Point-of-Care Echocardiography by Pediatric Emergency Physicians

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Objective: Currently, pediatric emergency medicine (PEM) physicians have limited data on point-of-care echocardiography (POCE). Our goals were to (1) determine the overall accuracy of POCE by PEMs in assessing left ventricular (LV) systolic function visually, presence or absence of pericardial effusion, and cardiac preload by estimating inferior vena cava (IVC) collapsibility, in acutely ill children in the pediatric emergency department; and (2) assess interobserver agreement between the PEM physician and pediatric cardiologist.

Methods: This is a prospective, observational study conducted in an urban, tertiary pediatric facility with an annual census of 67,000 emergency department visits. Patients between the ages of 0 and 18 years meeting 1 or more of the following inclusion criteria were recruited: (1) cardiopulmonary arrest, (2) fluid refractory shock requiring vasoactive infusions, (3) undifferentiated cardiomegaly on chest radiography, and (4) receiving emergent formal echocardiography. All eligible patients underwent POCE by 1 of 2 trained PEM physicians. Dynamic video clips were recorded and reviewed by a pediatric cardiologist who was unaware of the clinical condition of the study patients.

Results: For a period of 18 months, we recruited 70 patients. Diminished LV function was noted in 17, pericardial effusion in 16, and abnormal IVC collapsibility in 35 patients. The κ statistics of agreement between the PEM and the cardiologist for detection of LV function, IVC collapsibility, and effusion were 0.87 (95% confidence interval [CI], 0.73–1.00), 0.73 (95% CI, 0.59–0.88), and 0.77 (95% CI, 0.58–0.95), respectively. The overall sensitivity and specificity of POCE compared with a formal echocardiogram was 95% (95% CI, 82%–99%) and 83% (95% CI, 64%–93%), respectively.

Conclusions: With goal-directed training, PEM physicians may be able to perform POCE and accurately assess for significant LV systolic dysfunction, vascular filling, and the presence of pericardial effusion. The model may be expanded to train physicians to use POCE.

Key Words: point-of-care, echocardiography, cardiac

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Optimizing cardiac function and intravascular volume is an important part of managing acutely ill or injured patients in the pediatric emergency department (PED). Traditionally, this is accomplished at the bedside with the aid of clinical parameters and, less frequently, by placing a central venous catheter. Physical examination has been shown to be unreliable in differentiating hypovolemia from cardiogenic causes of hypotension.[1,2] Clinicians have sought other, less invasive methods to obtain accurate hemodynamic information in the critically ill child. Transthoracic echocardiography (TTE) is an objective, noninvasive method of assessing vascular filling and ventricular function. Transthoracic echocardiography has been shown to accurately detect preload and cardiac output when compared with conventional invasive hemodynamic monitoring techniques.[3]

Although several publications cite TTE as a useful bedside monitoring tool in the hands of noncardiologists, few researchers have discussed training requirements, components, and accuracy of a goal-directed TTE in PED patients.[4–12] Two small studies of a convenience sample of pediatric patients admitted to the critical care unit suggest that, with appropriate instruction by a pediatric cardiologist, pediatric emergency medicine (PEM) and critical care physicians can perform goal-directed TTE accurately.[13,14] To date, data on PED subjects are limited to small case series.[15–18]

The purpose of our study was to evaluate (1) interobserver agreement between the PEM physician with goal-directed training in point-of-care echocardiography (POCE) and a pediatric cardiologist and (2) the test characteristics of POCE by PEMs in acutely ill patients when compared to a formal echocardiogram. The components of this POCE examination included assessing (*a*) left ventricular (LV) function visually on the parasternal long-axis and short-axis view at the level of the papillary muscle, (*b*) presence or absence of pericardial effusion, and (*c*) cardiac preload by estimating inferior vena cava (IVC) collapsibility during normal respiration.

METHODS

We performed a prospective, observational study at a freestanding, tertiary-level, pediatric facility that serves as a comprehensive, regional referral center with an annual ED census of 67,000 patient visits. A convenience sample of patients between the ages of 0 and 18 years who presented to the ED or intensive care unit (ICU) between August 2007 and January 2009 and who met our inclusion criteria were enrolled. The study was approved by our institutional review board. Recruitment of patients depended on the availability of the PEM investigators.

