



Original Contribution

Directed bedside transthoracic echocardiography: preferred cardiac window for left ventricular ejection fraction estimation in critically ill patients

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Background: Bedside transthoracic echocardiography (TTE) performed by emergency physicians (EPs) is valuable in the rapid assessment and treatment of critically ill patients. We sought to determine the preferred cardiac window for left ventricular ejection fraction (LVEF) estimation by EP sonographers in a critically ill patient population.

Methods: Prospective investigator-blinded study of focused bedside TTE in a convenience sample of surgical intensive care patients. Investigators were faculty, fellows, or residents from an academic emergency medicine department. Five standard cardiac views were performed: parasternal long axis (PSLA), parasternal short axis (PSSA), subxiphoid 4-chamber, subxiphoid short axis, and apical 4-chamber (AFC). LVEF was determined using at least 1 cardiac view. Investigators rated their preference for each cardiac view on a 5-point Likert scale.

Results: A total of 70 studies were performed on 70 patients during a 6-month period. Users rated the PSLA as the most useful view for estimation of LVEF (mean 4.23; 95% confidence interval, 3.95–4.51). Pairwise comparisons of cardiac ultrasound views revealed PSLA was preferred over all other views ($P < .05$) except PSSA ($P = .23$). Complete 5 view examinations were not achieved in all patients (PSLA in 98%, PSSA in 96%, apical 4-chamber in 74%, subxiphoid 4-chamber in 35%, and subxiphoid short axis in 18%). Interobserver correlation of LVEF estimation was good ($r = 0.86$, $r^2 = 0.74$, $P < .0001$).

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Conclusion: Parasternal long axis and PSSA are the preferred echocardiographic windows for EP estimation of LVEF using focused bedside TTE in critical care patients. This may be an important consideration in patients who often have physical barriers to optimal echocardiographic evaluation, are relatively immobile, and have unstable conditions requiring rapid assessment and intervention.

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1. Introduction

1.1. Background

Optimization of intravascular volume and cardiac performance is a primary goal in the management of critical illness. Studies have shown that physical examination and vital signs alone are often inadequate as markers of effective resuscitation in the critically ill [1-3]. Either underestimation or overestimation of intravascular volume needs can be severely deleterious, and direct evaluation of gross cardiac function may be needed to identify impaired systolic function, grossly impaired cardiac filling, signs of acute pulmonary hypertension, or cardiac tamponade.

Clinician-directed bedside ultrasonography is noninvasive, rapid, repeatable, inexpensive, and does not necessitate removal of the patient from the resuscitation area. Bedside echocardiography has been proposed as a readily accessible noninvasive diagnostic modality in critically ill patients [4-6]. Studies of critically ill patients both in the ED and intensive care unit have shown that emergency physicians (EPs) can make reasonable estimations of left ventricular ejection fraction (LVEF) using focused bedside transthoracic echocardiography (TTE) [7-9].

Despite the widespread use of clinician-performed bedside ultrasonography in critical and emergency care settings, little is known about which of the many cardiac windows and views of a standard TTE examination are most useful or reliable for LVEF estimation by clinician-sonographers. Our hypothesis was that, in a patient population consisting of surgical intensive care patients, many of whom are mechanically ventilated, parasternal images would be rated as the most useful views, given their relative ease of acquisition irrespective of patient mobility. This study was conducted as part of a larger investigation of clinician-performed ultrasonography in surgical intensive care patients.

