CLINICAL INVESTIGATIONS

Determination of Left Ventricular Function by Emergency Physician Echocardiography of Hypotensive Patients

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Abstract. **Objective:** To determine whether emergency physicians (EPs) with goal-directed training can use echocardiography to accurately assess left ventricular function (LVF) in hypotensive emergency department (ED) patients. **Methods:** Prospective, observational study at an urban teaching ED with >100,000 visits/year. Four EP investigators with prior ultrasound experience underwent focused echocardiography training. A convenience sample of 51 adult patients with symptomatic hypotension was enrolled. Exclusion criteria were a history of trauma, chest compressions, or electrocardiogram diagnostic of acute myocardial infarction. A five-view transthoracic echocardiogram was recorded by an EP investigator who estimated ejection fraction (EF) and categorized LVF as normal, depressed, or severely depressed. A blinded cardiologist reviewed all 51 studies for EF, categorization of function, and quality of the study. Twenty randomly selected studies were reviewed by a second cardiologist to determine interobserver variability. **Results:** Comparison of EP vs. primary cardiologist estimate of EF yielded a Pearson's correlation coefficient $R = 0.86$. This compared favorably with interobserver correlation between cardiologists ($R = 0.84$). In categorization of LVF, the weighted agreement between EPs and the primary cardiologist was 84%, with a weighted kappa of 0.61 ($p < 0.001$). Echocardiographic quality was rated by the primary cardiologist as good in 33%, moderate in 43%, and poor in 22%. The EF was significantly lower in patients with a cardiac cause of hypotension vs. other patients (25 ± 10% vs. 48 ± 17%, $p < 0.001$). **Conclusions:** Emergency physicians with focused training in echocardiography can accurately determine LVF in hypotensive patients. **Key words:** echocardiography; ejection fraction; emergency medicine; hypotension; shock; ultrasound. ACADEMIC EMERGENCY MEDICINE 2002; 9:186–193

SYSTEMIC hypotension represents a common and often life-threatening emergency. Physical examination has been shown to be unreliable in differentiating hypovolemic from cardiogenic causes of hypotension,[1,2] and the rapid determination of left ventricular function (LVF) may have important implications for diagnosis and treatment.[3,4] Studies performed in the intensive care unit setting have suggested echocardiography may supplement or replace invasive measures of volume status, such as the pulmonary artery catheter, and have provided information regarding short- and long-term prognoses.[5–11] In the emergency department (ED), echocardiography performed by cardiologists has been shown to provide prognostic information in patients with suspected cardiac ischemia.[12–14]

Limited echocardiography by emergency physicians (EPs) is helpful in determining the presence of cardiac contraction during cardiac arrest and in detecting the presence of cardiac tamponade in unstable patients.[15–19] It has been suggested that transthoracic echocardiography by EPs may be helpful in patients with hypotension of undetermined etiology,[20] but to the best of our knowledge, this has not been investigated prospectively.[18] Debate continues over whether EPs should perform echocardiography at all, and what training is required.[21–25] Therefore, the purpose of this study was to determine whether EPs with ultra-

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sound experience and goal-directed training in echocardiography could accurately assess LVF in symptomatic hypotensive ED patients.

METHODS

Study Design. We performed a prospective observational study of the accuracy and utility of echocardiographic determination of LVF in patients presenting to the ED with symptomatic hypotension. Informed consent was obtained from all patients or available next of kin if the patient was too ill to consent. This study was reviewed and approved by the institutional review board for the conduct of human research prior to enrollment of patients.

Study Setting and Population. All subjects were enrolled in the ED at Carolinas Medical Center, an 800-bed teaching hospital with >100,000 ED visits per year. An initial screening examination was performed by the treating physician with appropriate therapeutic measures and diagnostic studies initiated. Patients who were recognized to have persistent symptomatic hypotension were referred to an investigator via pager (24 hours/day, 7 days/week). An attempt was made to enroll all eligible patients, but ultimately, patients were enrolled only when one of four investigators was able to arrive at the ED within approximately 10 minutes of notification. Explicit criteria for enrollment included age >18 years, systolic blood pressure <100 mm Hg measured at least two times 15 minutes apart, no history of trauma, and electrocardiogram not diagnostic of myocardial infarction. We excluded subjects who reported a history of "low blood pressure" at baseline and patients with asymptomatic hypotension. Symptoms included syncope, lightheadedness, extreme fatigue, dyspnea, or altered mental status. Patients were not enrolled if chest compressions or defibrillation had been initiated at any time.

