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Original Article

Validity of Clinical Indications of Pediatric Bedside Echocardiography in Critically Ill Children: A Single Center Study

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Abstract:

Background: Management of critically ill pediatric patients is a demanding task that relies on a combination of clinical skills and measurement of hemodynamic variables. Echocardiography is currently considered a key tool for the hemodynamic assessment in intensive care units, able to identify causes of hemodynamic instability and to correctly guide therapy.

Aim of the work: To determine the type of indications for requesting bedside echocardiography in neonatal and pediatric intensive care units in our center, and to find which of these indications have the highest sensitivity to confirm the presence of echocardiographic abnormalities.

Methods: We conducted a prospective study at Cairo University Children's Hospital on 271 critically ill patients admitted to neonatal and pediatric intensive care units and who underwent bedside echocardiography examination. Detailed clinical examination, chest X-ray and echocardiography were done for all patients and comparative results were evaluated.

Results: The commonest encountered condition detected with bedside echocardiography in the neonatal intensive care units was pulmonary hypertension representing 35.8% of the examined neonates, while in the pediatric intensive care units it was impaired cardiac contractility representing 33.1% of the totally examined children. The commonest indication for requesting bedside echocardiography was screening for hemodynamically significant patent ductus arteriosus in preterm infants (n= 73, 42%) in neonatal intensive care units' group, while the most common indication for requesting bedside echocardiography was in pediatric intensive care units' group assessment of the cardiac function (n= 60, 61.9%). Of the total requested bedside echocardiography examinations, we found that 51.7% of those performed in neonatal intensive care units' and 19.6% in the pediatric intensive care units' had no significant cardiac abnormality.

Conclusion: The use of bed side echocardiography by intensivists and pediatric cardiologists is necessary. Adequate training to attain skills for bedside echocardiography examination by neonatal and pediatric intensivists is an essential requisite for sound primary echocardiographic assessment.

Level of Evidence of Study: IIB (*1*)**.**

Keywords: echocardiography; pulmonary hypertension; hemodynamically significant patent ductus arteriosus.

Abbreviations: CHD: congenital heart defect; CPAP: continuous positive airway pressure; CVC: central venous catheter; DBP: diastolic blood pressure; FS: fractional shortening; hsPDA: hemodynamically significant patent ductus arteriosus; NICU: neonatal intensive care unit; NI-SIMV: non-invasive synchronized intermittent mandatory ventilation; PICU: pediatric intensive care unit; RDS: respiratory distress syndrome; SD: standard deviation; SBP: systolic blood pressure.

Introduction

Prompt management of critically ill pediatric patients necessitates proper diagnosis and timely intervention (*2*). Hemodynamic assessment is vital to the management of critically ill

patients (*3*). Echocardiography has become a bedside tool in the pediatric intensive care unit (PICU) and neonatal intensive care unit (NICU) (*4*). It has become indispensable in diagnosis because of its real time ability to visualize the heart, lack of invasiveness and because it does not need specific installation precautions (*5*). Echocardiography provides confirmation of disease suggested by clinical findings, or rules it out (*6*). Echocardiography has limitations and the most important limitation is that it is operator dependent, and needs training to achieve the required skill. Yet, echocardiography is not a replacement for physical examination and clinical assessment for hemodynamic stability while making clinical decisions (*7*).

Clinical indications for request of echocardiography in the pediatric and neonatal intensive care units are summarized as TINEC (training in intensive care and neonatal echocardiography). The indications include, evaluation of cardiac function, structural anomalies of cardiac muscle and valves, pulmonary hypertension, pericardial effusion and tamponade, transitional circulation of the newborn, evaluation of line placement and as a guide for interventions within the intensive care unit(*8*).

Subjects and Methods

This prospective study was conducted at Cairo University Children's Hospital. Bedside echocardiography was performed in critically ill children and neonates who were admitted to the neonatal and pediatric intensive care units between November 2020 and April 2021. The study was approved by Higher Studies Research Committee of Faculty of Medicine, Cairo University, in compliance with Helsinki declaration guidelines (*9*).

