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Bedside Limited Echocardiography by the Emergency Physician Is Accurate During Evaluation of the Critically Ill Patient

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Pediatrics 2004;114;e667; originally published online November 15, 2004;
DOI: 10.1542/peds.2004-0881

Bedside Limited Echocardiography by the Emergency Physician Is Accurate During Evaluation of the Critically Ill Patient

Jay Pershad, MD*‡; Sharon Myers‡; Cindy Plouman‡; Cindy Rosson‡; Krista Elam‡; Jim Wan, PhD§; and Thomas Chin, MD, FACC, FACS‖

ABSTRACT. ***Objective.*** **Echocardiography can be a rapid, noninvasive, objective tool in the assessment of ventricular function and preload during resuscitation of a critically ill or injured child. We sought to determine the accuracy of bedside limited echocardiography by the emergency physician (BLEEP) in estimation of (1) left ventricular function (LVF) and (2) inferior vena cava (IVC) volume, as an indirect measure of preload.**

Methods. **We conducted a prospective observational study of a convenience sample of patients who were admitted to our intensive care unit. All patients underwent BLEEP followed by an independent formal echocardiogram by an experienced pediatric echocardiography provider (PEP). IVC volume was assessed by measurement of the maximal diameter of the IVC. LVF was determined by calculating shortening fraction (SF) using M-mode measurements on the parasternal short-axis view at the level of the papillary muscle. An independent blinded pediatric cardiologist reviewed all images for accuracy and quality. Estimates of SF obtained on the BLEEP examination were compared with those obtained by the PEP.**

Results. **Thirty-one patients were enrolled. The mean age was 5.1 years (range: 23 days–16 years); 48.4% (15 of 31) were girls; 58.1% (18 of 31) were on mechanical ventilatory support at the time of their study. There was good agreement between the emergency physician (EP) and the PEP for estimation of SF ($r = 0.78$). The mean difference in the estimate of SF between the providers was 4.4% (95% confidence interval: 1.6%–7.2%). This difference in estimate of SF was statistically significant. Similarly, there was good agreement between the EP and the PEP for estimation of IVC volume ($r = 0.8$). The mean difference in the estimate of IVC diameter by the PEP and the EP was 0.068 mm (95% confidence interval: −0.16 to 0.025 mm). This difference was not statistically significant.**

Conclusions. **Our study suggests that PEP sonographers are capable of obtaining images that permit accurate assessment of LVF and IVC volume. BLEEP can be performed with focused training and oversight by a pediatric cardiologist.** ***Pediatrics*** **2004;114:e667–e671. URL: www.pediatrics.org/cgi/doi/10.1542/peds.2004-0881;** ***cardiovascular, emergency medicine.***

ABBREVIATIONS. ED, emergency department; BLEEP, bedside limited echocardiography by the emergency physician; CVP, central venous pressure; EP, emergency physician; FAST, focused abdominal sonography in trauma; US, ultrasound; IVC, inferior vena cava; RA, right atrium; LVF, left ventricular function; PEP, pediatric echocardiography provider; SF, shortening fraction; PE, pericardial effusion.

From the *Division of Emergency Medicine, Department of Pediatrics, University of Tennessee Health Sciences Center, Memphis, Tennessee; ‡Le Bonheur Children's Medical Center, Memphis, Tennessee; §Department of Preventive Medicine, University of Tennessee Health Sciences Center, Memphis, Tennessee; and ‖Division of Cardiology, Department of Pediatrics, University of Tennessee Health Sciences Center, Memphis, Tennessee.
Accepted for publication Aug 11, 2004.
doi:10.1542/peds.2004-0881
No conflict of interest declared.
Reprint requests to (J.P.) Le Bonheur Children's Medical Center, 50 N Dunlap St, Memphis, TN 38103. E-mail: jpershad@pediatricemergencyspecialists.com

Hypotension is observed in late decompensated shock. It occurs when compensatory mechanisms that maintain end-organ perfusion fail. Although shock can be broadly categorized into hypovolemic, cardiogenic, septic, or distributive, there is considerable overlap in clinical presentation and underlying pathophysiology.[1,2] Varying degrees of relative or absolute hypovolemia and myocardial dysfunction may exist in each category, particularly in sepsis.[3] Similarly, although hemorrhagic (hypovolemic) shock is most common in the severely traumatized patient, neurogenic shock (secondary to severe craniospinal injury), obstructive shock (from pericardial tamponade), or cardiogenic shock (secondary to myocardial contusion) may coexist in polytrauma.