Training. Echocardiographic examinations were performed by one of four participating EPs with various levels of initial training. At a minimum, EP investigators must have completed ten hours of basic ultrasound instruction and 100 documented non-cardiac ultrasound examinations prior to echocardiography training.

The training phase of this study consisted of three parts: didactics, specific echocardiography training, and pilot study/review. The EP investigators initially viewed approximately six hours of videotaped instruction on echocardiography with focus on LVF.[26,27] The EPs spent a minimum of ten hours observing and performing echocardiography in a cardiologist-supervised echocardiography laboratory with specific attention to two-dimensional echocardiography techniques and determination of LVF and ejection fraction (EF). Each EP investigator then prepared a pilot tape on a non-hypotensive ED patient, which was reviewed by the primary cardiologist for adequacy of the five basic views included in the study (parasternal long axis, parasternal short axis, apical four chamber, apical two chamber, and subcostal). This pilot tape was approved by the primary cardiologist prior to enrollment of subjects.

Equipment. All echocardiographic examinations were conducted on an Apogee CX-100 ultrasound machine (Interspec, Ambler, PA) using a 3.5-MHz mechanical sector probe and a dedicated cardiac software package. All examinations were recorded on high-quality ½-inch VHS tape.

Study Protocol. After informed consent, a clinical data form was completed. Cutaneous electrodes were placed to monitor the lead II electrocardiogram on the ultrasound machine. Patients were placed in the left lateral decubitus position (as tolerated) and transthoracic views were obtained and recorded in the parasternal long axis, parasternal short axis, apical four-chamber, apical two-chamber, and subcostal views. Studies were not terminated on the basis of suboptimal acoustic window as long as any cardiac image was observed. The decision to enroll a patient was made prior to performance of the echocardiography, and all patients who were enrolled had an echocardiogram recorded. However, if patient care mandated emergent transfer of the patient out of the ED, the imaging process was terminated.

Measurements. Cross-sectional M-mode measurements of left ventricular diameter were performed at the level of the tips of the mitral leaflets in the parasternal long and short axes. Volume measurements were made by manual border tracing in mechanical systole and diastole in both apical four- and two-chamber views using the area–length method for volume calculation provided with the cardiac software package. The entire examination was recorded on videotape.

Following performance of the echocardiogram, the EPs recorded their quantitative visual estimation of EF within ±5% and categorized LVF into one of three levels (arbitrarily defined as: 1 = hyperdynamic/normal, EF > 50%; 2 = moderate depression, EF 30–50%; 3 = severe depression, EF < 30%). To measure interobserver variability between EPs, a second echocardiographic examination was performed immediately in a convenience sample (n = 8) by another EP investigator who was blinded to the interpretation of the first investi-

TABLE 1. Clinical Characteristics of 50 Emergency Department (ED) Patients with Systemic Hypotension Who Underwent Transthoracic Echocardiography Performed by an Emergency Physician

Age—mean ± SD (range)	57 ± 16 (18–90) years
Cormorbidities*—mean ±SD	1.3 ± 1
Sex	
Male	60% (*n* = 30)
Female	40% (*n* = 20)
Race	
White	52% (*n* = 26)
African American	46% (*n* = 23)
Other	2% (*n* = 1)
SBP† during ED stay—mean ± SD	90.7 ± 9.3 mm Hg
SBP at echocardiography—mean ± SD	90.1 ± 10.8 mm Hg
Intubated at echocardiography	14% (*n* = 7)
Pressors used during stay	36% (*n* = 18)
Disposition	
Discharged from ED	20% (*n* = 10)
Admitted to floor	10% (*n* = 5)
Admitted to monitored bed	30% (*n* = 15)
Admitted to ICU	36% (*n* = 18)
Death in ED	4% (*n* = 2)
Hospital days—mean ± SD	10.6 ± 14.5
SBP at discharge—mean ± SD	115 ± 20 mm Hg
Death during hospital stay	18% (*n* = 9)
Death during study period	24% (*n* = 12)