Inclusion criteria included 1 or more of the following: (1) if the treating physician deemed that care warranted emergent pediatric cardiology consultation and the patient underwent a formal echocardiography as part of the consult; (2) fluid-refractory shock on vasoactive infusions initiated by the treating clinician; (3) new-onset undifferentiated cardiomegaly on chest radiography interpreted by the treating clinician; and (4) cardiorespiratory arrest. Children were excluded if they were receiving extracorporeal membranous oxygenation or had a known, preexisting, congenital cardiac defect with single-ventricle physiology. We excluded patients with single ventricle because this would require additional training and expertise to evaluate ventricular function in the face of altered anatomy. Besides, patients with Fontan physiology have abnormal IVC collapsibility, rendering assessment of this parameter inaccurate.

After enrollment of patient, 1 of 2 trained PEM physicians who were experienced in ultrasonography and had undergone focused training performed the POCE examination. Both the investigators have performed 50 or more bedside focused abdominal sonography in trauma examinations. The goal-directed

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TABLE 1. Components of the POCE Examination

Clinical Parameter	Assessment	View(s)	Measurement
Beat	Contractility	Parasternal long axis, parasternal short axis	Qualitative estimate of LV function (hypocontractile or normal)
Effusion	Pericardial effusion	Parasternal long axis, parasternal short axis	Present or absent
Preload	Right ventricular filling	Subcostal	IVC collapsibility (normal, increased, or decreased)

training module was composed of a cumulative of 2 hours of reading material and didactic instruction, 5 proctored examinations with a pediatric echocardiography technician, and 10 POCE examinations performed on healthy volunteers and critiqued by the pediatric cardiologist.

Point-of-care echocardiography consisted of a qualitative assessment of LV function (normal or diminished) and the presence or absence of pericardial effusion in the parasternal long-axis and short-axis view. Further, a visual assessment of IVC collapsibility (normal, increased, or decreased) was obtained in the subcostal view in the transverse and sagittal planes just cephalad to the confluence of the hepatic vein. The respiratory variation in IVC diameter was used as a surrogate measure of right ventricular filling and preload. A 50% decrease or more in IVC diameter during quiet inspiration was considered normal. Complete collapse of the IVC or less than 50% decrease in diameter during inspiration was considered abnormal (Table 1).[7]

The POCE was performed before the formal study in all cases. Dynamic video clips of the 3 components of the POCE, without any patient identifiers, were saved for independent, future review by the pediatric cardiologist who was unaware of the clinical status of the patient. On the basis of a prior understanding, all POCE studies were saved on a portable memory device and submitted by the primary investigator in groups of 10 to 15 video files, 4 to 6 weeks after the images were acquired. The collaborating pediatric cardiologist investigator is a subspecialist with certification in pediatric echocardiography, who also serves as director of our pediatric echocardiography laboratory. He reads more than 2500 echocardiograms a year and oversees quality assurance of studies performed by the echocardiography technicians. All studies were performed using a SonoSite Titan (Bothell, Wash) machine with an 8-5 MHz 11-mm broadband-phased array probe.

We measured 2 outcomes: (1) overall accuracy of POCE when compared to a formal echocardiogram and (2) interobserver agreement between the PEM and cardiologist for the 3 components of POCE (LV function, pericardial effusions, and IVC collapsibility).

Statistics

From prior data, comparing the ED physician's estimate of ejection fraction with that of the cardiologist yielded a correlation coefficient R of 0.86.[8] A sample size of 67 patients was determined assuming an acceptable lower limit of $R = 0.6$, $\alpha = 0.05$, and power = 80%. A statistical software (version 8.0; SAS Institute, Inc, Cary, NC) was used for the analysis. The κ statistics was used to characterize the agreement between PEM physician and cardiologist. The accuracy of POCE when compared to the formal echocardiogram was described by sensitivity and specificity. Confidence intervals were calculated using the Wilson score.[19] $P < 0.05$ was considered statistically significant.

RESULTS

During an 18-month period, 72 patients who met our inclusion criteria were approached for consent. Two families declined participation. One of these patients who had presented in cardiac arrest had parasternal long-axis view images obtained during resuscitation, but the family subsequently declined to participate. Seventy patients were enrolled after informed consent. When applicable, consent was also obtained from the patient. Three examinations were excluded for assessment of IVC collapsibility because the images were deemed to be of inferior quality by the reviewing pediatric cardiologist.