Critically ill or injured patients are being cared for in the emergency department (ED) with increasing frequency. Furthermore, there has been a 152% increase in the number of patients with ED length of stay of >6 hours from 1988 to 1997.[4,5] This reality necessitates provision of critical care in the pediatric ED. In a recent study of management of pediatric-neonatal septic shock referred from community hospitals to a referral urban pediatric center, 91 patients were identified during a 9-year period.[6] In a database of severely injured children who presented to the ED at a level 1 pediatric trauma center, using initial base deficit as a marker of tissue hypoperfusion and shock, 117 patients were identified during a 6-year period.[7]

We are also an urban, tertiary-level regional pediatric referral center with an annual ED census of 80 000 visits. Most initial encounters of hemodynamically unstable patients mandate prompt goal-directed resuscitation. The exact cause and underlying pathophysiology of shock are not immediately evident in most clinical situations. We speculate that bedside limited echocardiography by the emergency physician (BLEEP) would be useful in 2 to 3 ED patient encounters per month of undifferentiated hypotension or shock.

Physical examination and chest radiography have been shown to be unreliable in differentiating hypovolemia from cardiogenic causes of hypotension.[8–13] Absolute or relative hypovolemia is frequently present in critically ill or injured pediatric patients. Conventional teaching recommends rapid fluid resuscitation up to 40 to 60 mL/kg as the initial management of undifferentiated shock while assessing for liver size and lung fields as evidence of vascular overfill. These recommendations can be viewed as guidelines only, because they do not incorporate an objective evaluation of central venous pressure (CVP). Additional therapy, including inotropic support, is recommended for continued impaired circulatory status and aimed at normalizing perfusion pressure.[14,15] The latter is contingent on establishing an invasive CVP monitor. Clinical practice parameters for hemodynamic support of pediatric and neonatal patients with septic shock also recommend echocardiogram-directed therapy.[16] Early reversal of the shock state with aggressive fluid resuscitation has been shown to have a positive impact on survival in pediatric and neonatal septic shock.[6,17,18] In a recent trial of adult patients, early goal-directed therapy aimed at maintaining normal CVPs in conjunction with adjustments in contractility and afterload provided significant benefit in outcome of adult patients with severe sepsis and septic shock.[19] Therefore, an immediate determination of diminished cardiac function, mechanical compromise of the heart, or hypovolemia in the hemodynamically unstable patient is important, and prompt action can be life saving.

Focused ultrasonography has emerged as an important, noninvasive, bedside diagnostic tool for emergency physicians (EPs) to facilitate early detection of potentially reversible and time-dependent conditions. Currently, the 2 primary indications for ED echocardiography are the diagnosis of pericardial tamponade and confirmation (or refutation) of pulseless electrical activity.[20] A single subcostal view to rule out cardiac tamponade is included in the focused abdominal sonography in trauma (FAST) protocol for assessment of blunt abdominal trauma by the Advanced Trauma Life Support course sponsored by the American College of Surgeons.[21] Doppler echocardiography has been recommended by the Pediatric Advanced Life Support guidelines of the American Heart Association to distinguish between "true" and "pseudo" pulseless electrical activity.[18] The presence of cardiac activity on ultrasound (US) may drive a concerted search for reversible causes. Bedside echocardiography can also play a valuable role in the pulseless patient as it can discriminate asystole from ventricular fibrillation. Identification of fibrillation would direct appropriate countershocks.[22] Previous studies have also demonstrated the utility of this technology for other, similar time-sensitive clinical conditions such as suspected hemoperitoneum, undifferentiated shock, and penetrating chest trauma.[9,23–31]

Echocardiography has been shown to detect accurately preload and cardiac output when compared with conventional invasive hemodynamic monitoring techniques.[32,33] The inferior vena cava (IVC) is an easily identified structure on the commonly performed FAST examination in the setting of blunt abdominal trauma.[23,26] By turning the transducer toward the right, on the subxiphoid view of the FAST, the IVC is visualized. Normal IVC size, extrapolated from adult data, is 9.2 + 2.4 mm/mt,[2] and it collapses by >50% during quiet inspiration.[34–37] Variations in the internal dimensions of the IVC may be detected on the M-mode echocardiogram in relation to cardiac and respiratory cycle. In nonobstructed states, these variations may be considered to be an expression of changes in patterns of IVC to right atrium (RA) flow. In the presence of increased right ventricular filling pressures as in heart failure or pericardial effusion, the IVC is enlarged with reduced respiratory variations. Assessing IVC dynamics may serve as a straightforward reproducible echocardiographic screen for assessing right ventricular filling and function.[36–38] It was with this background and evidence that we proposed that a point-of-care echocardiogram (or BLEEP) may serve as a rapid noninvasive tool in rapidly assessing myocardial function and CVP using IVC dynamics.