Participants

The study included 271 patients with critically ill conditions; 174 neonates admitted in neonatal intensive care units and 97 children admitted in pediatric intensive care units.

Methods

All enrolled children underwent:

Careful history taking, clinical examination and relevant investigations. Examination inluded anthropometric measures (length/height, body weight), oxygen saturation, blood pressure and heart rate**,** cardiac examination and hemodynamic stability (inotropes and degree of respiratory support). Indications for bedside echocardiography in the echocardiography request and the included clinical signs that caused the physicians to ask for echocardiography such as presence of a cardiac murmur, or abnormal heart sound, congenital anomalies, unexplained cyanosis, or otherwise.

Imaging and Conventional Echocardiography:

Chest X-ray was done to assess cardiac size and pulmonary vasculature.

Echocardiography 2 D and M mode, (GE Vivid 5 Echo machine, USA) was used to assess pulmonary artery pressure (PAP), hemodynamically significant patent ductus arteriosus, global left ventricular systolic function major congenital heart defects including duct dependent circulation and diagnose of infective endocarditis especially in patients with long-standing central venous lines.

Statistical Analysis

The collected data were revised, coded, tabulated and introduced to a PC using statistical package for social sciences (SPSS 16.0 for windows; SPSS Inc., Chicago, IL, 2001). Data were presented and the suitable analysis was done according to the type of data obtained for each parameter. Descriptive data were presented as mean, standard deviation (±SD), range for numerical data and frequency and percentage for non-numerical data. For independent samples t test was used to assess the statistical significance of the difference between means. Chi-square test was used to examine the relations between qualitative variables. One way ANOVA test was used to assess the statistical significance of the difference between means. $P < 0.05$ was the level of significance employed in the study.

Results

Neonatal ICU Group:

The mean age of the enrolled 174 neonates was 5 days (range 1 to 51 days); while the mean weight was 2.1 kg. Seventy nine (45.4%) were full term, and 95 (54.6%) were preterm (mean ±SD= 37± 2 weeks; range 34-39 weeks). (Tables 1 and 2). Thirteen (7.5%) of the examined infants did not require respiratory support, 10.3% were on nasal oxygen, 31.6% were on continuous positive airway pressure and non-invasive synchronized intermittent mandatory ventilation, and 50.6% were on invasive mechanical ventilation. Upon cardiac auscultation, 36 infants had cardiac murmurs while 138 had no audible murmurs. Screening for a hemodynamically significant PDA in the preterm infants was the most encountered indication representing 42%, while exclusion of cardiac abnormalities in infants of diabetic mothers was the least common indication representing 6.9%. (Figure 1). The bedside echocardiographic examination confirmed that 37 of 66 infants with clinical signs suggestive of pulmonary hypertension did have pulmonary hypertension, and that 22 of the 36 infants who were clinically suspected to have congenital heart defects, did have congenital heart defects. Table 3 outlines correlation between the clinical assessment and findings encountered after echocardiographic examination in neonates admitted to the NICU.

Table 1. Characteristics of studied neonates in the NICU (n= 174)

		Mean	SD	Minimum	Maximum
Age (days)		5	7	1	51
Length (percentile)		5	7	3	10
Weight (percentile)		10	2	3	15
SpO_2 (%)		94	5	65	99
Heart rate (beat/min)		143	15	118	270
SBP (mmHg)		55	12	30	100
DBP (mmHg)		31	8	16	70
Respiratory rate (/min)		52	6	37	70
				Number	%
Gender	Male			108	62.1
	Female			66	37.9
Maturity	Preterm			95	54.6
	Full term			79	45.4
Respiratory support	Nil			13	7.5
	Nasal oxygen			18	10.3
	CPAP/NI-SIMV			55	31.6
	Invasive ventilation			88	50.6
Cardiac murmur	No			138	79.3
	Yes			36	20.7
Need for inotropes	No			85	48.9
	Yes			89	51.1
Chest X-ray	Normal			27	15.5
	RDS			121	69.5
	Cardiomegaly			9	5.2
	Pneumonia			12	6.9
	Diaphragmatic hernia			1	0.6
	Pleural effusion			4	2.3

CPAP= continuous positive airway pressure; DBP= diastolic blood pressure NI-SIMV: non-invasive synchronized intermittent mandatory ventilation; RDS: respiratory distress syndrome; SD: standard deviation; SBP: systolic blood pressure; SpO_2: oxygen saturation.