The mean age of the subjects was 7 years with a range of 17 hours old to 17 years. Fifty-seven percent (40/70) were males. The majority (69/70) of subjects were recruited in the ED. Seventy-four percent (52/70) of the patients were admitted; 50% (26/52) were admitted to our ICU. One patient died in the ED. Ninety-one percent (64/70) of the study participants had a formal echocardiography performed while in the ED or ICU. The POCE was performed before the formal study in all cases. Fifty-six percent (39/70) had echocardiography performed in the ED in conjunction with a cardiology consultation. Three percent (2/70) of the patients were included as a result of cardiopulmonary arrest. Thirty-six percent (25/70) of the patients were included because of suspicion of cardiomegaly based on the chest radiograph. Six percent (4/70) of POCE examinations

TABLE 2. Discharge Diagnoses

Diagnosis	No. Patients
Congenital cardiac defects (atrial septal defect/ventricular septal defect/patent foramen ovale/coarctation of aorta/atrioventricular canal)	16
Pneumonia/upper respiratory infection	9
Myocarditis	7
Shock	6
Chest pain	4
Pericardial effusion	4
Cardiac contusion	3
Supraventricular tachycardia	3
Syncope	3
Tachycardia	3
Kawasaki disease	2
Cardiopulmonary arrest	2
Pulmonary hypertension	2
Acute bronchospasm	2
Cardiomegaly	2
Pleural effusion	2
Cardiomyopathy	1
Dextrocardia	1
Endocarditis	1
Hypertension	1
Acute life-threatening event	1
Central apnea	1
Prolonged neonatal transitioning	1

TABLE 3. Interobserver Agreement Between the Cardiologist and the PEM Physician

	% (n)	κ (95% CI)
Decreased LV function	24 (17/70)	0.87 (0.73–1.00)
Pericardial effusion	23 (16/70)	0.77 (0.58–0.95)
Abnormal IVC collapsibility	50 (35/67)	0.73 (0.59–0.88)

were for shock requiring inotropic support. The final diagnosis of the patients recruited is shown in Table 2. Ten percent (7/70) of the patients were intubated before image acquisition.

There was good to excellent agreement between the PEM investigators and cardiologist for all components of POCE (Table 3). The performance characteristics of POCE when compared with formal echocardiography revealed a sensitivity of 95% (95% confidence interval [CI], 82%–99%) and specificity of 83% (95% CI, 64%–93%) for detecting at least 1 of the following: significant LV dysfunction, pericardial effusion, or abnormal IVC collapsibility.

DISCUSSION

Our study demonstrates that POCE, a noninvasive bedside examination to assess hemodynamic variables, is straightforward and provides an accurate assessment of LV function, right ventricular filling (preload), and presence or absence of a pericardial effusion. We have also shown that PEM physicians experienced in the fundamentals of ultrasonography can perform a focused bedside echocardiographic examination accurately. We are not aware of any prior PED data describing the role of POCE by PEM physicians.

The findings of our study must be interpreted within the context of its limitations, however. Our study population consisted of a relatively small convenience sample of acutely ill children. Although we were able to assess most of our patients by using focused echocardiography, the role of POCE needs to be elucidated in a larger cohort.

The examination was performed by 1 of 2 trained PEM physicians who were experienced in using bedside ultrasonography. In the first phase of this endeavor, we established the feasibility of the instruction module, when offered to a small group of PEM physicians. Inclusion of a larger, diverse group of PEM practitioners with varying levels of motivation and interest was not practical at the outset. Hence, the results of our study cannot be generalized to other settings, where knowledge, training, and resources may vary.

A potential source of bias was that the formal study might have influenced the point-of-care study that was performed by the PEM physician who was aware of the clinical status of the patient. Because POCE was performed before the formal study and the reference standard was the independent interpretation by a single pediatric cardiologist, who was blind to the clinical condition of the patients, we believe that this bias was minimized. It is usual practice at our institution for the pediatric cardiology fellow to respond to all consults on patients in the ED. The case is then discussed with 1 of the 6 attending cardiologists, who is on call that day. Hence, although it is possible that this reviewer may have been on clinical service when some of the patients were enrolled, it is unlikely that he was aware of the clinical status of the patient at the time of the review, which was conducted 4 to 6 weeks after POCE was recorded.

