

# Clinical impact and efficacy of bedside echocardiography on patient management in pediatric intensive care units (PICUs): A prospective study

Sanliay Şahin, Mutlu Uysal Yazıcı<sup>1</sup>, Ganime Ayar, Tülin Köksal, İbrahim İlker Çetin\*, Filiz Ekici\*, Abdullah Kocabaş\*

Department of Pediatric Intensive Care and \*Cardiology Division, Ankara Children's, Hematology Oncology Education and Research Hospital; Ankara-Turkey

<sup>1</sup>Department of Pediatric Intensive Care Unit, Hacettepe University İhsan Doğramacı Children's Hospital; Ankara-Turkey

## ABSTRACT

**Objective:** To determine the indication and necessity of echocardiographic assessment and therapeutic interventions in critically ill children.

**Methods:** A total of 140 children, including 75 mechanically ventilated (MV) and 65 spontaneously breathing (SB) children, who were admitted consecutively from March to August 2013 were evaluated prospectively. Data regarding the indication for echocardiography and therapeutic approaches used were documented. For evaluating disease severity, the Pediatric Risk of Mortality Score III (PRISM) was ascertained. The correlation between PRISM score and the requirement of echocardiographic evaluations were analyzed.

**Results:** Patients ages were between 45 days to 18 years. The male-to-female ratio was 1.33. In 35.4% patients who underwent echocardiographic evaluation, no definitive alteration occurred in treatment approach, whereas in the remaining 64.6% patients, decisive or supplemental information was gathered. Echocardiography was indicated in 88% MV children and 46.2% SB children. Echocardiographic evaluation was necessary in MV children and there was a positive correlation between the PRISM score and the requirement of echocardiographic assessment ( $p < 0.001$ ).

**Conclusion:** Echocardiographic evaluation is an invaluable tool especially in MV children and the requirement of echocardiographic assessment increases according to clinical severity. Basic training for intensivists in this procedure is crucial and needs to be improved and supported in critically ill. (*Anatol J Cardiol* 2017; 18: 136-41)

**Keywords:** critically ill children, echocardiography, intensivist, mechanical ventilation, pediatric intensive care unit, training

## Introduction

To date, echocardiography has been used as an adjunct in predicting patient outcomes. Relevant and easily obtainable information about hemodynamics is required for effective therapeutic manipulation of circulation in critically ill children. Hemodynamic monitoring of critically ill infants and children noninvasively using echocardiography has been evaluated comprehensively (1–7). Echocardiography is an influential procedure that allows direct visualization of the heart, guiding patients' hemodynamic condition at the bedside. This hemodynamic estimate informs physicians to guide therapeutic approaches like volume resuscitation, initiation/discontinuation/alteration of vasopressor therapy and referral for specialist rapidly if cardiac or surgical attempt is necessary. Although there is plentiful evidence

regarding the use of echocardiography, clinicians lack data in the pediatric critical care field (8). In adults, WINFOCUS (World Interactive Network Focused on Critical Ultrasound) has outlined the ideal conditions and recommendations for intensivists' education, getting accredited for the use of echocardiography in the intensive care setting and the practical aspects of building an ICU-based echocardiography service (9). The Portuguese Working Group on Echocardiography has improved a skill-based program, FADE (Fast Assessment Diagnostic Echocardiography) to teach physicians in the use of bedside ultrasound as a diagnostic and follow-up instrument for critical patients (8). However; to our knowledge there are only two training programs that implemented a training curriculum for pediatric intensivists to perform fast and primary echocardiography allowing rapid modifications in treatment at the bedside (10–12). The use of echocardiography

Our article has been selected for Poster presentation and presented at the 5<sup>th</sup> Congress of the European Academy of Paediatric Societies– EAPS 2014, Barcelona, SPAIN.