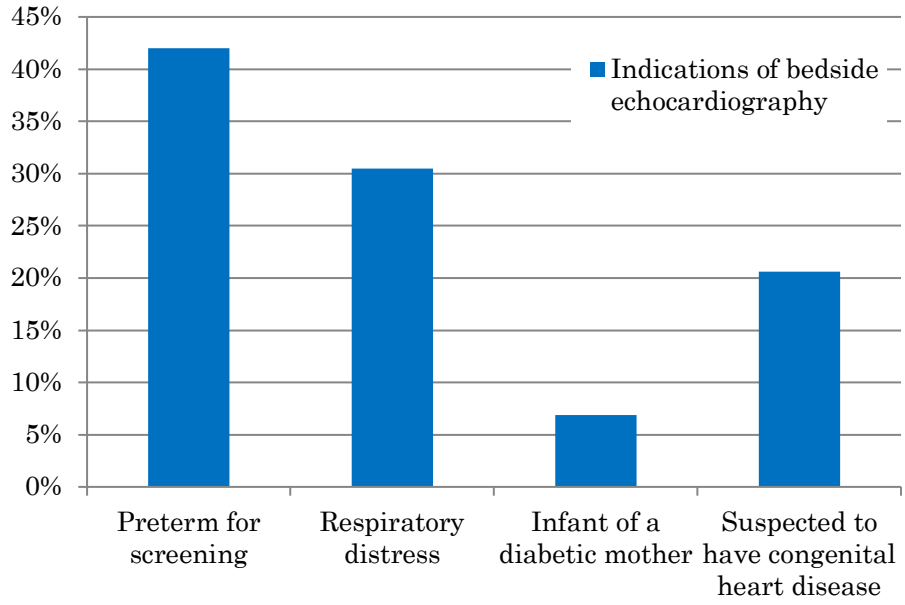
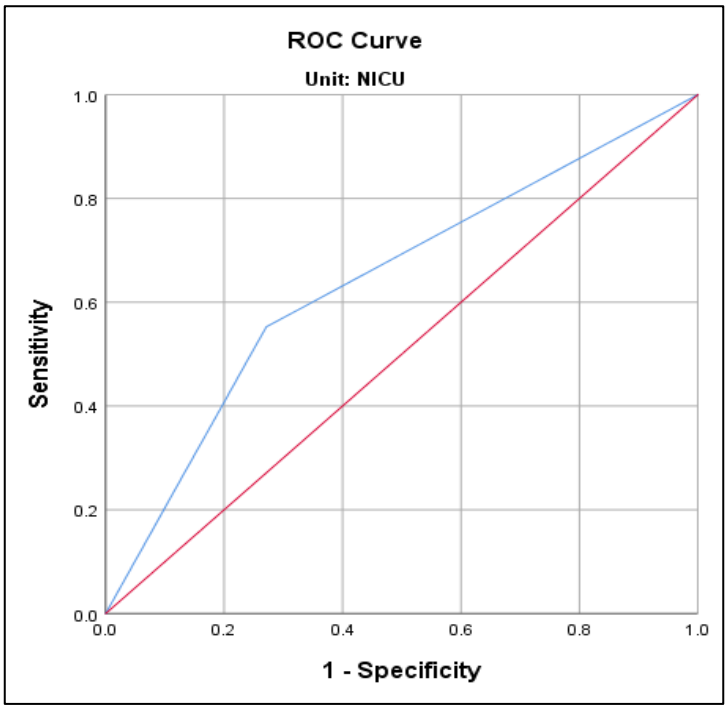


Figure 1. Indications for bedside echocardiography in the examined patients at NICU.