Three of the POCE examinations were deemed to be of inferior quality for assessing IVC parameters. If we excluded these cases from our analysis of interobserver agreement, the κ statistic decreased from 0.73 to 0.68 (95% CI, 0.52–0.83). In addition, 10% of our patients were intubated and were receiving positive pressure ventilation, which may have rendered the echocardiographic assessments of IVC dynamics less accurate. To address this concern, we conducted a worst-case analysis in which we excluded these 7 patients. The revised κ statistic for interobserver agreement was 0.75 (95% CI, 0.61–0.90).

Although we did not specifically conduct a subgroup analysis of patients with atrioventricular septal defects, our anecdotal experience during the study suggests that correlation of qualitative interpretation of LV function, the parameter most likely to be influenced by abnormal septal motion, was not affected by the presence of a septal defect.

Another limitation of our study is that we were unable to provide a precise count and details of patients who met inclusion criteria but were not enrolled in the study. As an estimate, approximately 350 echocardiographic studies are performed at our institution in conjunction with ED consultations during an 18-month period. We also did not measure interrater variability or time to complete each component. Such an analysis would require several repeated examinations by all investigators on a patient whose hemodynamic parameters are known and constant. Further, it is possible that the results of the formal echocardiogram may have been influenced by patients having received treatment in the ED after the POCE study but before the formal study. If this were significant, it would have decreased the performance characteristics of POCE when compared with formal echocardiography.

We used cardiologist-derived data as the criterion standard. These data may not provide an accurate assessment of LV preload and stroke volume. On the contrary, it is possible that echocardiographic data may actually be the criterion standard against which other hemodynamic measures should be tested (and perhaps our data were more accurate than reported).

We elected to use visual estimate of IVC collapsibility instead of actual measurements adjusted for body surface area because analysis of IVC measurements is already limited by the lack of normative data in pediatric patients. Preliminary data from studies conducted in adult patients suggest that the ratio of IVC to aortic dimensions may be a better metric to assess hypovolemia.[20,21] However, data on pediatric patients on the utility of the IVC/aorta index, which is based on the assumption that the aortic diameter is relatively unchanged in the face of hypovolemia, are limited. Although this may be true in older adults with less compliant vessels, vasoconstriction is an important compensatory mechanism in pediatric patients. Computed tomography has shown that the diameter of the pediatric aorta is sensitive to changes in intravascular volume.[22]

Last, usefulness of the information generated from any screening tool is highly related to its ability to alter outcomes. We did not measure the impact of POCE on clinical decision making.

In order for echocardiography to become useful in the PED, image acquisition should be relatively easy and the data should be accurate and available in real time. Physicians must also have the ability to archive dynamic, real-time images for quality assurance and review. Although it is not feasible to rely on cardiology consultants being available around the clock, it is also impractical to train PEMs in the advanced techniques of conventional echocardiography. A limited, goal-directed examination should provide the information needed to aid clinical decision making including the need to proceed with additional testing. This outcome is similar to what the focused abdominal sonography in trauma has accomplished in diagnosing hemoperitoneum or hemopericardium in the setting of blunt torso trauma.[23]

After didactic instruction and proctoring by an experienced echocardiography provider, the PEM investigators became reasonably facile and were able to successfully perform POCE in acutely ill patients in the PED. Other authors have also proposed a curriculum designed to teach focused echocardiography and that entails an 8- to 10-hour program that would include instruction on the various techniques of echocardiography and supervised hands-on training.

Several previous reports have compared data from focused echocardiography performed by an intensivist or emergency physician to data from invasive hemodynamic procedures, formal echocardiography, expert opinion, or interpretation by a cardiologist.[4,7,8,13,14,21,22,24,25] Each of these studies demonstrated that the data obtained were comparable with their reference standard.

An algorithm has been previously suggested, which includes focused echocardiographic evaluation in resuscitation and a structured process of an advanced life support–conformed TTE protocol to diagnose suspected myocardial failure, pericardial tamponade, or hypovolemia.[26] However, for POCE to be useful in the PED setting, clinicians must develop and retain competency in image acquisition and interpretation.

In summary, focused bedside echocardiography can be learned by PEMs and can provide valuable hemodynamic information in acutely ill patients. Future study of the ability of POCE-guided resuscitation of critically ill patients and its impact on patient care outcomes is warranted.

CONCLUSIONS

With goal-directed training, PEMs may be able to perform POCE and accurately assess for significant LV systolic dysfunction, right ventricular filling, and the presence or absence of pericardial effusion. The model may be expanded to train other physicians in using POCE.

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