There currently are limited data addressing the role of EP-directed limited echocardiography in critically ill pediatric ED patients. Therefore, the purpose of this study was to determine whether EPs with US experience and goal-directed training in echocardiography could accurately ascertain myocardial contractility and preload status. Our primary hypothesis was that BLEEP could accurately assess (1) left ventricular function (LVF) and (2) IVC volume in the critically ill pediatric patient. IVC dimensions were used an indirect measure of right ventricular filling or preload.

METHODS

We conducted a prospective observational study of a convenience sample of 33 patients who were admitted to the intensive care unit of our urban tertiary pediatric center from January to March 2004. A single EP investigator performed all BLEEP examinations using a Sonosite Titan US machine with a variable frequency convex probe. All patients underwent an independent formal echocardiogram by an experienced pediatric echocardiography provider (PEP) up to 60 minutes from the BLEEP examination. A staff cardiologist interpreted all of the reports.

Informed consent was obtained from the caregivers before the examination. We excluded the following groups of patients: (1) those who had suboptimal access to their subxiphoid or parasternal region and (2) those who were deemed by their critical provider to be unsuitable because of interference with patient management.

IVC volume was assessed by measurement of the maximal diameter of the IVC in the anterior-posterior plane just caudad to the hepatic vein confluence on the subxiphoid transverse view. This site was chosen so as to avoid interference from right atrial motion. LVF was determined by calculating shortening fraction (SF) using M-mode measurements on the parasternal short-axis view at the level of the papillary muscle.[32] Normally it is >30%. The SF was ascertained from BLEEP using the formula SF = (EDD − ESD)/EDD, expressed as a percentage, where EDD is end diastolic dimension and ESD is end systolic dimension. An independent pediatric cardiologist, who was blinded to the patient and his or her underlying diagnosis, reviewed all images for accuracy and quality. The EP investigator underwent 3 hours of focused cardiac US training that included 5-proctored BLEEP examinations on unenrolled patients. In addition, the EP had successfully completed 8 continuing education hours of an American College of Emergency Physicians–approved focused transthoracic echocardiography course.

Estimates of SF obtained on the BLEEP examination were compared with those obtained by the PEP. Concordance or agreement between the EP and the PEP for the measurement of SF and IVC was determined using the Pearson correlation coefficient. $P < .05$ was considered statistically significant. Paired t test was used to compare the magnitude of the difference in measurement of the SF and IVC volume by the EP and the PEP. The proportion of images obtained by the EP (2-dimensional image, M mode and IVC) that were assessed to be of "unacceptable" quality by the cardiologist were determined. A comparison between the proportions of unacceptable images between the groups was calculated using the McNemar test.

Our null hypothesis was that there is no correlation between the estimate of LVF obtained by the EP and the cardiologist. A sample size of 29 was calculated for an α of .001 and a power of 90% using a correlation coefficient r of 0.71 from previous data.[39]

Two patients were excluded because of incomplete data. One of these patients did not have a formal echocardiogram performed within 60 minutes of the BLEEP. The other patient's images failed to record because of equipment malfunction. Because of technical difficulty, EP images of the IVC were not recorded on 1 patient. However, the remainder of echocardiography data from this patient was included in the analysis.

RESULTS

Thirty-one patients were enrolled. The mean age was 5.1 years (range: 23 days–16 years); 48.4% (15 of 31) were female; 58.1% (18 of 31) were on mechanical ventilatory support at the time of their study. The list of patient diagnoses is shown in Table 1.

There was good agreement between the EP and the PEP for estimation of SF ($r = 0.78$, $P < .001$). The mean difference in the estimate of SF between the providers was 4.4% (95% confidence interval: 1.6%–7.2%). This difference in estimate of SF was statistically significant ($P = .003$).

Similarly, there was good agreement between the EP and the PEP for estimation of IVC volume ($r = 0.8$, $P < .001$). The mean difference in the estimate of IVC diameter by the PEP and the EP was 0.068 mm (95% confidence interval: −0.16 to 0.025 mm). This difference was not statistically significant ($P = .14$; Table 2).