ROC curve= receiver operating characteristic curve.

Figure 2. ROC curve analysis for clinical cues in detecting pulmonary hypertension in NICU

The most common clinical signs associated with echocardiographic abnormalities were those indicating the presence of pulmonary hypertension in neonates 37 (55.2%), such as a preductal-post ductal saturation gradient and a loud single second heart sound. Figure 2 and 4 represent the receiver operating characteristic curve, which shows that clinical cues suggestive of the presence of pulmonary hypertension are the most sensitive to detection after echocardiographic examination in NICU and PICU respectively.

Table 2: Indications for requesting bedside echocardiographic in the NICU group:

	Number	%
Concerning fetal echocardiogram suspicious for cardiovascular abnormality	7	4
Murmur with pathological acoustic characteristics	36	20.7
Abnormal chest X-ray findings including cardiomegaly (transverse diameter of the cardiac silhouette ≥ 50% of the transverse diameter of the chest), boot-shaped heart in tetralogy of Fallot, and gooseneck in endocardial cushion defect	9	5.2
Desaturation demonstrated on pulse oximetry (a pulse oxygen level <90% in either right hand or foot, or a level <95% that continued to be low after repeated measurements) that was not explained by pulmonary diseases	33	18.9
Suspected cases of congenital heart diseases by history and examination including central cyanosis, respiratory distress, murmurs and certain syndromes that are known to be associated with cardiac abnormalities as Down syndrome	36	20.7
Assessment of the pulmonary artery pressure in cases with history of obstructed labor or meconium aspiration that were followed by respiratory distress and desaturation	53	30.5

Table 3. Correlation between the clinical assessment and findings encountered after echocardiographic examination in neonates admitted to the NICU

Clinical Indication	**Echocardiographic Finding (n=174)**				
Clinical signs of pulmonary hypertension e.g. preductal-post ductal saturation gradient, loud single second heart sound	Pulmonary hypertension		**P value**	**Sensitivity**	**Specificity**
	Yes	No			
Yes	37 (55.2%)	29 (27.1%)	<0.001	55.2%	72.9%
No	30 (44.8%)	78 (72.9%)			
Preterm infants or clinical signs of presence of hsPDA e.g PDA murmur.	hsPDA				
	Yes	No			
Yes	15 (25.9%)	56 (48.3%)	0.005	25.9%	51.7%
No	43 (74.1%)	60 (51.7%)			
Clinical signs of presence of other CHD e.g. cyanosis, murmur	Presence of other CHD				
	Yes	No			
Yes	22 (47.8%)	14 (10.9%)	<0.001	47.8%	89.1%
No	24 (52.2%)	114 (89.1%)			

CHD= congenital heart defect; hsPDA= hemodynamically significant patent ductus arteriosus.

Pediatric ICU Group:

The mean age of the studied 97 children admitted to pediatric ICU was 58.6 ± 53.7 months (range 1 to 168 months). Table 4 summarizes their findings. Table 5 and Figure 3 summarizes the indications for bedside echocardiography among this group. The bedside echocardiographic examination confirmed that 25 of 29 children with clinical signs suggestive of pulmonary hypertension were found to have pulmonary hypertension, 32 of 44 children suspected clinically of having impaired cardiac contractility showed impaired cardiac contractility after echocardiographic examination, 5 of the 8 children who were clinically suspected of having cardiac vegetation revealed cardiac vegetation after echocardiographic examination and 5 of the 7 children who were clinically suspected of having pericardial effusion did indeed have pericardial effusion. Table 6 outlines the correlation between the clinical assessment and findings encountered after echocardiographic examination in children admitted to the PICU.

Table 4. Characteristics of children admitted to the PICU (n= 97).

