Review Article

Bedside Ultrasound in the Diagnosis and Treatment of Children with Respiratory Difficulty Following Cardiac Surgery

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ABSTRACT

Many children frequently fail extubation or require a prolonged period of positive pressure ventilation support after cardiac surgery. Pediatric cardiac Intensive Care Unit (PCICU) ultrasound (US) stands as a simple, basic bedside tool that can be performed by trained intensivists for the diagnosis with immediate implication on therapeutic decisions in multiple scenarios that physicians may face in PCICU. Bedside US is widely available, convenient, and inexpensive. This educational article based mainly on our own experience is highlighting the role of US in detecting the most common causes of respiratory weaning difficulties and extubation failure in postoperative cardiac children through proposed illustration and algorithm.

KEYWORDS: *Extubation, pediatric cardiac surgery, ultrasound, ventilation*

INTRODUCTION

Postoperative management of children undergoing congenital heart surgery has improved over the years. Despite this improvement many children frequently fail extubation or require a prolonged period of positive pressure ventilation support. Extubation failure after pediatric cardiac surgery is quite common, and it is seen in up to 10%–14% of cases.[1,2] The most common reported risk factors for respiratory difficulties postpediatric cardiac surgery are lung disease, cardiac dysfunction, diaphragmatic dysfunction, upper airway obstruction, and tracheobronchomalacia.[1,2] These respiratory problems lead to longer intensive care and hospital stays and may increase morbidity and mortality.[1,2]

Investigating a child with respiratory difficulties postcardiac surgery requires full assessment with a panel of sequential investigations to exclude the most common causes leading to extubation or weaning failure from positive pressure ventilation support. These investigations can be invasive such as bronchoscope, or require physical transportation of a patient from one area to another unit (computed tomography [CT]/magnetic resonance imaging [MRI]) or may expose the child to significant radiation risk such being the case in fluoroscopy or CT scanning or require sedation and monitoring outside the critical care area such as in CT and MRI units.

The use of ultrasound (US) has increased in the last 30 years to become a practical bedside tool for assessment

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of critically ill children.[3] It emerges as an urgent tool for diagnosis with immediate implication on therapeutic decisions, particularly in acute life-threatening disorders.[4] The application of US in postoperative pediatric cardiac patients can be of great help. Not only as a handy diagnostic tool but also as a safer and reliable diagnostic method that can answer specific questions related to certain scenarios such as failure of extubation or failure of liberation from positive pressure ventilation. In contrast to this, practical bedside tool even a simple bedside chest X-ray (CXR) has numerous limitations. Frequently, in pediatric cardiac Intensive Care Unit (PCICU), it is not possible to obtain quick high quality films, which impairs the efficacy of conventional radiology for the identification of important lung pathologies.[4]

In this regard, US has several advantages such as being a simple, quick, safe, and easily repeatable examination that does not expose the patient to radiation or mobilization.[3,5]

US has a diagnostic accuracy of 92%–100% when identifying pathological conditions such as pneumothorax, consolidation, interstitial syndrome (i.e., pulmonary edema of cardiogenic or noncardiogenic origin), and pleural effusion and may therefore be considered as an alternative to CT in critically ill patients.[4,6]

Our aim in this educational article is to describe the role of US in detecting the majority of common causes associated with the failure of extubation or weaning from mechanical ventilation in postoperative cardiac children. To this end, we are proposing a simple algorithm that is easily applicable in addressing how, why, and what to screen by the US in these type of patients commonly seen after pediatric cardiac surgery.

Methodology

We focused on the role of US in two groups of patients. The first group consists of patients who failed an extubation trial postsurgery and required reintubation; the second group is those patients who experienced respiratory weaning difficulties after pediatric cardiac surgery. Difficulties in weaning from invasive or noninvasive positive pressure ventilation were recognized by clinical symptoms and signs of intolerance such as tachypnea, diaphoresis, increased respiratory work, or presence of ineffective gas exchange reflected in arterial blood gas analysis (decreased SpO_2, hypoxemia, and respiratory acidosis).

In approaching a child who suffered any of these two conditions, we performed a comprehensive clinical examination that incorporated the use of US as an assessment bedside tool in our evaluation for a child with weaning difficulties or extubation failure. We used a general electric US machine. Linear, microconvex, or curve linear probes were used with a frequency of 6–12 MHz for detecting the abnormalities. A straight linear array high-frequency probe may be most helpful in analyzing superficial structures such as the pleural line as it provides a better resolution while a microconvex or curvilinear array probe may be more suitable for deeper lung imaging and cardiac screening as it allows better penetration at the cost of less resolution. Depth was adjusted to get optimal image size, and the other US system settings such as gain and gray scale were adjusted to improve image quality.