*Comorbidities include AIDS, chronic obstructive pulmonary disease, diabetes, end-stage renal disease, hypertension, and significant heart disease (myocardial infarction, coronary artery bypass grafting, percutaneous transluminal coronary angioplasty, valve replacement, pacemaker, and arrhythmia).
†SBP = systolic blood pressure.

gator. The second physician performed an echocardiographic examination in the same manner as the first and filled out an identical data sheet. The second echocardiogram was also recorded on videotape.

Videotapes from all 50 patients enrolled were reviewed by the primary cardiologist, who was blinded to patient characteristics as well as the EP estimation of EF. The primary cardiologist completed a data sheet that included visual estimation of EF, categorical estimate of LVF (as defined previously), and assessment of adequacy of the five views and overall quality. The primary cardiologist estimation of EF was considered the criterion standard.

To examine for interobserver variability between cardiologists, a sample of 20 videotapes were reviewed by a second cardiologist with similar credentials. The second cardiologist was blinded to patient characteristics and prior echocardiographic interpretations and reviewed the echocardiograms for EF and categorization of function only.

Medical records of all subjects were reviewed retrospectively to determine whether subjects were treated with inotropic or vasopressor infusions, and to establish total length of hospital stay, duration of intensive care services, cause of hypotension, and the mortality rates at 30 days and during the entire study period.

Data Analysis. The EF data were tested for presence of normality and equal variances using the Shapiro-Wilk test and the variance ratio F-test (StatsDirect, v. 1.8.5, Ashwell, UK). For the EF data, correlation between the EPs and the cardiologist was examined by calculation of Pearson's correlation coefficient (R). Agreement between the EPs and the cardiologist's categorizations of LVF was determined using the weighted kappa statistic (κ_w) and weighted percent agreement.[28] For the weighted kappa, a difference of two categories of function was twice as "serious" as a one-category disagreement, and there was no difference in weight based on whether the EP was higher or lower than the cardiologist. A Bland and Altman graph[29] was prepared to show a visual plot of discordance between the primary cardiologist and the EPs. Sample size of 50 was chosen to be consistent with previous studies that reported agreement between two readers of echocardiographically determined EF[30] as well as number needed to determine a statistically significant weighted kappa with three categories of function.[31–33]

RESULTS

Patient enrollment occurred between April 1 and September 1, 2000. Fifty-one subjects were approached for informed consent, and none refused. All five views were obtained in 36 (71%) patients. In eight subjects (16%), one view was lacking, in two subjects (4%), two views were lacking, and in four subjects (8%), only one view could be obtained. In one subject (2%), the acoustic window was judged to be so poor that the investigator could not visualize any cardiac structure, and this patient was excluded from further analysis.

The clinical characteristics of the enrolled patients are shown in Table 1. Patients enrolled by the four EPs did not differ in the mean EF, age, gender, or comorbidity. All EPs performed at least nine ED echocardiograms (17 by CLM, 14 by JAK, 11 by VST, and 9 by DMS). The average time to complete the echocardiography exam was 17.5 ±

10.8 minutes (range 4–45 minutes). This included thermal print recording of border tracing in diastole and systole for both apical four-chamber and apical two-chamber views as well as M-mode measurements in the parasternal long and short axes.

The primary cardiologist found that the mean EF of all 50 patients was 44 ± 16% (range, 10–65%). The mean EF reported by the EPs for all 50 subjects was 46 ± 17% (range 12.5–80%). The EF data for the cardiologist and EPs were both found to be normally distributed ($p = 0.085$ and $p = 0.132$, respectively) with equal variances (F-test on variances = 1.21, upper-limit $p = 0.358$). The primary cardiologist categorized 22 patients as having normal LVF, 18 with moderately depressed function, and ten with severely depressed LVF. The EPs categorized 24 patients as having normal LVF, 16 with moderately depressed function, and ten with severely depressed LVF. The categorization of function by the primary cardiologist and the EP is shown in Table 2. Categorization of LVF by cardiologists 1 and 2 is shown in Table 3.