		Number	%
Gender	Male	46	47.4
	Female	51	52.6
Respiratory support	Nil	5	5.2
	Nasal oxygen	66	68.0
	Invasive ventilation	26	26.8
Cardiac murmur	No	78	80.4
	Yes	19	19.6
Need for Inotropes	No	41	42.3
	Yes	56	57.7
Chest X-ray	Normal	27	27.8
	Cardiomegaly	22	22.7
	Pneumonia	45	46.4
	Pleural effusion	3	3.1

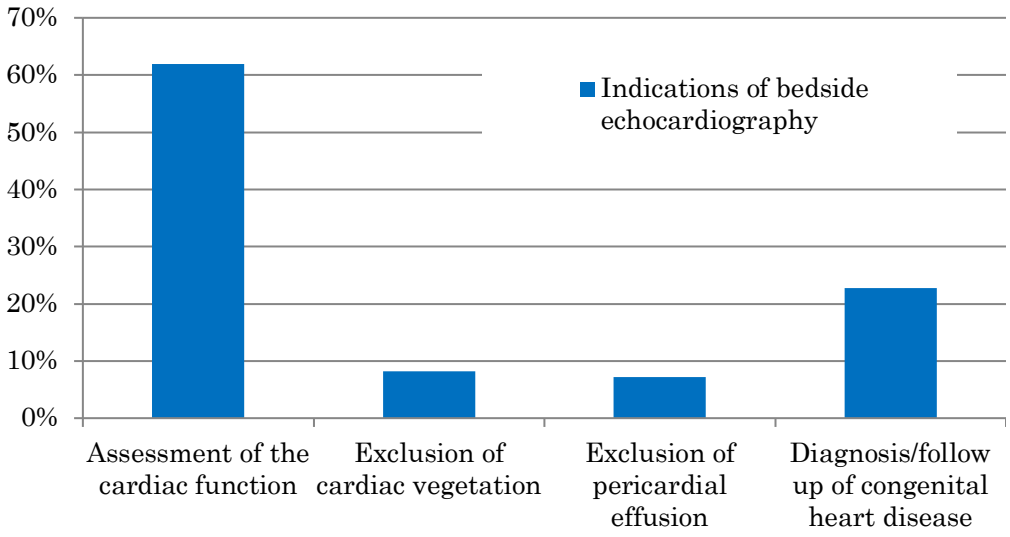


Figure 3. Indications of requesting bedside echocardiography in the patients at pediatric ICU.

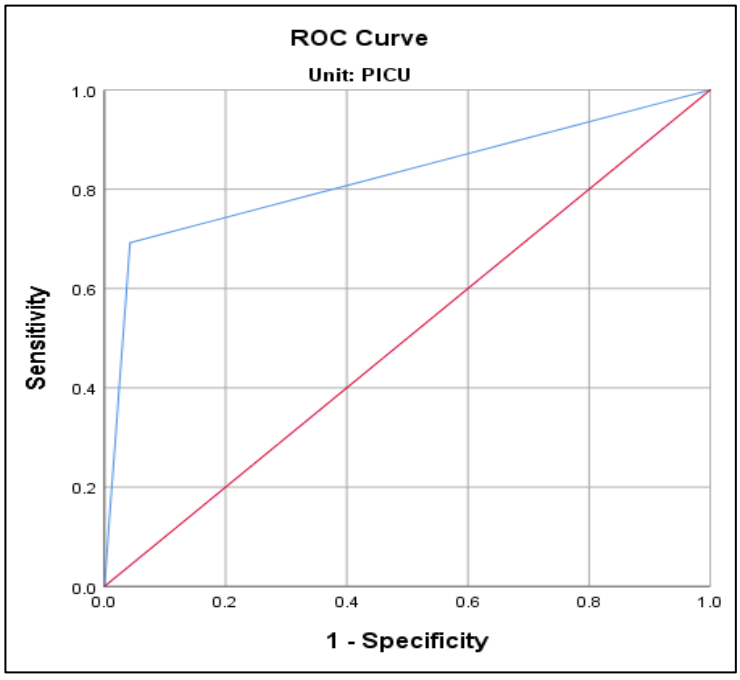
Table 5: Indications for requesting bedside echocardiographic in the pediatric ICU group.