In this educational review, we follow a common theme in approaching children who have respiratory difficulties, including (1) problem definition, (2) the incidence in postoperative cases, (3) the morbidity associated with it and finally, (4) the role of US to investigate this problem with images and movie for illustration provided from our own cases. Five main structures/areas were screened by US to evaluate certain pathologic entities contributing to respiratory difficulties:

Vocal cord US to investigate vocal cords dysfunction and abdominal US to investigate ascites, both studies were performed only if specific suggestive symptoms such as stridor or abdominal distention, respectively, were present. While, the other screening tools were performed routinely and included diaphragm US to diagnose diaphragm dysfunction, lungs US to evaluate four main certain pathologic entities (collapse\consolidation, interstitial syndrome, pneumothorax, and pleural effusion), and finally, echocardiography (ECHO) to assess cardiac function and to rule out pericardial effusion (PE) or any significant residual lesions postpediatric cardiac surgery. Anatomical points of the probe screening are shown in Figure 1 and supported by a simple algorithm that is presented in Figure 2 to guide the intensivist in US performance. Table 1 summarizes the major clinical conditions associated with respiratory difficulty postpediatric cardiac surgery and US imaging with correlated findings.

Clinical Applications of Bedside Ultrasound for Respiratory Difficulties Postcardiac Surgery

Vocal cords dysfunction

Pediatric vocal cord paralysis is not an uncommon complication after cardiac surgery and can result in serious sequelae with 45% rate of aspiration and 27% rate of complications that require surgical intervention.[7]

Any surgical treatment of a patent ductus arteriosus (PDA) or any major aortic arch manipulation places the recurrent laryngeal nerve and vocal fold function at risk. This was reported in 1% to 8.8% of PDA ligation cases after surgery in the previous retrospective studies.[7] In comparison to

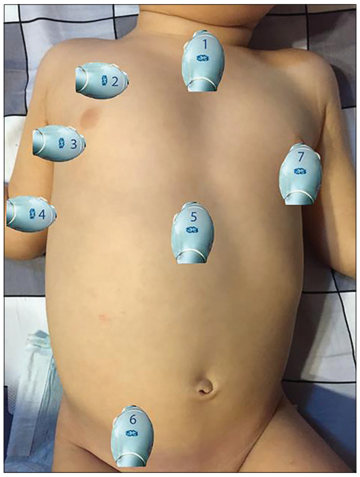

Figure 1: Illustrating image of transducer positions in postoperative cardiac children with respiratory difficulties; Zone 1: Imaging vocal cords in a transverse view of the larynx at the thyroid cartilage; Zone 2: Imaging lung sliding sign and lung point in each anterior chest in the mid clavicular line at 2nd–3rd intercostal space; Zone 3: Imaging lung point and lung sliding in each lateral chest in anterior axillary line inferior to nipple; Zone 4: Diaphragm function, hepatorenal fluid accumulation, pleural effusion, and lung consolidation, or collapse in each posterior chest in posterior axillary line; Zone 5: Subxiphoid window of the heart and both diaphragm; Zone 6: Imaging intraabdominal collection in each iliac fossa. Zone 7: The heart is screened to assess heart function, pericardial effusion and residual lesions.

other invasive tools, such as laryngoscope, laryngeal US is a new, noninvasive, and easily reproducible method of examining the larynx in infants and children.[8] This tool allows to perform dynamic studies during the respiratory cycle to compare the changes of vocal cords movements to diagnose vocal cords dysfunction.[9]

US examination of the vocal cords should be performed within at least two hours from last feeding. The child is usually positioned in supine position, breathing spontaneously with minimal neck extension. Linear or curve linear probes are placed in the axial (transverse) plane on the thyroid cartilage to obtain comparative imaging between right and left vocal cords simultaneously in abduction [Figure 3 and Videos 1,2].[10]

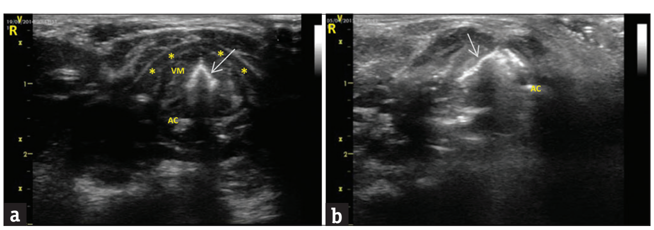

Figure 3: Two neonates postcoarctation of the aorata repair through left thoractomy, developed stridor postextubation. Vocal cords ultrasound helps to visualize vocal cord function through transverse sonograms of the true vocal cords in abduction; (a): Normal movements, (b): Left vocal cord dysfunction. True vocal cords appeared as 2 hypoechoic structures (the vocalis muscles), outlined medially by the hyperechoic vocal ligaments (white arrow), extending from the inner cortex of the thyroid cartilage to the vocal process of the arytenoid cartilage. AC indicates arytenoid cartilage; asterisks: Thyroid cartilage, and VM: Vocalis muscle.