**Address for correspondence:** Dr. Sanliay Şahin, Ankara Çocuk Hematoloji ve Onkoloji Eğitim ve Araştırma Hastanesi, Pediatrik Yoğun Bakım Ünitesi, Ankara-Türkiye  
E-mail: sanliay@yahoo.com

**Accepted Date:** 27.04.2017 **Available Online Date:** 21.06.2017

©Copyright 2017 by Turkish Society of Cardiology - Available online at [www.anatoljcardiol.com](http://www.anatoljcardiol.com)  
DOI:10.14744/AnatolJCardiol.2017.7659



in pediatric intensive care unit s (PICUs) is likely to become routine in the future. We believe that it is a good idea for the bedside clinician to be adept at basic echocardiographic evaluation that may influence ongoing therapy in a patient even though the parameters that may be useful remain unidentified. Therefore we aimed to find out indications for echocardiographic assessment in critically ill children, the relationship between the necessity and clinical severity of patients evaluated using the PRISM score and mechanical ventilation status, and to verify the therapeutic interventions performed after echocardiographic evaluation.

## Methods

After approval from the local ethics committee, we collected the data of 140 children, which included 75 mechanically ventilated (MV) and 65 spontaneously breathing (SB) children who were admitted to the PICU of Ankara Hematology Oncology Children's Education and Research hospital consecutively over a time period from March 2013 to August 2013. The design of the study was prospective. A total of 186 children were admitted to the unit between these dates. Forty-six patients with duration of admission in PICU <48 hours and who was admitted and discharged on weekends/public holidays, and therefore not personally observed by the authors, were excluded. The PICU is a 14-bed, multidisciplinary, tertiary referral center in which nearly 450 patients are followed-up annually. Children with all types of diseases with a high risk of organ dysfunction who admitted to PICU independent of the underlying disease were eligible for the study. The analysis of multiple organ dysfunction syndrome (MODS) was accomplished according to the Wilkinson's adapted criteria for children (13). The MV children had evident failure of at least one vital organ (respiratory) according to pediatric MODS criteria. For the assessment of disease severity, the Pediatric Risk of Mortality Score III (PRISM) was used (14). The age group of the admitted children ranged from 45 days to 18 years. According to the diagnosis, all patients were subjected to anamnesis, physical examination, and routine laboratory investigations. All children were monitored for parameters related to the cardiovascular system, respiratory system and urine output. According to the primary diagnosis at PICU admission, patients were classified into subgroups, which is detailed at Table 1. Demographic data like age; gender; weight; PRISM III; primary illness; manifest organ failure; mechanical ventilation type [noninvasive, invasive, or HFOV (high-frequency mechanical ventilation)]; mechanical ventilation duration; PICU stay length; echocardiography indications; cardiovascular and hemodynamic parameters that require cardiac evaluation like hypotension, hypertension, arrhythmia, and symptoms suggesting congestive heart failure (i.e., dyspnea, edema, hepatomegaly) were collected and documented prospectively for statistical evaluation.

Distribution of patients according to echocardiographic findings were determined as follows: normal cardiac findings, heart disease requiring medical treatment/surgical intervention (pres-