	Number	%
Follow up of cases that were known to have cardiac abnormality e.g. cardiomyopathy, congenital structural heart diseases	11	11.4
Murmur with pathological acoustic characteristics	19	19.5
Abnormal chest X-ray findings including cardiomegaly (transverse diameter of the cardiac silhouette ≥ 50% of the transverse diameter of the chest), boot-shaped heart in tetralogy of Fallot, and gooseneck in endocardial cushion defect	11	11.4
Desaturation demonstrated on pulse oximetry (a pulse oxygen level <90% in either right hand or foot, or a level <95% that continued to be low after repeated measurements) that was not explained by pulmonary diseases	12	12.4
Suspected cases of infective endocarditis especially in patients with central venous catheters who had fever, positive blood culture and elevated sepsis markers	8	8.2
Systemic disorders with suspected cardiac abnormalities as dilated coronaries in Kawasaki disease and signs of congestive heart failure as tachycardia, tachypnea and tender hepatomegaly in patients admitted with septic shock to assess fractional shortening	29	29.9
Suspected pericardial effusion e.g. hypoalbuminemia patients with nephrotic syndrome who had muffled heart sounds	7	7.2

Table 6. Correlation between the clinical assessment and findings encountered after echocardiographic examination in children admitted to the PICU

Clinical Indication	Echocardiographic Finding (n=97)		P value	Sensitivity	Specificity
Clinical signs of pulmonary hypertension e.g. loud, single second heart sound	Pulmonary hypertension				
	Yes	No			
Yes	25 (64.1)	4 (6.9)	<0.001	64.1%	93.1%
No	14 (35.9)	54 (93.1)			
Clinical signs suggestive of impaired cardiac contractility (FS) e.g. tachycardia, tachypnea, hepatomegaly	Impaired FS				
	Yes	No			
Yes	32 (71.1)	12 (23.1)	<0.001	71.1%	76.9%
No	13 (28.9)	40 (76.9)			
Clinical signs suggestive of presence of cardiac vegetation e.g. fever in children with CVC	Cardiac vegetation				
	Yes	No			
Yes	5 (41.7)	3 (3.5)	0.001	41.7%	96.5%
No	7 (58.3)	82 (96.5)			
Clinical signs suggestive of presence pericardial effusion e.g. muffled heart sounds	Pericardial effusion				
	Yes	No			
Yes	5 (35.7)	2 (2.4)	0.001	35.7%	97.6%
No	9 (64.3)	81 (97.6)			
Clinical signs suggestive of presence of CHD e.g. cyanosis, murmur	Presence of CHD				
	Yes	No			
Yes	18 (69.2)	3 (4.2)	<0.001	69.2%	95.8%
No	8 (30.8)	68 (95.8)			

CHD= congenital heart defect, CVC= central venous catheter, FS= fractional shortening.



ROC curve= receiver operating characteristic curve.

Figure 4. ROC curve analysis for clinical cues in detecting congenital heart defects in pediatric ICU.

Discussion

Echocardiography is a valuable tool that has become a standard service in neonatal and pediatric intensive care units to provide prompt timely assessment of cardiac structure and function, follow up of medications and guide intervention (*10*). Bedside echocardiography is increasingly being relied upon as an extension of physical examination, and in conjunction with the existing clinical parameters in making clinical decisions (*11*, *12*).

In the current study, clinical signs suggestive of pulmonary hypertension were found to be the most sensitive parameter, while signs suggestive of the presence of congenital heart defects (other than patent ductus arteriosus) were found to be the most specific parameter in detecting cardiac problems in neonatal intensive care units (NICU) settings. Bedside echocardiography has provided statistically significant more accurate diagnosis of pulmonary hypertension, structural cardiac anomalies and impaired cardiac contractility in both the NICU and the pediatric ICU. More diligent clinical examination and search for signs to improve the clinical examination accuracy and decision making is seen as a necessity. Again, there is a need for training of physicians caring for NICU and pediatric ICU patients to acquire bedside echocardiography skills (*13*).