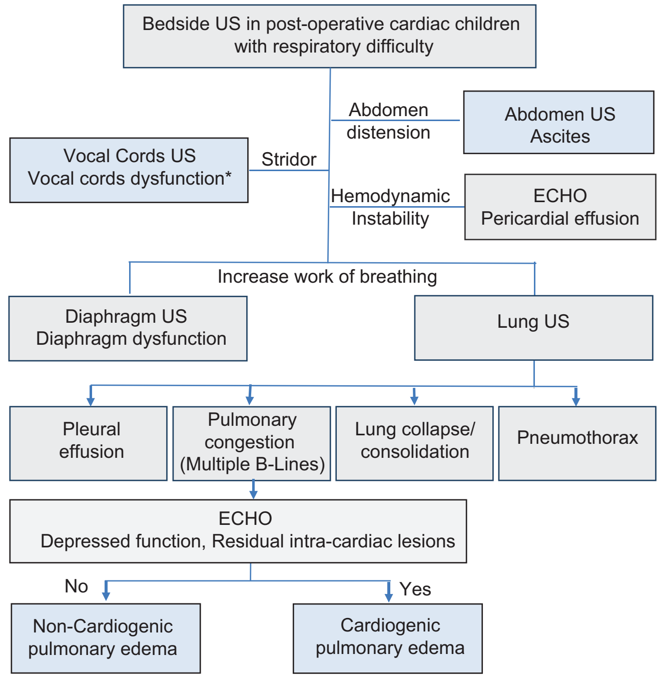

Figure 2: Algorithm for enhanced ultrasound approach in postoperative cardiac children with respiratory difficulties. *Consider other causes of stridor in case of normal vocal cords movements (such as edema, subglottic stenosis).

Video 1: A 3-week neonate postcoarctation of the aorata repair, developed sudden respiratory distress and stridor after extubation most likely related to edema; two-dimensional comparative sonogram imaging shows normal vocal cords movements. Arrows indicate right and left vocal cords.

Video 2: A 4-week neonate posttruncus arteriosis repair, developed sudden respiratory distress and stridor after extubation related to left vocal cord paralysis; two-dimensional comparative sonogram imaging of vocal cords movements shows left vocal cord paralysis; arrow indicates left vocal cord paralysis.

Table 1: Summary of major conditions associated with respiratory difficulty postpediatric cardiac surgery and ultrasound imaging with correlated findings

Clinical presentation or CXR findings	Suspected abnormalities/pathology	Proposed US study	US signs
Stridor, suprasternal retraction, respiratory distress after extubation	Vocal cord dysfunction (paresis or paralysis)	Vocal cord US	Weak motion or fixed (unilateral or bilateral) vocal cord in abduction
Respiratory distress with paradoxical breathing Difficulties in weaning from positive pressure ventilation Needing reintubation within 24 h after a trial of extubation after surgery Abnormal elevation of the diaphragm on serial CXR	Diaphragmatic dysfunction (paresis or paralysis)	Diaphragm US (2D and M-mode)	Paresis: Weak motion with shallow excursion <0.4 cm Flat M-mode tracing Paradoxical inspiratory movement with downward deflection of the wave by M-mode
Respiratory distress Abnormal unilateral haziness seen in CXR Abnormal elevation of the diaphragm dome on CXR	Pleural effusion Lung collapse/consolidation	Lung US	Hepatized lung surrounded by pleural fluid
Respiratory distress Clinical or CXR findings of pulmonary edema	Pulmonary congestion	Lung US	Prominent and increased B-lines
Sudden onset of respiratory distress or increased requirements in positive pressure ventilator settings, especially after removal of chest drain	Pneumothorax	Lung US (2D and M-mode)	Lung point Absence of B lines Stratosphere sign Absence of lung sliding
Abdominal distention with respiratory distress Capillary-leak syndrome with increased abdominal girth Oliguria with increased intra-abdominal pressure	Ascites Organomegaly	Abdominal US	Ascites (abdominal fluid collection in the peritoneal cavity) Distended bladder Hepatosplenomegaly Edematous bowel loops
Respiratory distress associated with hemodynamic compromise Low-cardiac output syndrome	Pericardial effusion Depressed cardiac function Residual cardiac lesions	ECHO	Fluid collection around the heart with or without tamponade Poor cardiac contractility with low ejection fraction Residual cardiac lesions: Such as mitral regurgitation, ventricular septum patch leak

ECHO: Echocardiography, 2D: Two-dimensional, CXR: Chest X-ray

Diaphragm dysfunction

Diaphragm dysfunction indicates either paresis or paralysis. The diaphragm is the main muscle of inspiration in infants and is responsible for 75% of normal breathing effort.[11] Unilateral diaphragm dysfunction compromises pulmonary function by about 25% in older children.[11] Cardiothoracic surgical procedures adjacent to the phrenic nerve are the most common causes of diaphragm dysfunction in children with a reported incidence rate up to 12.8%.[11] The incidence of diaphragm dysfunction was reported in literature to be more frequent, especially after arterial switch operation, arch repair, systemic to pulmonary shunt, and Fontan surgeries.[11]

Motion of diaphragm is classified as follows: normal, paresis (decreased or weakness), or paralysis (absent motion or paradoxical motion) [Table 2, Videos 3, 4 and Figure 4]. During inspiration, the normal diaphragm moves in the two-dimensional (2D) caudally toward the legs of the patient, resulting in upstroke of the M-mode tracing. We analyzed two parameters during screenings – namely, direction of motion and the amplitude of excursion [Table 2, Videos 3, 4 and Figure 4].[11]