2. Materials and methods

2.1. Study design

Patients were enrolled as part of a larger investigation of the utility of noninvasive cardiovascular monitoring using clinician performed focused echocardiography in critically ill surgical patients. Data were collected between February 1, 2006, and July 31, 2006. This study was approved by the University of Pennsylvania Institutional Review Board

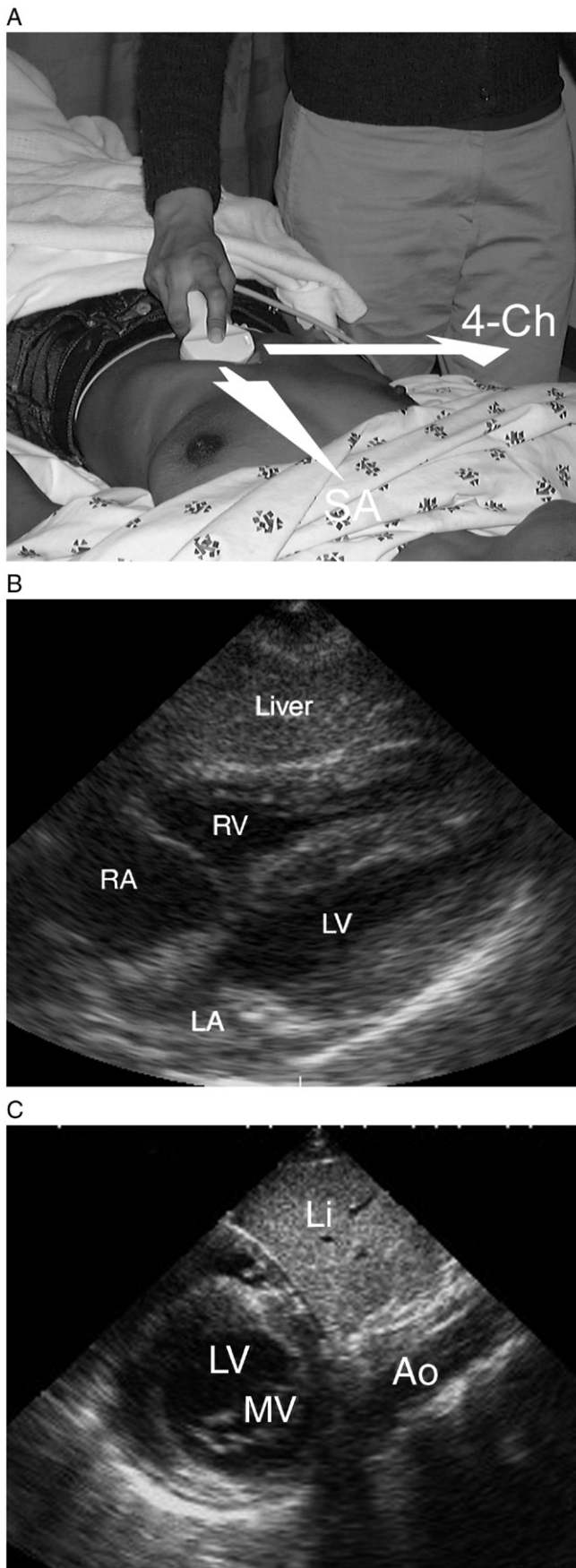
with a waiver of informed consent, as bedside ultrasonography is a standard component of clinical care at the investigation site.

2.2. Selection of subjects

This was a prospective cross-sectional study of a convenience sample of patients hospitalized in the surgical intensive care unit of an urban 695-bed tertiary care level 1 trauma center. It is staffed at all times by board-certified intensivists. A total of 70 patients were prospectively enrolled by investigators who were unaware of the patient's clinical history and were blinded to both noninvasive and invasive hemodynamic monitoring data. Inclusion criteria included a request from the critical care team for a focused bedside TTE, the presence of an invasive vascular monitor (central venous or pulmonary artery catheter), and an investigator available to perform bedside TTE. No exclusion criteria existed.