The weighted kappa statistic for the categorization of LVF by the primary cardiologist and the EPs was 0.61 (95% CI = 0.39 to 0.83; $p < 0.001$), with weighted agreement of 84%. When the patients were stratified according to the category of function, using the primary cardiologist's interpretation as the criterion standard, the data show that the EPs misclassified five of the 22 patients with normal LVF (23%) and two of the ten patients with severe left ventricular dysfunction (20%).

The plot of the estimate of EF for EPs versus the primary cardiologist is shown in Figure 1. Calculation of Pearson's correlation coefficient returned an $R = 0.86$ with standard error of the estimate ±8%. Because it is possible for data to have excellent correlation without excellent agreement, a modified Bland-Altman[29–31] plot was prepared to show agreement between the EP and cardiologist estimations of EF. Figure 2 shows that the difference between the EP estimated EF and the average of the EP and cardiologist EF was within 1 standard error of the estimate in 96% of patients.

Interobserver correlation and agreement were also measured between two cardiologists' estimated EFs on a sample of 20 echocardiographic studies. The Pearson's correlation coefficient for the two cardiologists' estimations was 0.84 and the modified Bland-Altman plot showed agreement within 1 standard error of the estimate in 95% of patients (plots not shown).

Agreement in estimate of EF between the EPs in the convenience subset of eight patients who underwent echocardiography by two EPs yielded an $R = 0.94$ (plot not shown).

TABLE 2. Echocardiographic Categorization of Left Ventricular Function (LVF) for 50 Emergency Department Patients with Systemic Hypotension*

Cardiologist LVF Category	EP LVF Category 1	2	3	TOTAL
1	17	5	0	22
2	7	9	2	18
3	0	2	8	10
TOTAL	24	16	10	50

LVF: 1=normal/hyperdynamic
2=moderately depressed
3=severely depressed

*This table compares the category of LVF assigned by emergency physicians (EPs) with the category assigned by the primary cardiologist. Darker shading indicates better aggreement. For example, while 18 patients were categorized by the cardiologist as having moderately depressed LVF, nine of these were placed in this category by the EP, seven in a higher category and two in a lower. Weighted kappa based on this table is 0.61, with weighted agreement of 84%.

TABLE 3. Cardiologist Categorization of Left Ventricular Function (LVF)*

Cardiologist #1 LVF Category	Cardiologist #2 LVF Category 1	2	3	TOTAL
1	5	2	0	7
2	0	7	0	7
3	1	1	4	6
TOTAL	6	10	4	20

LVF: 1=normal/hyperdynamic
2=moderately depressed
3=severely depressed

*This table shows categorization of LVF by the primary cardiologist (#1) compared with the second cardiologist (#2) in the subset of 20 patients analyzed by both. As in Table 2, the distribution of categorization of LVF for each observer is shown, with darker shading indicating better agreement. Weighted kappa is 0.70, with weighted agreement of 88%.