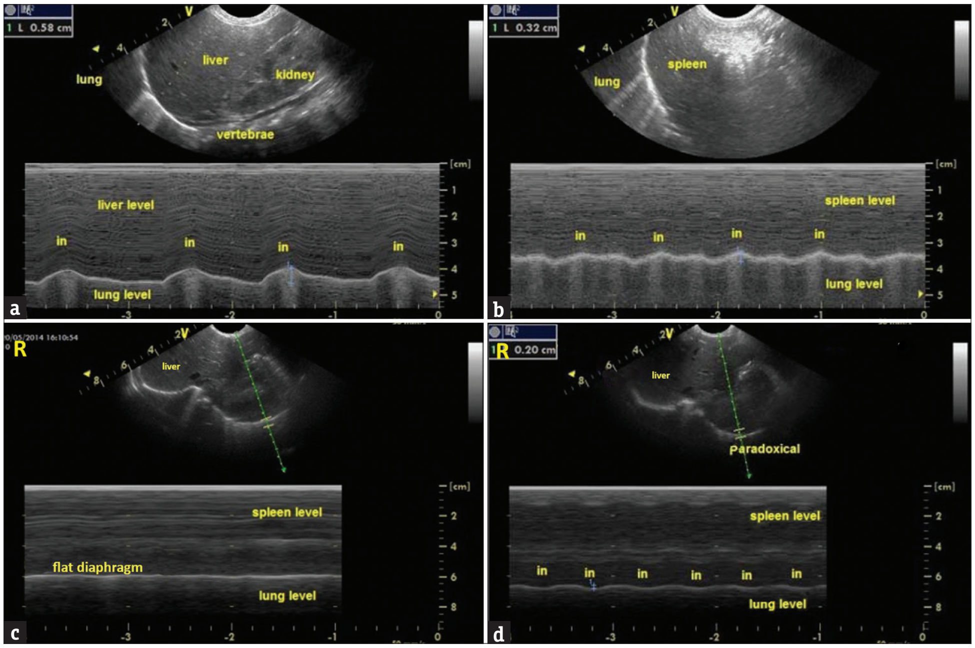

Figure 4: Diaphragm function by M mode ultrasound in four infants with extubation failure postcardiac surgery: (a) Normal right diaphragm movement in infant postventricular septum defect repair: Upward diaphragm motion with amplitude (5.8 mm) during inspiration in sagittal plane. (b) Left diaphragm paresis in infant postarterial switch operation: Normal direction toward the transducer, but the excursion is decreased (3.2 mm) in sagittal plane. (c) Left diaphragm paralysis in infant postglenn shunt: Flat M mode ultrasound tracing in oblique transverse plane in sub xiphoid window. (d) Left diaphragm paralysis posttetralogy of Fallot repair: Paradoxical inspiratory motion in oblique transverse plane in sub xiphoid window. In indicates inspiration.

We used a high-frequency curvilinear transducer (8C) with a frequency range of 8–12 MHz for recording an average of three respiratory cycles. Patients were scanned in the supine position during quiet, spontaneous breathing, and positive pressure respiratory support was temporarily interrupted during the examination in two main views:

(a) An oblique transverse plane [Videos 3, 4 and Figure 4c,d] from subxiphoid window with the probe marker directed to 9 O'clock to obtain comparative imaging between the right and left sides simultaneously. (b) Sagittal plane [Figure 4a and b] by placing the transducer perpendicular to the chest wall, with the probe marker directed to 12 O'clock in the eighth or ninth intercostal space, between the anterior and mid axillary lines.[11]

Video 3: A 4-week neonate postarterail switch operation and interrupted aortic arch repair developped respiratory distress after extubation with paradoxical breathing pattern; diaphragm ultrasound (two-dimensional) demonstrates left diaphragm paralysis in subcostal view with absent movement compared to the right diaphragm; diaphragm ultrasound (M-mode) shows a flat line of the left diaphragm.

Table 2: Classification of diaphragm motion

Diaphragm motion categories	Diaphragm motion description in inspiration (2D, M-mode ultrasound)
Normal	Diaphragm is moving caudally toward liver or spleen with upward flexion wave
	The excursion is ≥4 mm and the difference between the hemidiaphragms domes is <50%
Paresis	Motion is toward liver or spleen
	The excursion is <4 mm or the difference between the hemidiaphragms domes is >50%
Paralysis	
Absent motion	Tracing shows a flat line by M-mode
Paradoxical motion	Diaphragm moves cephalic during inspiration away from liver or spleen with downward deflection of the wave by M-mode (inverted wave)

2D: Two-dimensional

Lung ultrasound

Bedside US interrogation of the thorax can aid the clinician in determining the cause of the respiratory dysfunction. Often plain radiographs are not sufficient to differentiate pathology. Lung US helps in identification the hardly distinguished lung opacities on CXR; it can differentiate effusion from atelectasis, consolidation, mass, or an elevated hemidiaphragm.[12] In addition, lung US presents as an advanced tool in detecting pneumothorax and pulmonary congestion. We used mainly the curvilinear probe to perform lung US in 3 positions [Figure 1, Zone 2 through 4].