2.3. Ultrasound examinations

Examinations were conducted with a C15/4-2 MHz tightly curved array transducer on portable ultrasound unit (Sonosite Titan, Sono, Inc, Bothwell, Wash). Investigators were composed of emergency medicine faculty, emergency medicine ultrasound fellows, and senior emergency medicine residents. As a prerequisite, all investigators had spent at least 200 hours performing bedside ultrasonography in the ED for noncardiac applications. Before the study commencement, investigators underwent a 3-hour training program developed by the emergency ultrasound director (AJD) focusing on intravascular volume assessment using inferior vena cava measurements and LVEF estimation using 5 standard TTE views (parasternal long axis [PSLA], parasternal short axis [PSSA], subxiphoid 4-chamber [SXFC], subxiphoid short axis [SXSA], and apical 4-chamber [AFC]; see Figs. 1-3). After the training, the investigators performed at least 10 proctored and reviewed echocardiographic examinations before enrolling patients in the study. All patients were studied in a strictly supine position without mobilization to a left lateral position. Duplicate examinations of the same patient by the same investigator were not included in the preferred view analysis. If 2 or more investigators studied the same patient, data were taken from the investigator who reported using the most cardiac windows, or if reported views were equal, from the investigator with fewer studies included in the final analysis. Duplicate examinations used for the interobserver



correlation analysis of LVEF estimation were performed within 24 hours of one another.

2.4. Data collection

All information was recorded by the investigator performing the ultrasound examination on a standardized datasheet, which was completed at the patient's bedside immediately after ultrasonography. Investigators ranked their preference for each of the 5 standard cardiac ultrasonographic windows for determination of LVEF on a Likert scale from 1 to 5 (1 being least preferred, 5 being most preferred). Rankings were not mutually exclusive. In cases in which a standard cardiac window could not be obtained, because of external barriers (eg, bandages, chest tubes, wounds, etc), patient intolerance of the examination, or poor sonographic tissue transmission, investigators could indicate that the view was not obtained. Investigators were asked to make an estimate of LVEF based on their cumulative impression from obtained cardiac views, rounded to the nearest 5%. No calculated measurements of LVEF were made. Datasheets included demographic information, vital signs, and invasive hemodynamic and ventilation data, if applicable. This information was filled out by a member of the intensivist team and was not available to the ultrasound investigator until after the completion of his or her examination.

2.5. Data analysis

Initial analysis of differences between preferred view utility scores was made using a Kruskal-Wallis test. Absolute differences between individual groups were analyzed using the Mann-Whitney *U* test. Data are reported as percentages and mean values with 95% confidence intervals. Interobserver agreement of LVEF estimation was determined using the Pearson correlation coefficient. All statistical calculations were performed using NCSS (Kayesville, UT).

3. Results

A total of 70 examinations performed on 70 patients by 7 separate investigators were used for analysis (range, 10%-20% of total examinations per investigator). Patient demographics are shown in Table 1. Fifty-nine percent of the patients were mechanically ventilated at the time of cardiac ultrasound examination. Using the average reported 5-point Likert scale for utility of a cardiac window for determination

Fig. 1 The subxiphoid window. (A) shows transducer placement and pointer orientation to obtain the subxiphoid 4-chamber view (4-Ch). The probe is rotated 90° clockwise to obtain the subxiphoid short-axis view (SA). (B) and (C) show images of the SXFC and the SXSA views, respectively. RA indicates right atrium; RV, right ventricle; LV, left ventricle; LA, left atrium; Li, liver; Ao, aorta.