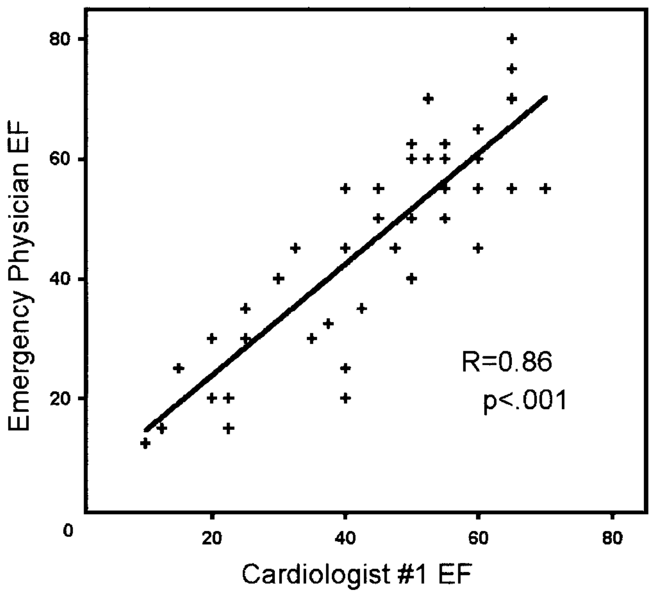

Figure 1. Scatter plot comparing the ejection fraction (EF) determined by the emergency physician with that determined by the primary cardiologist who reviewed the videotaped echocardiogram. Calculation of Pearson's correlation coeffcient yielded an R = 0.86

The EF was also calculated using measurements obtained during ED echocardiography. Ejection fraction calculated using M-mode measurements by the Teichholz method[34] and border detection using volume calculations based on the area–length method revealed an R = 0.73 and R = 0.70 vs. cardiology EF, respectively.

The cause of hypotension, as determined from review of the medical chart, is shown in Table 4, along with the initial EP estimate of EF. Initial EF was significantly lower in patients with congestive heart failure from all causes (n = 6, EF 23 ± 8% vs. 48 ± 15%, p < 0.001), including one patient with decompensated thyrotoxicosis , or any cardiac cause (n = 8, EF 25 ± 10% vs. 48 ± 17%, p < 0.001). The initial EF in those patients who died within 30 days tended to be lower, but the difference did not reach statistical significance (38 ± 17% vs. 47 ± 17%).

DISCUSSION

To the best of our knowledge, this is the first study that has evaluated the accuracy of EPs in determining LVF by echocardiography in ED patients. The correlation coefficient between EPs and the primary cardiologist (R = 0.86) is similar to correlation data found between echocardiographic estimation of EF by a cardiologist compared with EF estimation by other imaging modalities. For example, prior studies that compared EF estimated by cardiologist-interpreted echocardiography with EF determined by radionuclide angiography and contrast ventriculography reported R = 0.81–0.94,[31,35,36] and R = 0.75–0.93,[34,36,37] respectively.

Previous studies that examined the correlation between visual determination of EF by two cardiologists reading the same echocardiogram have demonstrated an R of 0.77–0.90.[31,35] This compares with the R = 0.85 between two cardiologists and R = 0.94 between two EPs in this study.

The criterion standard for this study was the visual estimate of EF and LVF by a cardiologist with fellowship training in echocardiography interpretation. However, it is important to note that this estimate was based on images obtained by the EP with our machine. This differs from the usual method in our institution, which is visual estimate of EF based on images obtained by an echocardiography technician using more modern cardiology machines. The cardiology literature supports visual estimate of EF by a trained observer as being equal to or better than EF calculated by measured echocardiographic parameters, and comparable to EF determined by radionuclide or contrast ventriculography, even with echocardiograms of suboptimal quality.[31,36–38]

The primary cardiologist rated 22% of the studies as poor, 43% as of moderate quality, and only 33% as good quality. The cardiologist deemed two of 50 examinations as uninterpretable for EF estimate, although he was able to make a categorical determination of LVF for these patients. Part of the problem with obtaining good images is inherent to the ED patient population. Obesity, presence of chronic obstructive pulmonary disease, and mechanical ventilation may obscure transthoracic windows. Many ED patients are also either obtunded or uncomfortable making patient cooperation and positioning difficult. Because several patients were critically ill, their need for intensive management made it difficult to obtain echocardiographic images specified in the protocol.

Ideally, independent determination of EF by radionuclide or contrast ventriculography would have also been used to confirm EF, but was not feasible in all patients. Of the 51 patients in the study, 27 (54%) underwent an independent study during their admission with determination of EF. These included formal transthoracic echocardiography, transesophageal echocardiography, radionuclide studies, or cardiac catheterization. Although timing of these studies varied, correlation with EP determination of EF showed a correlation coefficient of R = 0.79. For the four patients (8%) who underwent cardiac catheterization during admission, agreement between EP estimation of EF and EF by catheterization correlated with an R = 0.99.