Pleural Effusion

Pleural effusions are a significant problem following cardiac surgical procedures in children with a reported incidence of more than 25%.[13] They cause significant morbidity following cardiac surgery in children and contribute to their increased stay in the ICU or hospital in addition to frequent respiratory failure and the need for reintubation. The common types of pleural effusions are bloody, serous, chylous, and infectious effusion.

Pleural effusions are particularly common following univentricular palliation and repair of the Tetralogy of Fallot.[13] Prolonged mechanical ventilation is also associated with an increased incidence of pleural effusion.[13] Early diagnosis and quantification of pleural effusion warrants an ideal postoperative course with adequate treatment. US could quantify pleural effusion [Figure 5a] and thereby helping to decide cost and time effectively whether or not to perform a thoracentesis.[14]

Thoracentesis performed under US [Figure 5] showed a reduced rate of complications.[15,16] An interpleural distance of 30 mm in adults with clearly visualization of the diaphragm, liver, and spleen are presenting as reasonable conditions before tapping to avoid accidental puncture. Thoracentesis of an estimated 500 ml or more of pleural effusions in adult patients following cardiac surgery under US guidance proved to be a safe procedure, improved postoperative recovery and shortened the postoperative stay.[14] However, the minimum amount of estimated drainable fluid and the interpleural distance in the pediatric patient population requires further investigations.

For pleural fluid diagnosis and estimation, US shows a better sensitivity and reliability than CXR [Figure 5], which is highly dependent on the necessity of the upright view.[17] Bedside CXR rarely detects small effusions and can also miss effusions of up to 500 ml in adults.[18] On the other hand, the sensitivity and specificity of US for the detection of pleural effusions are as high as 93% compared with CT.[19] Visualization of internal echoes [Figures 5 and 6] is highly suggestive of an exudate or a hemothorax.[20,21] The probe is positioned mainly on posterior chest along the posterior axillary line at most inferior point at the level of diaphragm [Figure 1 and Zone 4]; however, in loculated effusions, the probe position will be chosen according to the anatomical site.

Video 4: A 33-day infant with aortic stenosis, coarctation of the aorta and ventricular septum defect underwent for Yasui procedure, had difficulty to wean from ventilator and chest X-ray showed high cupula of the left diaphragm; diaphragm ultrasound (two-dimensional and M-mode) demonstrates left diaphragm paralysis in subcostal view with paradoxical movement compared to the right diaphragm; diaphragm ultrasound (M-mode) of the left diaphragm confirmed paradoxical movements during inspiration with negative excursions (−2 mm).

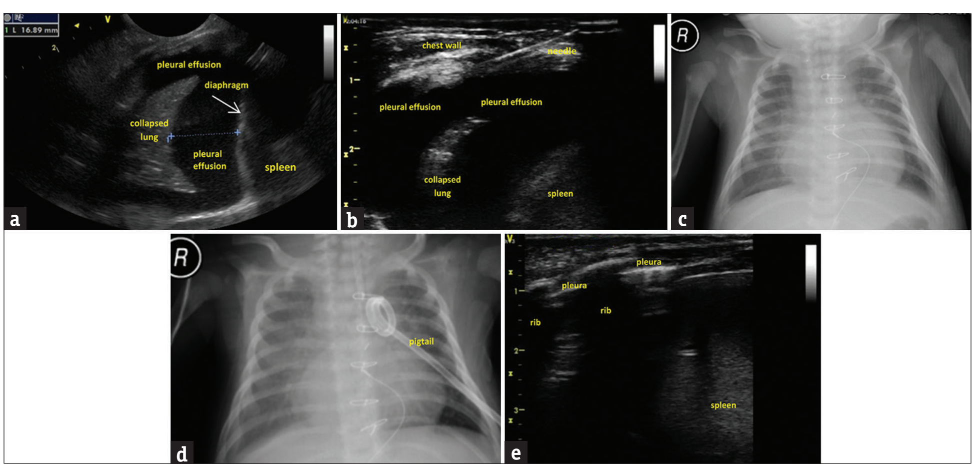

Figure 5: A 2 month old infant post Blalock Taussig shunt with difficulty to liberate from ventilator: (a) Ultrasonographic longitudinal view of the left inferior chest region shows pleural effusion surrounding the collapsed lung, delimited by the costodiaphragmatic recesses (white arrow), and spleen; The distance is around 18 mm between diaphragm and collapsed lung (asterisks). (b) Ultrasound guided pleural centesis using linear probe; 100 ml (30 ml/Kg) serous fluid drained. (c) Chest X ray demonstrating minimal amount of the left pleural effusion blunting the costodiaphragmatic angle. (d) Chest X ray after pigtail insertion; The costodiaphragmatic angle is clearer. (e) Longitudinal ultrasonographic view after effusion drainage revealed reopening and expansion of the lung with the absence of pleural fluid.