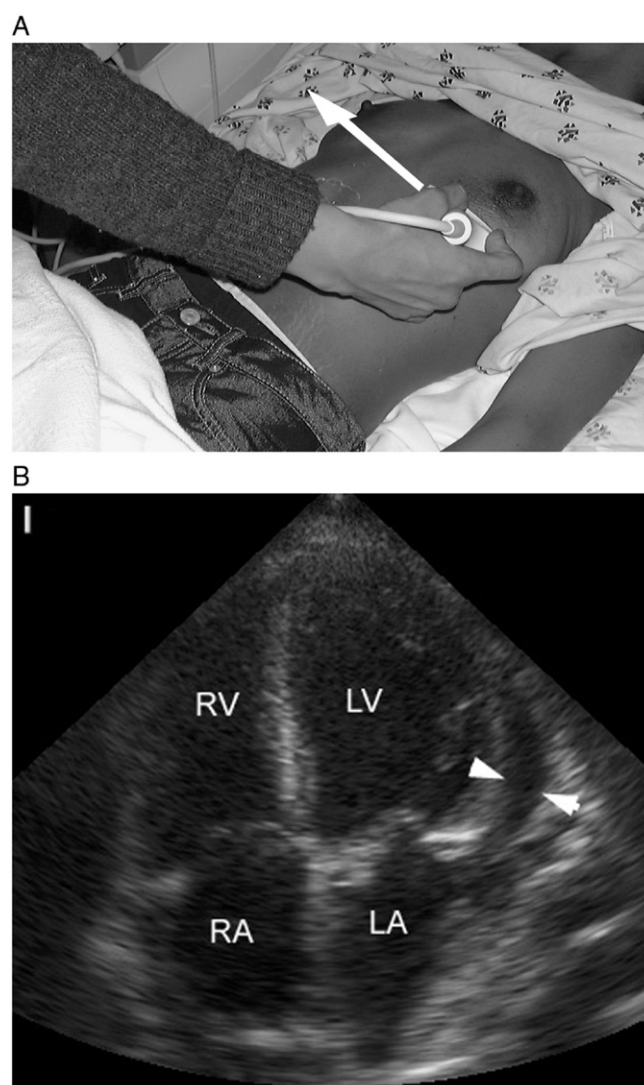
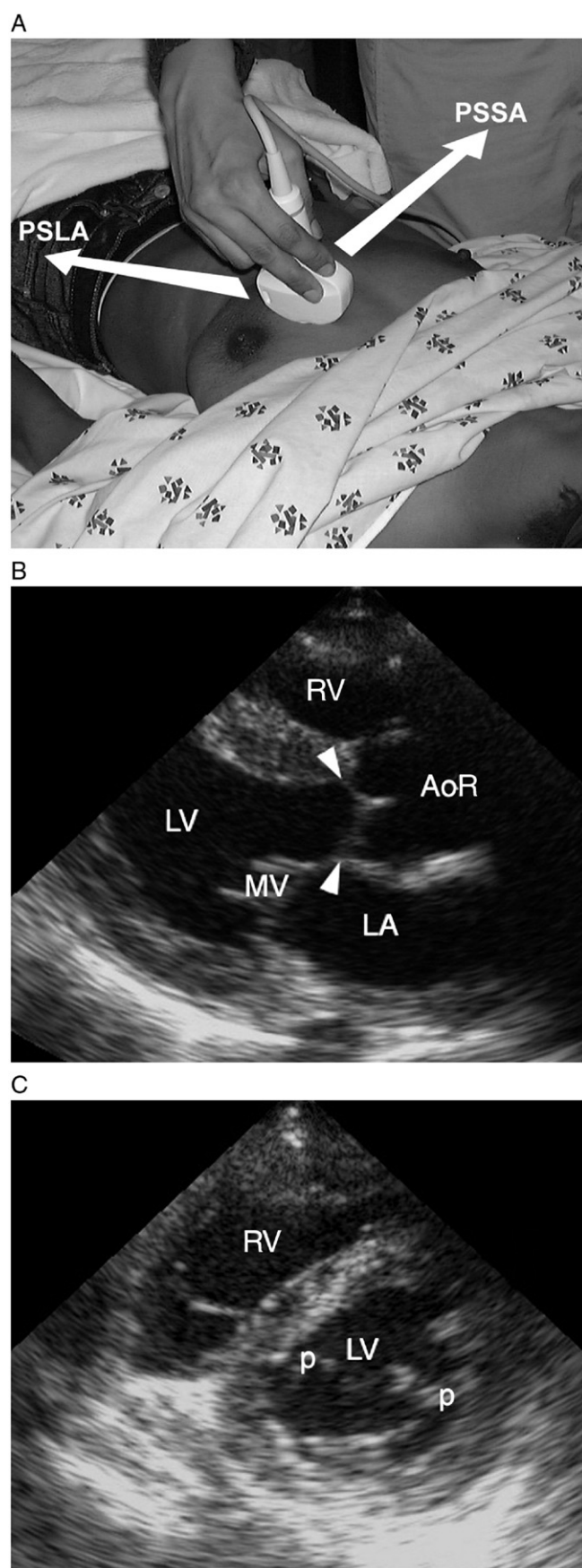