All of the parasternal short-axis view 2-dimensional echocardiogram images recorded were of acceptable or higher quality. The proportion of M-mode and IVC images obtained by the EP that were of unacceptable quality were 9.6% (3 of 31) and 3.2% (1 of 31), respectively (Table 3). This difference in proportions was not statistically significant ($P = .32$).

TABLE 1. List of Patient Diagnoses

Diagnosis	*n*
Chest trauma, blunt head trauma, s/p motor vehicle crash	4
Bronchopulmonary dysplasia, pulmonary hypertension	8
Brain tumor with acute hydrocephalus	2
Spinal cord injury	1
Status asthmaticus	1
Severe pneumonia	1
Chronic renal failure, LV dysfunction	1
Severe hypertension	2
Postoperative, s/p atrioventricular canal repair	3
Septic shock	1
Severe aortic stenosis, s/p cardiorespiratory arrest during cardiac catheterization	1
Neuromuscular disease on chronic ventilation	4
Cerebral palsy, s/p spinal fusion	1
Postoperative, s/p total anomalous pulmonary vein return	1

s/p indicates status post.

TABLE 2. Absolute Values for SF and IVC Diameter Obtained by the EP and the Cardiology Provider

Patient	IVC/EP	SF/EP, %	IVC/ Cardiology	SF/ Cardiology, %
1	0.75	40.60	0.75	38.00
2	0.31	45.09	0.39	51.00
3	0.44	31.64	0.47	53.40
4	0.93	52.68	0.91	53.60
5	0.74	40.78	0.92	46.00
6	0.55	34.27	0.86	30.50
7	1.06	23.33	1.38	38.80
8	0.60	37.97	0.67	45.30
9	0.38	33.54	0.33	46.40
10	1.06	31.19	1.16	33.00
11	0.85	28.25	1.56	40.00
12	0.28	23.70	0.43	23.70
13	0.65	31.44	NA	NA
14	0.32	30.57	0.33	42.70
15	0.92	31.71	0.83	36.30
16	0.74	29.28	0.59	50.00
17	0.39	38.83	0.70	41.00
18	0.59	37.53	0.60	42.40
19	1.57	33.55	1.48	36.00
20	0.56	51.38	0.63	51.10
21	0.36	21.91	0.58	30.30
22	0.45	23.50	0.47	28.70
23	0.69	55.00	0.84	46.00
24	1.50	49.12	0.70	44.40
25	0.71	48.81	0.61	49.40
26	NA	40.91	0.39	43.40
27	1.57	15.56	1.75	24.20
28	1.39	40.30	1.48	46.20
29	0.37	28.40	0.67	31.80
30	0.69	47.83	0.62	47.10
31	0.65	74.34	0.67	63.20

NA indicates not available.

DISCUSSION

Our results demonstrate that with focused training, pediatric EPs can determine SF and IVC diameter accurately. In addition, the images obtained by the BLEEP examination were of acceptable quality, as judged by an independent pediatric cardiologist.

Several studies have also addressed the role of goal-directed echocardiography by EPs in primarily adult patients.[25,29,30,40–43] Rose et al[25] proposed a limited echocardiographic screening examination by EPs in the evaluation of adult patients with undifferentiated hypotension. Their protocol incorporates (1) a single view of Morison' pouch to detect free intraperitoneal fluid; (2) focused qualitative cardiac examination to rule out presence of pericardial effusion (PE) and assess for contractility (if PE is present, then assess for presence of diastolic collapse of the right

TABLE 3. Overall Quality of BLEEP Images as Judged by the Cardiologist

Quality	2-Dimensional Echocardiogram (Parasternal Short-Axis View)	LV M Mode	IVC
Excellent	0	0	0
Good	0	3	1
Fair	22	3	4
Acceptable	9	22	24
Unacceptable	0	3	1

ventricle); and (3) focused aortic evaluation for presence of a leaking aortic aneurysm. Plummer et al[44] showed that EPs could detect PE with resulting tamponade in a single view. Mandavia et al[40] in a prospective trial showed that EPs can detect PE with an overall accuracy of 97.5% when performed in a high-risk adult population. Similarly, Moore et al[42] concluded that EPs with focused training in echocardiography could accurately determine LVF in hypotensive adult patients. More recently, Randazzo et al[39] concluded that EPs with limited bedside echocardiography training can qualitatively assess ejection fraction and CVP using IVC dynamics in a subset of adult patients in the ED. It has been previously been shown in pediatric and adult studies that CVP measured in the IVC accurately reflects RA pressures in ventilated and nonventilated patients.[45–48] IVC dimensions, as measured by US, have been shown to provide useful information about right atrial pressure and baseline blood volume in patients who undergo hemodialysis.[49,50] In a study of adult volunteers before and after blood donation, measurement of IVC diameter was noted to be a reliable indicator of blood loss.[51]