Lung collapse/consolidation

Lung collapse/consolidation after cardiac surgery is common and occurring in up to 70% of cases in literature[22] and may lead to reintubation or significant respiratory dysfunction on many occasions. Lung atelectasis and consolidation are different in pathophysiology but similar in their image presentation on US.[23] Atelectasis is the primary result of airless lung due to weak respiratory muscles, especially in prolonged ventilation or over sedation, which leads to frequent mucoid impaction in the bronchus. It ranges in severity from microatelectasis to complete collapse of the lobe or the lung. During cardiopulmonary bypass (CPB), the lungs are not perfused, and they are allowed to collapse to the functional residual capacity level. When the lungs are subsequently reexpanded then variable degree of pulmonary atelectasis remains.[22] On the other hand, lung consolidation is the result of various processes such as an infection [Figure 7b and c], obstructive atelectasis, or acquired respiratory distress syndrome (ARDS). Bedside US had a good accuracy (91.4%) in the diagnosis of lung atelectasis/consolidation.[23] However, the value of US in imaging upper lungs is not as effective as in lower lungs when compared to CT. Most of the lung atelectasis/consolidations occurred in bilateral lower lobes [Figure 7a and b], thus US could be clinically helpful especially with regard to real-time monitoring of dynamic changes of lung atelectasis/consolidation during recruitment due to positive pressure ventilation.[23]

In general, the airless lung is similar in echogenicity and echo texture to the liver [Figures 5a,b and 7a,b], which is called "lung hepatization." The hepatized lung may contain air bronchograms which appear as multiple hyperechoic bright dot-like or as hyperechoic branching tubular structures within the lung parenchyma [Figure 7b and c]. There are some sonographic clues to differentiate collapse from consolidation. Atelectasis tends to appear biconcave and be found floating in a large pleural effusion [Figures 5a and 7a], in addition, air bronchograms in atelectasis look more crowded and parallel to one another.[24]

In most recent studies, the shred sign, which is the irregular border between consolidated and aerated lung, as well as dynamic air bronchograms with inspiratory dynamic movement of at least 1 mm in adults' population are used for diagnosing pneumonia and distinguishing it from resorptive atelectasis [Figure 7c].[25]

Pulmonary congestion (interstitial lung disease)

A degree of postoperative temporary pulmonary dysfunction after cardiac surgery is inevitable and may be related to hemodynamic impairment, acute lung

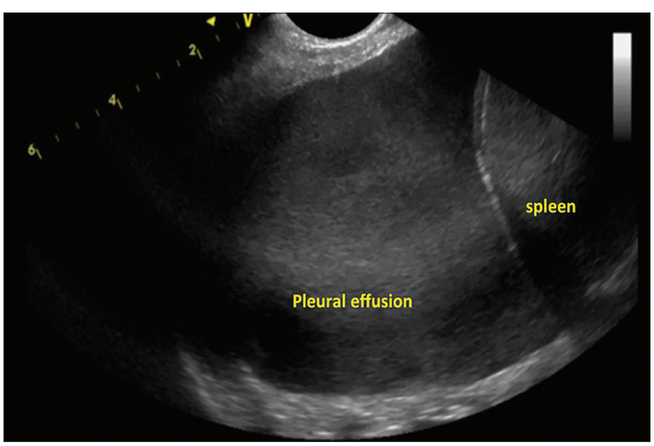

Figure 6: A 4-year-old child with high pressure Fontan developed respiratory distress. Ultrasonographic longitudinal view of the left inferior chest region shows pleural effusion of a large size with heterogeneous consistency; Pleural fluid analysis revealed chylothorax.

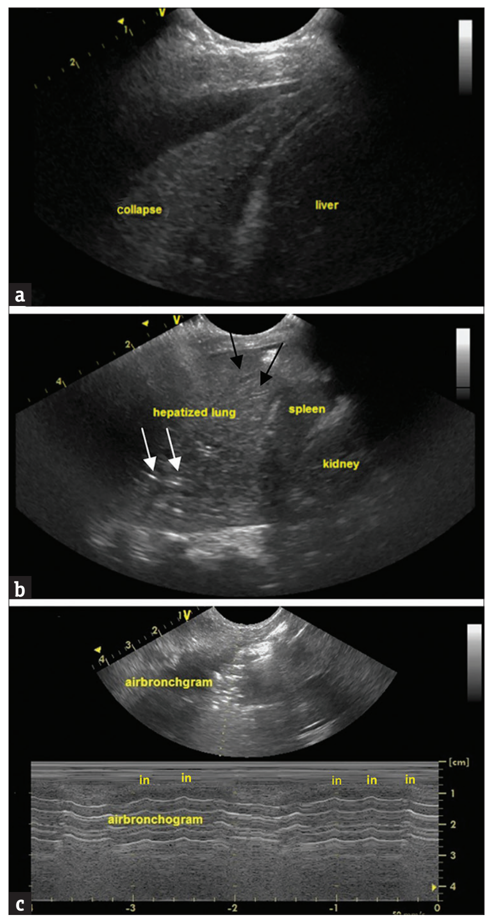

Figure 7: A 2-year hypotonic child with persistent dyspnea and fever postbilateral pulmonary artery reconstruction: (a) Ultrasonographic longitudinal view of the right inferior chest region shows collapsed lung with mild pleural effusion; the airless lung is similar in echogenicity and echo-texture to liver. (b) Ultrasonographic longitudinal view of the left inferior chest region shows punctiform air bronchograms (white arrows) and branching tubular structures (black arrows) within the consolidated lung parenchyma. (c) M-mode of the left consolidated lung shows dynamic air bronchograms in sinusoidal line with the inspiratory excursion (in) of 2 mm.