This study included a population that varied widely in their degrees of illness. Forty percent of the patients enrolled either were admitted to an intensive care unit or died in the ED, and 24% of the patients died during the study period; however, 20% were discharged from the department after treatment. Inclusion criteria were designed to include an unselected group of patients suffering from undifferentiated circulatory shock. Inevitably, these criteria included a subset of hypotensive patients who proved not to be seriously ill in view of their improvement after infusion of intravenous fluids and time. In real practice, knowledge of the estimated LVF may not change decision making to any significant degree in a similar subset of patients.

This study did not produce EF data to suggest a strong association between depressed LVF with either short-term mortality or length of stay. Prior research has established a strong inverse relationship between EF and mortality in patients with myocardial infarction and congestive heart failure.[38,39] On the contrary, other studies have shown that hyperdynamic left ventricular function was associated with increased mortality from septic shock.[40] Eleven patients in our study (22%) were diagnosed as having sepsis-related hypotension, and five of these patients died within 90 days. Thus, our data do not support the broad concept that a decreased LVF can be used for short-term prognosis of all patients with undifferentiated shock in the ED.

The data suggest that echocardiography may assist in recognition of a cardiogenic cause of hypotension in ED patients. Although patients diagnosed as having myocardial infarction in the ED were excluded from this study, the mean EF of patients with a final diagnosis of either congestive heart failure or subsequently documented myocardial infarction was 25%, which was significantly lower than the EF of 48% found in the other 42 patients diagnosed as having a noncardiogenic cause of hypotension. We submit that in an adult population with unexplained hypotension, echocardiographic examination of the heart adds significantly to diagnostic evaluation.

The average time required to perform an echo-

TABLE 4. Ejection Fraction (EF) by Cause of Hypotension*

Cause of Hypotension	No. of Patients	Average EF
All causes	50	46 ± 17%
Sepsis	11	52 ± 9%
Dehydration	10	44 ± 16%
Medication effect (including 3 intentional overdoses)	7	61 ± 7%
Cardiomyopathy/CHF	5	23 ± 9%
Endocrine (3 adrenal insufficiency, 1 thyrotoxicosis with secondary CHF)	4	35 ± 23%
Gastrointestinal bleed	3	43 ± 13%
Cardiogenic secondary to acute myocardial infarction	2	30 ± 14%
Other (acute cor pulmonale, amyloidosis, hypothermia, pulmonary embolism, third degree heart block, acute valvular dysfunction, undetermined)	8	50 ± 18%

*This table shows the number of patients with hypotension determined to be from various causes, and the average initial EF determined by the emergency physician. The EF in patients with hypotension due to cardiomyopathy/congestive heart failure (CHF) was significantly lower ($p < 0.001$) than the EF with hypotension from other causes, and was the only one that reached statistical significance.

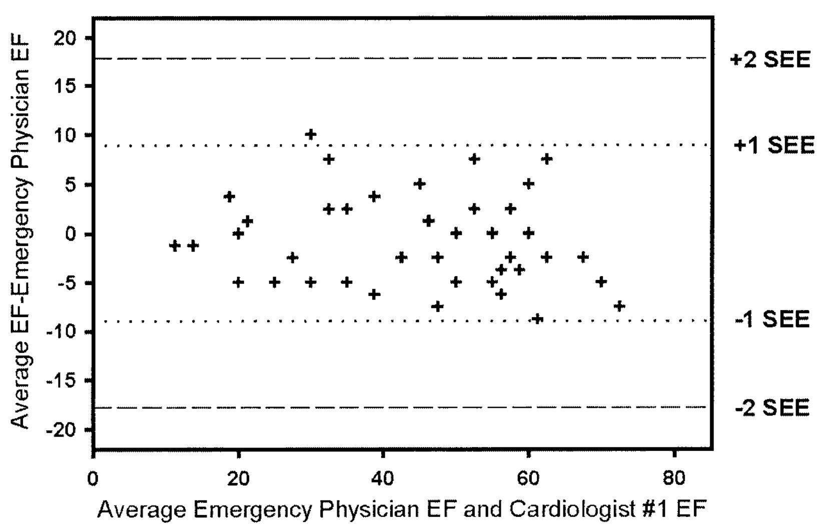

Figure 2. Modified Bland-Altman plot of ejection fraction (EF) between the primary cardiologist and the emergency physician. The x axis is the average of the estimated EFs and the y axis is the difference between the average EF and the EP EF. The difference falls within 1 standard error of the estimate 96% of the time.