The need for bedside echocardiography is especially required in settings of ventilator care where child is not ambulant. Many cardiac abnormalities in neonates are associated with respiratory distress, which is one of the reasons for requesting a bedside echocardiographic evaluation in neonates who needed respiratory assistance but had no obvious cause for chest abnormalities. In our study, we found that a total of 31.6% neonates were on continuous positive airway pressure whereas 50.6% neonates were on synchronized intermittent mandatory ventilation plus pressure support ventilation. Out of 161 neonates with respiratory distress, 76 (47.2%) of cases showed abnormal echocardiographic findings. Fifty percent of the studied neonates and 26% of the children in our study were on ventilator care. The ambulation of the echo machine is another important factor that should be addressed in the NICU and pediatric ICU setting (*8*). Again the value of echocardiography extends to screening for peripheral lung pathology as well, for its proven high sensitivity and specificity (*14*).

In the present study, it was observed that the most common indication for requesting bedside echocardiography in neonates was screening for hemodynamically significant patent ductus arteriosus (PDA) in preterm infants (n= 73, 42%). After the preterm screening, assessment of the pulmonary artery pressure in infants with severe respiratory distress (n= 53, 30.5%) and exclusion of congenital cardiac anomalies (20.6%) were the next most common indications. Physicians caring for preterm neonates were more commonly inclined to ask for confirmatory bedside echocardiography. Having immature organ systems, a preexisting intrauterine milieu that led to preterm delivery, and the resulting need for surfactant administration, ventilatory support, and vasoactive medications, make them more vulnerable to complications during the transition from fetal to postnatal life. The need for bedside diagnosis is highlighted by fact that the hemodynamically unstable cardiac anomalies are crucial predictors of the outcome (*10*).

In the present study, it was observed that the most common indication for requesting bedside echocardiography in the pediatric intensive care unit (PICU) group was assessment of the cardiac function (n= 60, 61.9%). Diagnosis/follow up of congenital heart disease (n= 22, 22.7%) and exclusion of cardiac vegetation (7.2%) were the next most common indications. Among 56 examined cases who were on inotropic cardiac support, 16 (28.5%) cases demonstrated impaired FS (25, 30%) while 18 (32.1%) cases showed poor FS (<25%). This reflects that the decision for inotropic support is a purely clinical decision and does not correlate to the echocardiographic findings.

Clinical signs suggestive of impaired cardiac contractility were found to be the most sensitive parameter in the current study, while signs suggestive of pericardial effusion were found to be the most specific parameter in detecting cardiac problems in pediatric intensive care units (PICU) settings.

By analyzing the total number of requested bedside echocardiography we found that 51.7% of the neonatal intensive care units (NICU) group and 19.6% of the pediatric intensive care units (PICU) group showed no significant cardiac abnormality. The excessive requests should not be viewed as abuse of resources but rather as an indication for the need for rendering the bedside echocardiography as a real time part of physical examination of the critically ill neonate or child.

Conclusion

Echocardiographic evaluation is a valuable tool and the requirement of echocardiographic assessment increases according to clinical severity. The most commonly encountered indication for requesting bedside echocardiography was screening for hemodynamically significant patent ductus arteriosus in the neonatal intensive care units and assessment of cardiac function in the pediatric intensive care units. Clinical signs of pulmonary hypertension were found to be the most sensitive parameter reflecting cardiac problems in neonatal intensive care unit, while clinical signs of impaired cardiac contractility were found to be the most sensitive parameter reflecting cardiac problems in pediatric intensive care units. In the neonatal intensive care units, the number of echocardiograms that revealed no cardiac abnormalities outnumbered those that revealed a cardiac problem.

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CONFLICT OF INTEREST

The authors declare no conflict of interest in connection with the study.

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