injury, or both;[26] this temporary dysfunction most often leads to a postoperative pulmonary edema and abnormal gas exchange which manifests itself clinically with respiratory distress.

There are limited data for US imaging to assess pulmonary congestion in the pediatric population. However, it was reported in literature that US may allow very early detection of pulmonary edema with a sensitivity of 98% and a specificity of 88% in diagnosing the presence of the interstitial syndrome as seen in CT, performing better than both auscultation and CXR.[19,27]

B lines [Video 5, Figures 8 and 9] which are long, vertical, well defined, hyperechoic dynamic lines originating from the pleural line have been proposed as a bedside, easy to use, alternative diagnostic tool for clinical monitoring of pulmonary congestion in heart failure patients.[28,29] Since B lines can dissolve within few minutes by an acute diuretic load, they may represent a useful bedside tool to monitor diuretic therapy response [Video 5, Figure 8a-c].[28] Acute cardiogenic pulmonary edema is frequently seen after the removal of positive pressure ventilation in patients with significant depressed cardiac function or residual lesions such as mitral regurgitation [Figure 8]. US will show multiple diffuse bilateral B lines in the presence of abnormal ECHO findings. On the other hand, noncardiogenic pulmonary congestion (acute lung injury/ARDS/reperfusion injury) is frequently seen after reconstruction or augmentation operations of pulmonary blood flow in previously oligemic lungs or due to prolonged bypass time in the presence of normal ECHO findings. US will show nonhomogenous distribution of B lines as areas of normal sonographic lung appearance surrounded by the areas of multiple B lines; in addition

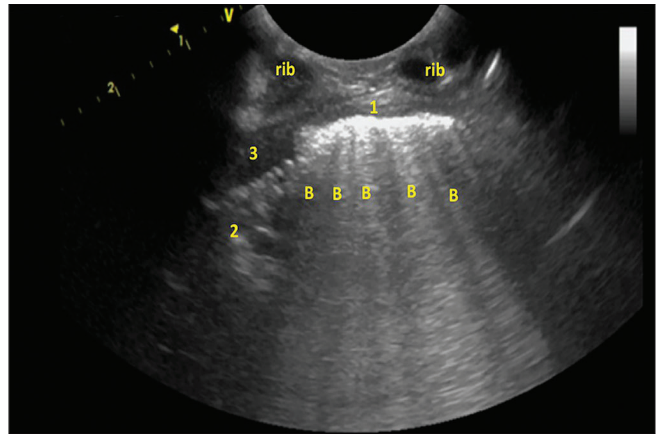

Figure 9: A 2-month-old infant postnorwwod procedure developed ventilator associated pneumonia that worsened to acquired respiratory distress syndrome; sonographic appearance of noncardiogenic pulmonary edema due to pneumonia with areas of multiple B-lines, 1: Indicates thickened pleura; 2: Subpleural consolidations, 3: Collapsed lung.

Video 5: A 1-year-old infant with significant residual mitral valve regurgitation after repair; presented with difficulty to liberate from ventilator due to pulmonary interstitial syndrome with cardiogenic pulmonary edema; sonographic appearance of pulmonary congestion demonstrating multiple vertical hyperechoic B-lines (white-out) originating from the pleural line and spreading like a laser ray up to the edge of the screen, the pleural thickness looks normal. Sonographic follow-up of pulmonary congestion after diuresis and positive pressure ventilation shows some improvement (decrease) in B-lines intensity and number.