Fig. 3 The apical window. (A) shows transducer position and pointer orientation for the AFC view of a heart with a pericardial effusion. (B) shows an ultrasound image of the AFC view. Arrowheads indicate pericardial effusion.

of LVEF, we determined the PSLA view to be the most preferred (mean, 4.23; 95% confidence interval, 3.95-4.51; Table 2). After the PSLA view, the preferred views in descending order were the PSSA, AFC, SXFC, and SXSA. Complete 5 view examinations were not achieved in all patients (PSLA in 98%, PSSA in 96%, AFC in 74%, SXFC in 35%, and SXSA in 18%). Interobserver investigator correlation of LVEF estimation was determined using 17 patients in whom a focused cardiac ultrasound was

Fig. 2 The parasternal window. (A) shows transducer placement and pointer orientation to obtain the PSLA view. The probe would be rotated 90° clockwise to obtain the PSSA view. (B) and (C) show images of the PSLA and PSSA views, respectively. MV indicates mitral valve; AoR, aortic root; p, papillary muscle; arrow heads, aortic valve.

Table 1 Patient demographics ($n = 70$)

Age, mean \pm SD	52.3 \pm 18.4 y
Male, n (%)	37 (52.8%)
Intubated, n (%)	41 (59%)
Pulmonary artery catheter, n (%)	16 (23%)

performed by 2 separate investigators within a 24-hour period. Correlation was found to be good ($r = 0.86$, $r^2 = 0.74$; Fig. 4).

4. Discussion

Many diseases, including coronary artery disease, sepsis, and trauma, can result in hypotension from intravascular hypovolemia as well as direct and/or indirect myocardial injury [10–12]. Methods currently used to determine cardiac and intravascular volume status include central venous pressure and oxygen saturation monitors, pulmonary artery catheters, systemic arterial catheters, esophageal Doppler monitors, transesophageal echocardiography, and TTE. Historically, these devices have been considered to be the standard in the management of critical illness, but they are invasive, time consuming, and resource intensive, and there is no consensus on their indications or accuracy [13–15]. Invasive methods have potential morbidities associated with their use, and several studies have suggested at best clinical equipoise and at worst increased mortality in patients exposed to invasive monitoring devices [16–18]. For these reasons, the development of noninvasive tools and/or methods to estimate volume status and cardiac function is highly appealing [19].

Many studies have shown that clinically important echocardiographic information can be attained by clinician-sonographers including EPs, surgical intensivists, and medical students, after only brief, focused training periods [4,20–22]. The ability of clinician sonographers to determine LVEF within the broad, clinically pertinent categories of “normal,” “moderately decreased,” and “severely decreased” has been repeatedly demonstrated [7,8,22]. Gross visual estimates of ejection fraction have been shown to be as accurate as those attained by complex and time-consuming computational techniques [23,24]. Clinician-performed bedside TTE has also been shown to be useful in the