**Table 1. Demographic characteristics of the patients**

Variables	MV (n=75)	SB (n=65)	P
<b>Age, years, Mean±SD, median</b>	4±5.1 (1.9)	8.1±6.3 (6)	p<0.001
0–1	31 (41.3)	10 (15.4)	
1–5	26 (34.7)	17 (26.2)	
5–10	4 (5.3)	15 (23.1)	
10–15	9 (12)	6 (9.2)	
>15	5 (6.7)	17 (26.2)	
<b>Gender</b>			
Male, n (%)	42 (56)	38 (58.5)	p>0.05
Female, n (%)	33 (44)	27 (41.5)	
<b>Weight, kg, Mean±SD, median</b>	15.8±17.7 (9.2)	30.7±23.3 (22)	p<0.001
<b>PRISM III Mean±SD, median</b>	17.1±9.3 (14)	7.2±8.4 (5)	p<0.001
<b>Primary illness, n (%)</b>			p<0.05
Infectious diseases	18 (24)	17 (26.2)	
Cardiogenic	7 (9.3)	2 (3.1)	
Pulmonary	6 (8)	1 (1.5)	
Neurological	16 (21.3)	8 (12.3)	
Hematological–oncological	9 (12)	6 (9.2)	
Metabolic	6 (8)	2 (3.1)	
Nephrological	–	1 (1.5)	
Endocrinological	1 (1.3)	1 (1.5)	
Gastroenterological	2 (2.7)	–	
Trauma/postoperative care	9 (12)	1 (1.5)	
Poisoning	1 (1.3)	26 (40)	
<b>MODS criteria, n (%)</b>			
Cardiovascular	32 (42.7)	8 (12.3)	
Respiratory	75 (100)	9 (13.8)	
Neurological	67 (89.3)	28 (43.1)	
Hematological	19 (25.3)	10 (15.4)	
Renal	11 (14.7)	1 (1.5)	
Hepatic	22 (29.3)	8 (12.3)	
<b>MV, n (%)</b>			p<0.001
Noninvasive	22 (29.3)	–	
Invasive	72 (96)	–	
HFOV	1 (1.3)	–	
<b>Duration of MV, days, Mean±SD, median</b>			
Noninvasive	3.7±2.2 (3)	–	
Invasive	16.3±17.9 (9)	–	
HFOV	2 days	–	
<b>PICU Stay Length, days</b>	20.6±20.7 (13)	3.3±3.0 (2)	p<0.001

ence of serious structural heart defects with significant left-right shunts, severe congenital valve malformations, significant patent arterial duct, dilated and hypertrophic cardiomyopathies, tetralogy of Fallot, Pompe disease, pulmonary hypertension, intracardiac thrombus, idiopathic hypertrophic subaortic stenosis, myocarditis, left ventricular hypertrophy secondary to hypertension), and heart disease not requiring medical/surgical treatment with only follow-up recommended (insignificant structural heart defects and mild congenital valve malformations, patent foramen ovale, small patent arterial duct, minimal pericardial effusion, subclinical hypoxic damage of the heart).

In our center, protective conventional mechanical lung ventilation was employed with positive pressure ventilation (15). Mechanical lung ventilation was executed in collaboration with volume treatment, parenteral and enteral nutrition and medical support of circulation. We prefer minimally invasive procedures to gather clinically useful hemodynamic data. The attending PICU physician evaluates the hemodynamic condition of the patient as part of the routine and indicates echocardiography if necessary. Transthoracic echocardiography (TTE) was performed at bedside by the pediatric cardiologist and the echocardiographic evaluation of cardiac performance was repeated according to clinical necessity. Severe circulatory symptoms, such as reduction or rise in systemic pressures, arrhythmia, symptoms suggesting congestive heart failure and changing medical conditions were indications for consecutive investigations.

Patients were categorized to six groups according to indication for assessment of echocardiography;

1. Cardiac murmur/suspected cardiac disease
2. Hypotension/Shock
3. Hypertension
4. Arrhythmia
5. Symptom suggesting congestive heart failure (i.e., dyspnea, edema, hepatomegaly)
6. Others; postcardiac arrest, acute pneumothorax/pleural effusion, initiation of renal replacement therapy/chemotherapy, refractory hypoxia, organ donation, intractable drug therapy, postoperative hemodynamic problems, severe acidosis, acute changes in serum calcium levels, troublesome seizures, chronic lung disease, preoperative evaluation/before invasive procedures (i.e., tracheostomy, bronchoscopy, installing ports), detailed in Table 2.

The echocardiographic examination was performed by a pediatric cardiologist using commercially available Doppler system (GE Vivid I; GE Medical Systems, Milwaukee, WI) and a Pedoff transducer (3-MHz frequency). Two dimensional, M-mode, color-Doppler and spectral flow imaging were implemented according to the recommendations of professional communities (16, 17).