cardiogram in our study was 17 minutes. While this may seem prohibitive in a busy ED, the majority of this time was spent performing border tracing, taking M-mode measurements, and capturing adequate views for printing pictures. Given that the EF calculated by M-mode and border detection measurements showed only moderate correlation with the EF determined by the primary cardiologist, these steps do not appear to add substantial value to the determination of LVF. We believe that a five-view echocardiogram with visual estimation of LVF by the EP could be obtained in less than 5 minutes with reasonable accuracy.

We do not propose that echocardiograms performed by EPs in this study replace a formal diagnostic echocardiogram interpreted by a cardiologist. However, this should not preclude the EP who has had training sufficient for goal-directed examination of the heart from obtaining valuable information in an acute setting when a cardiologist or formal echocardiogram is not immediately available.

Limitations and Future Questions

Both the number of patients enrolled and the number of physicians performing echocardiograms in this study were small. The ultrasound experience of participating physicians prior to training for this study was variable, but may exceed that of the average practicing EP. Furthermore, training and equipment will vary depending on the institution, and may not be reproducible. For these reasons, results of this study would benefit from further validation at another institution.

While an attempt to include all hypotensive patients was made, this study did not enroll consecutive patients. Owing to the high level of medical attention required for patients with circulatory shock, the investigators may not have been notified for some of the more acutely ill patients with hypotension who presented during the study period.

This study did not compare echocardiograms performed and interpreted by EPs with echocardiograms performed by trained technicians and then interpreted by cardiologists. Limitations in the availability of echocardiography technicians around the clock and cost considerations prohibited this. In addition, our machine was several years old and did not have tissue harmonics or phased-array transducers, technologies that improve image quality and are becoming more widely available.

Because of the limitations noted above, transthoracic echocardiography is not always the ideal method to image the heart. The critical care literature has demonstrated the superiority of transesophageal echocardiography in patients in shock.[8,9,11,41,42] The feasible of transesophageal echocardiography in ED patients who are not endotracheally intubated could be questioned. Only 14% of patients in this study were intubated.

This was intended to be a purely observational study, and not intended to guide therapy. Future research from our group will test whether recognition of depressed LVF in patients with undifferentiated shock changes EP behavior regarding the frequency of use of inotropic therapy, and the specific type of imaging study performed (e.g., coronary vascular imaging versus pulmonary vascular, abdominal, or cranial imaging).[38]

Given the number of patients in this study, some disease processes were not represented. While there were patients with pericardial effusions, none were deemed hemodynamically significant. A larger study would be more likely to enroll patients with hypotension and tamponade, a condition for which echocardiography is widely considered to be the criterion standard of diagnosis. We did have one patient with massive pulmonary embolism who had significant right ventricular dilatation, and further study may include EP measurement of right ventricular parameters in hypotension. Determination of LVF in the ED may have diagnostic or prognostic implications in patients presenting with complaints other than unexplained hypotension. Such instances may include patients with shortness of breath, pulmonary edema, chest pain, or myocardial infarction. The feasibility and utility of EP determination of LVF in these cases merit further study.

Conclusions

In this study, emergency physicians with limited goal-directed training in echocardiography were able to determine left ventricular function with reasonable accuracy in hypotensive emergency department patients. Echocardiographic windows permitting estimation of left ventricular function were obtained in 50/51 (98%) of patients. Patients who were ultimately diagnosed as having cardiogenic hypotension had significantly depressed left ventricular function compared with patients who had noncardiogenic hypotension.

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