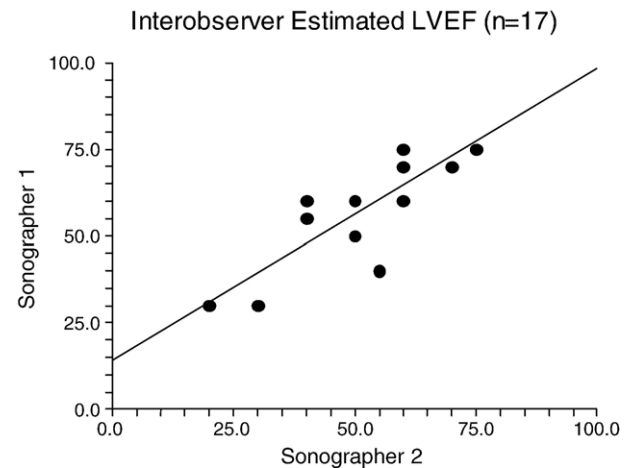


Fig. 4 Scatter plot of interobserver correlation of LVEF estimation. Calculation of Pearson's correlation coefficient revealed $r = 0.86$ and $r^2 = 0.74$ ($P < .0001$).

emergent management of hypotensive patients [9,25]. A recent study further demonstrated the usefulness of intensivist-directed focused bedside TTE in the setting of critical illness, with particular emphasis on fluid and vasoactive medication management [4].

Although clinician-performed bedside TTE has been proven to be reliable and useful, as outlined above, the preferred cardiac view(s) for LVEF estimation by clinician-directed TTE has not been previously reported to our knowledge. This study found that among EP sonographers performing focused bedside TTE using a tightly curved array transducer in critically ill surgical patients, the precordial windows (PSLA, PSSA, and AFC) were highly favored over the subxiphoid windows for the estimation of LVEF. Of these, the PSLA appears to be the most useful single view, followed closely by PSSA. This is an important consideration in this population owing to the frequent presence of physical barriers to optimal echocardiographic evaluation, such as abdominal and thoracic dressings and wounds, which inhibit effective subcostal examination in a large proportion of surgical patients. Our finding is interesting in light of the fact that current literature on echocardiography in the critically ill notes that transthoracic windows are difficult to achieve, owing to patient immobility and lung hyperinflation secondary to mechanical ventilation, and thus subcostal views are recommended [12]. Given the low percentage of patients in whom subcostal

Table 2 Preferred bedside cardiac ultrasonographic windows

	PSLA	PSSA	AFC	SXFC	SXSA
% Examinations with window used	98%	96%	74%	35%	18%
Average utility (5 maximum)	4.23 \pm 0.28 ^a	3.97 \pm 0.33 ^b	3.62 \pm 0.36 ^c	2.80 \pm 0.44 ^d	2.20 \pm 0.70

^a $P = .23$ vs PSSA, $P = .0041$ vs AFC, $P < .0001$ vs SXFC and SXSA.

^b $P = .0859$ vs AFC, $P < .0001$ vs SXFC and SXSA.

^c $P = .0046$ vs SXFC, $P = .0009$ vs SXSA.

^d $P = .1023$ vs SXSA.

views were obtained in this study, this strategy may not be as readily applicable in the surgical intensive care unit population. Fortunately, parasternal views were achieved and deemed useful in the vast majority of patients for the purpose of estimating LVEF.

To assure that investigators demonstrated reasonable interobserver agreement in their visual estimates of LVEF, a subset of patients had duplicate examinations performed. Prior studies of clinician ability to estimate LVEF accurately in comparison to formal echocardiography indicate reasonable concordance with minimal training requirements [4,7-9]. These studies used either planimetry, M-mode measurements in short axis, or visual estimation in 2 orthogonal planes to determine LVEF. Our study used the latter method, which has been previously validated in comparison to the former 2 methods [26,27]. This method of LVEF estimation was further validated by measuring the interobserver correlation between investigators in the study, which was found to be highly reliable. This indicates that our results were unlikely to be biased by those investigators who performed the most examinations.

Limitations of our study include a lack of standardization for view preference and ejection fraction determination. However, we feel the methods used here are adequate to determine the value of various cardiac views using a handheld ultrasound machine to estimate LVEF at the bedside of a critically ill patient. Regarding LVEF estimation, we report interobserver correlation not as an indicator of measurement accuracy, but as a marker of reproducibility to ensure relative uniformity of examination ability between investigators. As prior studies have proven that EPs are accurate in their ability to estimate LVEF using TTE [7-9], we did not feel it was necessary to validate these findings when designing our initial study protocol, although it is admittedly a shortcoming of our current data.