Therapeutic interventions performed after echocardiography is recorded as: insignificant cardiac problem—follow-up recommended, fluid replacement and regulation of vasopressor therapy, regulation of antihypertensive therapy and recommendation/regulation of antiarrhythmic therapy, cardiac surgery and

**Table 2. Indications of echocardiography**

Indication	MV (n=66)	SB (n=30)	P
Cardiac murmur/Suspected cardiac disease, n (%)	3 (4.5)	4 (13.2)	p<0.05
Hypotension/Shock, n (%)	24 (36.2)	4 (13.2)	p<0.001
Hypertension, n (%)	6 (9)	3 (10)	p<0.05
Arrhythmia, n (%)	9 (13.6)	7 (23.1)	p<0.05
Congestive heart failure symptom, n (%)	2 (3)	1 (3.3)	p<0.05
Pulmonary hypertension	5 (6.7)	2 (3.1)	p>0.05
Others, n (%)	22 (33.2)	11 (33.3)	p<0.05
Postcardiac arrest	3 (4.5)	0	
Refractory hypoxia	3 (4.5)	1 (3.3)	
Organ donation	1 (1.5)	0	
Initiation of renal replacement therapy/Chemotherapy	5 (7.6)	6 (19.8)	
Trauma/Postsurgery hemodynamic problems	6 (9)	1 (3.3)	
Severe acidosis (Metabolic disease)	1 (1.5)	2 (6.7)	
Preoperative evaluation/before invasive procedures	3 (4.5)	1 (3.3)	

others [initiation or alteration of drug therapy (i.e., anticoagulation, prophylaxis of infective endocarditis, regulation of sedative/analgesic drugs), and treatment of pulmonary hypertension]. At the same time; effect of echocardiography to medications; if it helped in decision making or provided a supplemental information or if it has no effect on patient's treatment was recorded.

### Statistical analysis

All the data were analyzed using software; SPSS for Windows 20 (Statistical Package For Social Sciences Inc., Chicago, IL). According to Kolmogorov–Smirnov and Shapiro–Wilk normality tests, none of the variables were normally distributed. Therefore, the collected data were analyzed using the Mann–Whitney U test and Spearman correlation coefficient was applied to analyze positive correlations between the variables. A p value of <0.05 was considered as statistically significant.

### Results

Demographic characteristics of the patients are listed on Table 1. The male-female ratio was 1.33. Mean age was 5.9±6.0 (median=3) years. Echocardiography was indicated in 88% (n=66) of MV children and 46.2% (n=30) of SB children by PICU clinician. A total of 186 echocardiographic examinations were performed according to clinic urgency, 137 in MV and 49 in SB children respectively. Number of echocardiographic assessments were 2.8±1.4 times (median 2) in the MV group and 1.6±0.9 times (median 1) in the SB group.

Echocardiography indications are summarized in Table 2, and the therapeutic interventions performed after echocardiographic evaluation (some patients were evaluated more than once and some had more than one cardiac problem) are listed in Table 3. Symptoms of circulatory compromise, reduction or rise in systemic pressures, arrhythmia, and congestive heart failure were indications for consecutive echocardiographic investigations. In 35.4% (n=34) of all patients who underwent echocardiographic assessment, no definitive change was made in the treatment approach; on the other hand, in 64.6% (n=62) of all patients decisive or supplemental (clinically important) information was gathered. Echocardiography confirmed the clinical impression and frequently resulted in a change in management or prompted additional investigations. In our study, 12 (16%) of MV children and 3 (10%) of SB children required a multidisciplinary approach; thus, additional consultations and investigations were required.

The study demonstrated that the necessity of echocardiographic evaluation was more prevalent in the MV group ( $p<0.001$ ) than the SB group. In addition, there was a positive correlation between PRISM score and the requirement of echocardiographic evaluation ( $r=0.26$ ) and this was statistically significant ( $p=0.002$ ,  $p<0.05$ ).

