the Optigo HCU (Philips Medical Systems) improved the assessment of LV function in 10 of 13 residents. DeCara et al[10] also trained internal medicine residents in portable echocardiography with a structured 20-hour program. The resident examinations had similar sensitivity (63% vs 65%) and specificity (92%-95%) compared with standard echocardiography. However, for clinically significant findings that altered patient care, sensitivity was significantly higher for the standard echocardiograms (88% vs 80%).[10] Alexander et al[11] also looked at training internal medicine residents with the HCU Optigo device (Philips Medical Systems). The residents participated in a 3-hour training program using 2D and color flow Doppler in the same 3 imaging planes used in this study. Agreement (κ) between the medical residents' portable examinations and standard echocardiography was 75% for LV dysfunction, 79% for mitral regurgitation, 92% for aortic valve disease, and 98% for moderate or large pericardial effusions.[11] This are similar results to our study and shows that HCU devices can be used in a limited and directed manner.

Our training protocol was very similar to the one used by Alexander et al.[11] This is less extensive than the training in the study by DeCara et al[10]; however, that study used HCU devices for more comprehensive examinations. Findings that were missed by residents in their study included an intracardiac thrombus and regional wall abnormalities.[10] We focused the clinical questions in our study, as did Alexander et al,[11] to reflect the limited nature of the training. This produced better results regarding LV size and function, and pericardial effusions.

There were limitations in our study related to the HCU device, imaging conditions, and patient population. The HCU devices have very small screens that can limit appreciation of more subtle findings and the Optigo device (Philips Medical Systems) did not have an electrocardiogram tracing to better identify ventricular diastole. Imaging in the intensive care setting has inherent limitations such as poor imaging windows, artificial ventilation, and ambient lighting. Pediatric patients pose other difficulties such as small intercostal spaces, decreased scanning depths, and faster heart rates. The probe used in this study was a 2.5-MHz probe with a footprint of 2.5 cm, whereas the previous pediatric study used a 4- to 7-MHz probe with a smaller footprint.[6]

Another limitation to this study is that the cardiologist did not perform a comparable portable echocardiogram. This method was chosen because the tests were in an acute setting and the standard echocardiogram needed to be performed in a timely manner so clinical decisions could be made. The portable studies were also limited to 2D imaging and to 3 clinical questions. We did not train the critical care physicians to use color Doppler, nor did we assess their ability to diagnose other pertinent echocardiographic findings.

Improving technology has lead to increasing use of HCU by cardiologists and noncardiologists alike. We have shown that pediatric critical care fellows and attending physicians can be trained to use HCU devices to answer questions regarding ventricular size and function, and pericardial effusions in pediatric patients who are critically ill. The time saved by a quick bedside evaluation may improve patient outcomes. However, we are cautious in the use of HCU devices beyond this capacity without further training and a cardiologist repeating the study soon thereafter. We speculate that much more elaborate training would be required, and become standardized in a systematic fashion, to assure the ability of noncardiologists to perform complete portable pediatric echocardiographic studies in the critical care setting.[12]

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