We are not aware of any previous data from the pediatric emergency medicine literature addressing the role of BLEEP. Our results seem comparable to data obtained from BLEEP performed on a subset of adult subjects. Randazzo et al[39] used a subjective visual estimation technique of LVF in patients who were scheduled to receive a formal echocardiogram from the ED. The overall agreement in estimation of function between the EP and the cardiologist in their study was good ($r = 0.712$). The time interval between these 2 echocardiograms was up to 4 hours. Unlike their study, we used an objective M-mode measurement technique of SF that has been endorsed by the American Society of Echocardiography.[32] The time interval between the EP and formal echocardiogram in our study was up to 60 minutes. Mandavia et al[40] investigated the performance of BLEEP in the diagnosis of PE in a high-risk population of adult ED patients. The overall sensitivity of BLEEP was 96% with a specificity of 98%.

Our study had several limitations. This was a convenience sample of patients. Within the context of a busy urban tertiary-level pediatric hospital, our patients were recruited on the basis of the availability of the EP and the PEP. We used admission to the intensive care unit as a surrogate marker of critical illness. Although the majority of our patients were intubated and on mechanical ventilation, the proportion of patients with diminished function (SF $<$ 30%) was low ($<$10%). In addition, we did not correlate preload with an objective comparative measure such as the CVP. In general, patients in a pediatric intensive care unit setting do not always have indwelling CVP monitoring devices in place. This was the case for several patients in our study.

Although the images obtained on our portable US machine were of acceptable quality to determine accurately LVF and IVC volume, only 10% of the images were deemed excellent or good by the pediatric cardiologist. We believe that this compromise in resolution and quality was partly attributable to the limitations of the portable US technology available in the ED as compared with the high-end equipment used by the division of cardiology.

It could be argued that because the images obtained by the EP and the PEP were not recorded at the same time, changes in the patient's clinical status could have confounded the results. However, our results did not support this argument. Despite a window of 60 minutes or less between the BLEEP and formal echocardiogram, the difference in the estimate of the IVC diameter by the EP and the PEP was not significant. Although statistically significant, the difference of 4.4% in the estimation of SF may not be clinically relevant.

There were technical limitations cited by the cardiologist who reviewed our images. At the level of the papillary muscles, the plane in which the M-mode measurements are obtained needs to be centered appropriately to assess SF accurately. This was not the case in several studies. Although we did not make any systematic attempt to assess the degree of difficulty in obtaining the appropriate echocardiography views, several patients were on mechanical ventilatory support (including high-frequency oscillator ventilation), making the BLEEP examination technically difficult. In contrast, some studies may have been technically easier to perform on patients who were heavily sedated. Hence, these results cannot be extrapolated to the ED setting, where a critically ill patient may not be relatively motionless.

There are limitations of using SF to measure LV systolic function in the presence of altered geometry of the left ventricle as in anomalous origin of the coronary artery from the pulmonary artery or critical coarctation. Both of these conditions can mimic sepsis in the neonatal period. Furthermore, the study is also limited by the fact that only 1 pediatric emergency physician performed the BLEEP studies. Hence these results cannot be generalized to other pediatric ED providers.

Last, the utility of the BLEEP examination needs to be validated in a pediatric ED population of critically ill patients. Furthermore, whether changes in IVC wall motion and diameter correlate with RA pressure in pediatric vascular underfill states such as dehydration, sepsis, and hemorrhagic shock has not yet been explored.

We anticipate that if the BLEEP examination is validated prospectively on ED patients in the next phase of our ongoing investigation, then all images will continue to be reviewed by the cardiologist. Any abnormality detected, as in diminished SF estimates, will receive a formal echocardiogram. The BLEEP is intended only to be a clinical decision support tool to the front-line pediatric emergency physician and not to supplant formal cardiac imaging.

CONCLUSIONS

Our results suggest that with goal-directed training and pediatric cardiology oversight, pediatric EP sonographers are capable of obtaining images that permit accurate assessment of LVF and IVC diameter. The BLEEP examination may serve as an objective, rapid, noninvasive tool in the assessment of ventricular function and right ventricular filling during resuscitation of the critically ill pediatric patient. Additional investigation is needed to evaluate the role of BLEEP in a population of critically ill patients in an ED setting.

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