## Discussion

In this study we aimed to determine the indication and need for echocardiographic assessment in critically ill children and according to our results, the need for echocardiographic evaluation was higher in MV children, and the severity of the patients significantly increased the requirement. An ultrasound or an echocardiographic machine is usually available in most centers. Bedside echocardiography can image the great veins, ventricular size, and contractility, and is an important, noninvasive, portable, and rapid diagnostic instrument in the PICU facilitating detection of reversible and time dependent conditions early (18–20). Some authors point out that a remarkable change in treatment occurs in only a small percentage of adult patients (21), whereas some other show that a significant change in management resulted in most of the patients (19, 22, 23). In our study, a decisive or supplemental information was obtained in 64.6% patients. To our knowledge, studies available in literature are very few in this regard (11, 23, 24) and our study is first to be conducted prospectively comparing the two groups. Stanko and coauthors reported that TTE resulted in a change in the diagnosis and management frequently (25). According to Kobr et al. (26), repeated bedside echocardiography was a useful addition to the inclusive hemodynamic monitoring of critically ill children because it complements standard monitoring about the cardiac status. Some studies confirm that the monitoring of changes in myocardial performance indexes provides valuable information (26–29) and their methodology can be performed by a trained intensivist (26). A study conducted in children with septic shock showed that bedside echocardiography was

**Table 3. Therapeutic interventions performed after echocardiography**

Intervention	MV n (%)	SB n (%)
Insignificant cardiac problem —Follow-up recommended	12 (18.1)	12 (40)
Fluid replacement and regulation of vasopressor therapy	44 (58.7)	3 (10)
Regulation of antihypertensive therapy	12 (16)	2 (6.7)
Recommendation/regulation of antiarrhythmic therapy	16 (21.3)	7 (23.1)
Cardiac surgery	3 (4.5)	Ø
Congestive heart failure treatment	8 (10.7)	1 (3.3)
Others	13 (19.7)	2 (6.7)
Pulmonary Hypertension therapy	5 (7.6)	1 (3.3)
Initiation/discontinuation/ alteration of other drugs	8 (12.1)	1 (3.3)
Additional investigations/ consultations recommended	12 (18.1)	3 (10)
*Some patients had more than one cardiac problem and underwent more than one assessment		

useful in assessing children in shock (30). Also Pershad et al. (20) determined that bedside limited echocardiography by the emergency physician (BLEEP) can be performed with focused training, and the images captured by BLEEP were of adequate quality when judged by an objective pediatric cardiologist. They suggested that BLEEP examination may provide unbiased, rapid, noninvasive information about ventricular function and right ventricular filling in critically ill pediatric patients in emergency department (20). The WINFOCUS experience has suggested the ideal conditions and recommendations for intensivists education in adults, getting accreditation for the use of echocardiography in the intensive care setting (9). At the same time, the Portuguese Working Group on Echocardiography has improved the skill-based program FADE to teach clinicians the use of bedside ultrasound to level-1 competency in echocardiography and chest ultrasound, enabling intensivists to determine major causes of hypotension, respiratory failure, and the need for a second opinion. Consistent with the literature, in our study the most common indications were hypotension (23) and assessment of left ventricular function.

Education and accreditation programs aiming to provide level-1 proficiency adapted to national needs and sensitivities are appearing in many countries and there are obvious national differences in education and accreditation programs, even for cardiologists (8). As far as we know, there is few training programs which implemented a training curriculum for pediatric intensivists to perform fast and primary echocardiography (12), which one of them allows the treatment to be arranged rapidly at the bedside in a tertiary, non-cardiac PICU as well as training intensivists established within their fellowship curriculum (11). In addition, in this study a pediatric cardiology specialist—who

was blinded to performer—scored and judged the image quality and interpretation with a global assessment which was striking. The credentialed providers had more precise image interpretation than the unsupervised noncredentialed group (10). Nevertheless, all intensive care echocardiography studies to date lacks a systematic training program at the institutional level (31) because the groups of patients admitted to PICU requires particular expertise relating to the specific needs, such as trauma, medical, and surgical conditions. Therefore, although many sources support the principle of training clinicians to perform echocardiography, the approach and the dataset still remains undefined.