In addition, it should be noted that our findings should only be considered when using tightly curved and phased array transducers and cannot be extrapolated to standard convex transducers such as the one depicted in the accompanying figures. The wide footprint used by convex transducers makes intercostal space examination, required for parasternal and apical view acquisition, technically inadequate in most cases. As some bedside ultrasound machines currently used in EDs and intensive care units may not be equipped with these transducers, this must be taken into consideration.

Future directions include the incorporation of tissue Doppler measurements to assess for elevated left ventricular diastolic pressures, as well as the use of lung ultrasound to assess for pulmonary edema not evident by auscultation or chest roentogram [28-31]. These are important diagnostic considerations given the large prevalence of heart failure with preserved systolic function (ie, diastolic heart failure) in ED and intensive care unit populations.

In summary, PSLA and PSSA are the preferred cardiac windows for bedside TTE estimation of LVEF in a critically ill surgical population. Visual estimates of LVEF using these

windows are highly reproducible between EP sonographers with minimal training.

References

- [1] Cortez A, Zito J, Lucas CE, et al. Mechanism of inappropriate polyuria in septic patients. *Arch Surg* 1977;112:471-6.
- [2] Rady MY, Rivers EP, Nowak RM. Resuscitation of the critically ill in the ED: responses of blood pressure, heart rate, shock index, central venous oxygen saturation, and lactate. *Am J Emerg Med* 1996;14:218-25.
- [3] Rivers E, Nguyen B, Havstad S, et al. Early goal-directed therapy in the treatment of severe sepsis and septic shock. *N Engl J Med* 2001;345:1368-77.
- [4] Manasia AR, Nagaraj HM, Kodali RB, et al. Feasibility and potential clinical utility of goal-directed transthoracic echocardiography performed by noncardiologist intensivists using a small hand-carried device (SonoHeart) in critically ill patients. *J Cardiothorac Vasc Anesth* 2005;19:155-9.
- [5] Kobal SL, Atar S, Siegel RJ. Hand-carried ultrasound improves the bedside cardiovascular examination. *Chest* 2004;126(3):693-701.
- [6] Sanfilippo AJ, Weyman AE. The role of echocardiography in managing critically ill patients. *J Crit Illn* 1998;13:27-44.
- [7] Randazzo MR, Snoey ER, Levitt MA, et al. Accuracy of emergency physician assessment of left ventricular ejection fraction and central venous pressure using echocardiography. *Acad Emerg Med* 2003;10:973-7.
- [8] Moore CL, Rose GA, Tayal VS, et al. Determination of left ventricular function by emergency physician echocardiography of hypotensive patients. *Acad Emerg Med* 2002;9:186-93.
- [9] Pershad J, Myers S, Plouman C, et al. Bedside limited echocardiography by the emergency physician is accurate during evaluation of the critically ill patient. *Pediatrics* 2004;114:667-71.
- [10] Kaarlola A, Tallgren M, Pettila V. Long-term survival, quality of life, and quality-adjusted life-years among critically ill elderly patients. *Crit Care Med* 2006;34:2120-6.
- [11] Maeder M, Fehr T, Rickli H, et al. Sepsis-associated myocardial dysfunction: diagnostic and prognostic impact of cardiac troponins and natriuretic peptides. *Chest* 2006;129:1349-66.
- [12] Price S, Nicol E, Gibson DG, et al. Echocardiography in the critically ill: current and potential roles. *Intensive Care Med* 2006;32:48-59.
- [13] Kumar A, Anel R, Bunnell E, et al. Pulmonary artery occlusion pressure and central venous pressure fail to predict ventricular filling volume, cardiac performance, or the response to volume infusion in normal subjects. *Crit Care Med* 2004;32:691-9.
- [14] Shah MR, Hasselblad V, Stevenson LW, et al. Impact of the pulmonary artery catheter in critically ill patients: meta-analysis of randomized clinical trials. *JAMA* 2005;294:1664-70.
- [15] The ESCAPE Investigators and ESCAPE Study Coordinators. Evaluation study of congestive heart failure and pulmonary artery catheterization effectiveness: The ESCAPE trial. *JAMA* 2005;294:1625-33.
- [16] The National Heart, Lung, and Blood Institute Acute Respiratory Distress Syndrome (ARDS) Clinical Trials Network. Pulmonary-artery versus central venous catheter to guide treatment of acute lung injury. *N Engl J Med* 2006;354:2213-24.
- [17] Sandham JD, Hull RD, Brant RF, et al. Randomized, controlled trial of the use of pulmonary-artery catheters in high-risk surgical patients. *N Engl J Med* 2003;348:5-14.
- [18] Richard C, Warszawski J, Anguel N, et al. Early use of the pulmonary artery catheter and outcomes in patients with shock and acute respiratory distress syndrome: a randomized controlled trial. *JAMA* 2003;290:2713-20.
- [19] Shoemaker WC, Wo CC, Chien LC, et al. Evaluation of invasive and noninvasive hemodynamic monitoring in trauma patients. *J Trauma* 2006;61:844-53.