In addition, we considered the methodology, parameter selection, and investigator experience while performing echocardiography during mechanical ventilation. In a previous study, authors stated that chest movement during mechanical ventilation does not decrease the quality of the obtained data (26). Restrictions of echocardiographic views are ventral pneumothorax or left-sided alveolar hyperinflation, which decreases image quality (32). Any inaccuracies were balanced when the same investigator assess all the measurements in each patient as in our study. Nevertheless all the above limitations do not decrease the importance of echocardiography because it is noninvasive, readily accessible, and repeatable for the assessment of cardiac performance (26). Khilnani et al. (33) stated that the use of bedside echocardiography by pediatric intensivists is evolving and fundamental but this may result in diagnostic and procedural mistakes without proper training and expertise. Formal training in courses of limited echocardiography obtained by intensivists has following limitations: learning curve is steep for the technique, there is interobserver variability, and interpretation is difficult in the presence of confounding factors—i.e., spontaneously breathing versus MV patients, raised intraabdominal pressure, low tidal volumes, and low lung compliance effects the assessment of echocardiography. There are few studies in adults regarding the feasibility and potential clinical utility of TTE performed by intensivists in critically ill patients with handheld devices (19, 34, 35). Also handheld ultrasound devices represent an alternative to standard echocardiographic systems in pediatric cardiology, so systems, including all echocardiographic modalities, offer unlimited versatility in intensive care (36). Baron et al. (37) reported that the use of echocardiography by intensivists under supervision of cardiologists goes together but still there is need for specific education in echocardiography for intensivists worldwide. Bedside echocardiography in critically ill children can sometimes be a dilemma because it depends on only pediatric cardiologists to come and evaluate on off hours and unfortunately we cannot consult a pediatric cardiologist for 24 hours. Even though PICU setting lacks the evidence supporting the introduction of echocardiography, we believe that training for intensivists in this technique, at least for basic echocardiography, is an emerging issue.

## Study limitations

As authors we are aware of limitations related to its design (single-centered) and the scarcity of existing opportunities in a developing country environment.

## Conclusion

In the light of our results; echocardiographic evaluation is an invaluable tool especially in MV children and the requirement of echocardiographic assessment increases according to clinical severity. This noninvasive monitoring tool helps intensivists in the adjustment of therapy in the PICU setting. We believe that the use of echocardiography by intensivists and pediatric cardiologists goes together. However, in the future, it can be used at the bedside in the hands of pediatric intensivists with adequate training and quality control for primary echocardiographic assessment. Training of intensivists in this regard is crucial and needs to be improved and encouraged in critically ill patients. Guiding future studies and formative programs regarding basic training are required to accomplish this expectation.

**Conflict of interest:** None declared.

**Peer-review:** Externally peer-reviewed.

**Authorship contributions:** Concept – S.Ş.; Design – G.A.; Supervision – İ.İ.Ç.; Materials – T.K.; Data collection &/or processing – M.U.Y., G.A., S.Ş.; Analysis and/or interpretation – İ.İ.Ç.; Literature review – M.U.Y.; Writer – S.Ş.; Critical review – F.E.; Other – A.K.

## References

1. Pratap UOV, Onuzo O, Kaplanova J, Franclin R, Radley-Smith R, Slavik Z. Myocardial performance index in children with ventricular septal defect. *Ces-slov Pediatr* 2004; 59: 271-4.
2. Eidem BW, O'Leary PW, Tei C, Seward JB. Usefulness of the myocardial performance index for assessing right ventricular function in congenital heart disease. *Am J Cardiol* 2000; 86: 654-8.
3. Tei C, Dujardin KS, Hodge DO, Bailey KR, McGoon MD, Tajik AJ, et al. Doppler echocardiographic index for assessment of global right ventricular function. *J Am Soc Echocardiogr* 1996; 9: 838-47.
4. Patel N, Mills JF, Cheung MM. Use of the myocardial performance index to assess right ventricular function in infants with pulmonary hypertension. *Pediatr Cardiol* 2009; 30: 133-7.
5. Calamandrei M, Mirabile L, Muschetta S, Gensini GF, De Simone L, Romano SM. Assessment of cardiac output in children: a comparison between the pressure recording analytical method and Doppler echocardiography. *Pediatr Crit Care Med* 2008; 9: 310-2.
6. Klugman D, Berger JT. Echocardiography as a hemodynamic monitor in critically ill children. *Pediatr Crit Care Med* 2011; 12(4 Suppl): S50-4.
7. Tomar M, Shrivastava S. Role of echocardiography in pediatric intensive care unit. *Indian Heart J* 2011; 63: 127-35.
8. Marum S, Price S. The use of echocardiography in the critically ill; the role of FADE (Fast Assessment Diagnostic Echocardiography) training. *Curr Cardiol Rev* 2011; 7: 197-200.