- [20] Habib FA, McKenney MG. Surgeon-performed ultrasound in the ICU setting. *Surg Clin North Am* 2004;84:1151-79.
- [21] Alexander JH, Peterson ED, Chen AY, et al. Feasibility of point-of-care echocardiography by internal medicine house staff. *Am Heart J* 2004;147:476-81.
- [22] DeCara JM, Kirkpatrick JN, Spencer KT, et al. Use of hand-carried ultrasound devices to augment the accuracy of medical student bedside cardiac diagnoses. *J Am Soc Echocardiogr* 2005;18:257-63.
- [23] Mueller X, Stauffer JC, Jaussi A, et al. Subjective visual echocardiographic estimate of left ventricular ejection fraction as an alternative to conventional echocardiographic methods: comparison with contrast angiography. *Clin Cardiol* 1991;14:898-902.
- [24] Amico AF, Lichtenberg GS, Reisner SA, et al. Superiority of visual versus computerized echocardiographic estimation of radionuclide left ventricular ejection fraction. *Am Heart J* 1989;118:1259-65.
- [25] Joseph MX, Disney PJ, Da Costa R, et al. Transthoracic echocardiography to identify or exclude cardiac cause of shock. *Chest* 2004;126:1592-7.
- [26] Stamm RB, Carabello BA, Mayers DL, et al. Two dimensional echocardiographic measurement of left ventricular ejection fraction: prospective analysis of what constitutes an adequate determination. *Am Heart J* 1982;104:136-44.
- [27] Amico AF, Lichtenberg GS, Reisner SA, et al. Superiority of visual versus computerized echocardiographic estimation of radionuclide left ventricular ejection fraction. *Am Heart J* 1989;118:1259-65.
- [28] Ommen SR, Nishimura RA, Appleton CP, et al. Clinical utility of Doppler echocardiography and tissue Doppler imaging in the estimation of left ventricular filling pressures: A comparative simultaneous Doppler-catheterization study. *Circulation* 2000;102:1788-94.
- [29] Lichtenstein D, Meziere G, Biderman P, et al. The comet tail artifact. An ultrasound sign of alveolar-interstitial syndrome. *Am J Respir Crit Care Med* 1997;156:1640-6.
- [30] Volpicelli G, Mussa A, Garofalo G, et al. Bedside lung ultrasound in the assessment of alveolar-interstitial syndrome. *Am J Emerg Med* 2006;24:689-96.
- [31] Agricola E, Picano E, Oppizzi M, et al. Assessment of stress-induced pulmonary interstitial edema by chest ultrasound during exercise echocardiography and its correlation with left ventricular function. *J Am Soc Echocardiogr* 2006;19:457-63.