9. Price S, Via G, Sloth E, Guarracino F, Breikreutz R, Catena E, et al. Echocardiography practice, training and accreditation in the intensive care: document for the World Interactive Network Focused on Critical Ultrasound (WINFOCUS). *Cardiovasc Ultrasound* 2008; 6: 49.
10. Conlon TW, Ishizuka M, Himebauch AS, Cohen MS, Berg RA, Nishisaki A. Hemodynamic bedside ultrasound image quality and interpretation after implementation of a training curriculum for pediatric critical care medicine providers. *Pediatr Crit Care Med* 2016; 17: 598-604.
11. Conlon TW, Himebauch AS, Fitzgerald JC, Chen AE, Dean AJ, Panebianco N, et al. Implementation of a pediatric critical care focused bedside ultrasound training program in a large academic PICU. *Pediatr Crit Care Med* 2015; 16: 219-26.
12. Gaspar HA, Morhy SS, Lianza AC, de Carvalho WB, Andrade JL, do Prado RR, et al. Focused cardiac ultrasound: a training course for pediatric intensivists and emergency physicians. *BMC Med Educ* 2014; 14: 25.
13. Wilkinson JD, Pollack MM, Ruttimann UE, Glass NL, Yeh TS. Outcome of pediatric patients with multiple organ system failure. *Crit Care Med* 1986; 14: 271-4.
14. Pollack MM, Patel KM, Ruttimann UE. PRISM III: an updated Pediatric Risk of Mortality score. *Crit Care Med* 1996; 24: 743-52.
15. Rodriguez P, Dojat M, Brochard L. Mechanical ventilation: changing concepts. *Indian J Critical Care Med* 2005; 9: 235-43.
16. Douglas PS, Garcia MJ, Haines DE, Lai WW, Manning WJ, Patel AR, et al. ACCF/AHA/ASA/ASNC/HFSA/HRS/SCAI/SCCM/SCCT/SCMR 2011 Appropriate Use Criteria for Echocardiography. A Report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, American Society of Echocardiography, American Heart Association, American Society of Nuclear Cardiology, Heart Failure Society of America, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, Society of Critical Care Medicine, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance American College of Chest Physicians. *J Am Soc Echocardiogr* 2011; 24: 229-67.
17. Picard MH, Adams D, Bierig SM, Dent JM, Douglas PS, Gillam LD, et al. American Society of Echocardiography recommendations for quality echocardiography laboratory operations. *J Am Soc Echocardiogr* 2011; 24: 1-10.
18. Beaulieu Y. Specific skill set and goals of focused echocardiography for critical care clinicians. *Crit Care Med* 2007; 35(5 Suppl): S144-9.
19. Vignon P, Chastagner C, Francois B, Martaille JF, Normand S, Bonnard M, et al. Diagnostic ability of hand-held echocardiography in ventilated critically ill patients. *Crit Care* 2003; 7: R84-91.
20. Pershad J, Myers S, Plouman C, Rosson C, Elam K, Wan J, et al. Bedside limited echocardiography by the emergency physician is accurate during evaluation of the critically ill patient. *Pediatrics* 2004; 114: e667-71.
21. Chandrasekhar J, Ammash NM, Aksamit TR. Echo in the medical intensive care unit: does it really impact patient management? A retrospective observational study. *Chest* 2003; 124: 174.
22. Orme RM, Oram MP, McKinstry CE. Impact of echocardiography on patient management in the intensive care unit: an audit of district general hospital practice. *Br J Anaesth* 2009; 102: 340-4.
23. Rabah F, Al Senaidi K, Beshlawi I, Alnair A, Abdelmogheth AA. Echocardiography in PICU: when the heart sees what is invisible to the eye. *J Pediatr (Rio J)* 2016; 92: 96-100.
24. Kutty S, Attebery JE, Yeager EM, Natarajan S, Li L, Peng Q, et al. Transthoracic echocardiography in pediatric intensive care: impact on medical and surgical management. *Pediatr Crit Care Med* 2014; 15: 329-35.
25. Stanko LK, Jacobsohn E, Tam JW, De Wet CJ, Avidan M. Transthoracic echocardiography: impact on diagnosis and management in tertiary care intensive care units. *Anaesth Intensive Care* 2005; 33: 492-6.
26. Kobr J, Fremuth J, Pizingerova K, Sasek L, Jehlicka P, Fikrlova S, et al. Repeated bedside echocardiography in children with respiratory failure. *Cardiovasc Ultrasound* 2011; 9: 14.
27. Murphy GS, Marymont JH, Szokol JW, Avram MJ, Vender JS. Correlation of the myocardial performance index with conventional echocardiographic indices of systolic and diastolic function: a study in cardiac surgical patients. *Echocardiography* 2007; 24: 26-33.
28. Gargani L. Lung ultrasound: a new tool for the cardiologist. *Cardiovasc Ultrasound* 2011; 9: 6.
29. Koga S, Ikeda S, Urata J, Kohno S. Effect of nasal continuous positive airway pressure in men on global left ventricular myocardial performance in patients with obstructive sleep apnea syndrome. *Am J Cardiol* 2008; 101: 1796-800.
30. Ranjit S, Kissoon N. Bedside echocardiography is useful in assessing children with fluid and inotrope resistant septic shock. *Indian J Crit Care Med* 2013; 17: 224-30.
31. Lambert RL, Boker JR, Maffei FA. National survey of bedside ultrasound use in pediatric critical care. *Pediatr Crit Care Med* 2011; 12: 655-9.
32. Peltier M, Slama M, Garbi S, Enriquez-Sarano ML, Goissen T, Tribouilloy CM. Prognostic value of Doppler-derived myocardial performance index in patients with left ventricular systolic dysfunction. *Am J Cardiol* 2002; 90: 1261-3.
33. Khilnani P. Bedside ultrasound and echocardiography by the pediatric intensivist: An evolving tool and a feasible option in a pediatric ICU. *Indian J Crit Care Med* 2013; 17: 201-2.
34. Manasia AR, Nagaraj HM, Kodali RB, Croft LB, Oropello JM, Kohli-Seth R, 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.
35. Melamed R, Sprenkle MD, Ulstad VK, Herzog CA, Leatherman JW. Assessment of left ventricular function by intensivists using hand-held echocardiography. *Chest* 2009; 135: 1416-20.
36. Dalla Pozza R, Loeff M, Kozlik-Feldmann R, Netz H. Hand-carried ultrasound devices in pediatric cardiology: clinical experience with three different devices in 110 patients. *J Am Soc Echocardiogr* 2010; 23: 1231-7.
37. Vieillard-Baron A, Slama M, Cholley B, Janvier G, Vignon P. Echocardiography in the intensive care unit: from evolution to revolution? *Intensive Care Med* 2008; 34: 243-9.