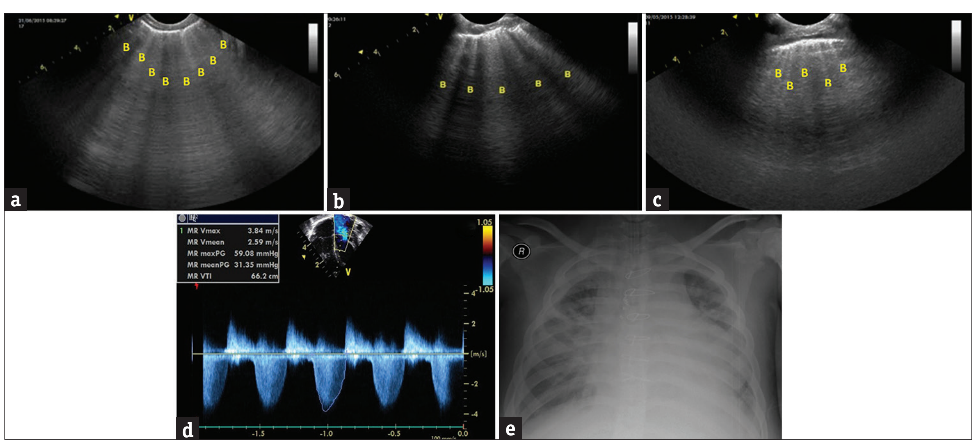

Figure 8: A 12 month old infant postcomplete atrioventricular septal defect repair with difficulty to liberate from ventilator due to pulmonary interstitial syndrome with cardiogenic pulmonary edema related to significant residual mitral valve regurgitation; (a) Focused lung ultrasound in longitudinal right anterior mid clavicular view demonstrating multiple B lines extending from the pleural line to the edge of the screen. The pleural thickness looks normal; (b,c) Sonographic follow up after diuresis and positive pressure ventilation showed some improvement in B lines intensity; (d) Mitral valve Doppler ultrasound demonstrates severe mitral valve regurgitation (blue jet); (e) chest X ray revealed cardiomegaly, bilateral pleural effusion, and congested lungs.

to parenchymal consolidation of different sizes[28] [Figure 9], it can be unilateral or bilateral.

Pneumothorax

Pneumothorax can occur after cardiothoracic surgery. Bedside CXR may misdiagnose it in up to 30% of cases in some reports.[30] Occult pneumothorax may rapidly progress to tension pneumothorax, especially in patients receiving mechanical ventilation.[31] Pneumothorax is an important cause of respiratory failure postpediatric cardiac surgery. It can occur also postchest tubes removal. US will show the typical signs of pneumothorax [Figure 10 and Video 6]:

(a) The absence of lung sliding by 2D US:[32] Lung sliding is the dynamic horizontal movement of the pleural line, synchronized with respiration. The presence of lung sliding allows pneumothorax to be confidently ruled out.[30] This test is very useful and quick and can be performed at bedside immediately when indicated. However, absent lung sliding is not pathognomonic for pneumothorax. (b) Stratosphere sign by M-mode: The abolition of normal lung sliding shows a characteristic pattern, the stratosphere sign by M-mode, which is opposed to the normal seashore sign. (c) The absence of B-lines: The presence of the slightest B-line allows prompt ruling out of pneumothorax.[33] (d) Lung point: This is the only pathognomonic sign of pneumothorax with a specificity of 100%, and sensitivity of about 65%. 2D and M-mode performed at the lung point, shows a sudden change from one pattern (regular reappearance) to the other (pneumothorax pattern) [Video 6].[34]

Video 6: A 2 month old infant postnorwwod procedure developed sudden respiratory distress and hemodyniamic instability after chest tube removal; Lung ultrasound indicates pneumothorax with sonographic appearance of lung point detected in lateral right chest below nipple line in anterior axillary line; two dimensional US shows a sudden change from the regular appearance on the right of the screen (with lung sliding and B Lines) to the pneumothorax pattern on the left of screen (with absent pleural sliding and disappearance of B lines).

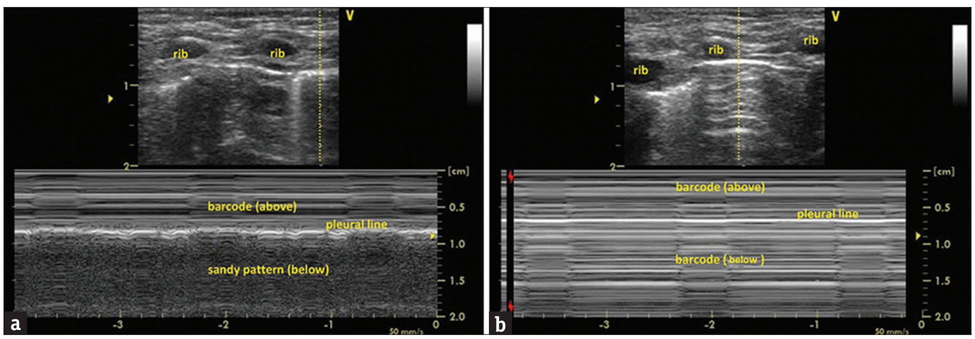

Figure 10: A 3-week neonate postcoarctation repair who developed sudden respiratory distress after extubation: (a) This M-mode image demonstrates a linear, laminar pattern in the tissue superficial to the pleural line (motionless superficial layers), and a granular or "sandy" appearance deep to the pleural line (deep artifacts follow the lung sliding). This phenomenon, known as the "seashore sign," indicates normal lung pattern. (b) This M-mode image demonstrates a linear, laminar pattern in the tissue superficial to the pleural line, and a similar linear pattern deep to the pleural line. This phenomenon, known as the "stratosphere sign" or "barcode sign" (Barcode lines above and below the pleural line), indicates pneumothorax pattern.

Basic echocardiography for intensivists

2D and Doppler ECHO are valuable tools for postoperative evaluation of cardiac structure and function. These methods permit analysis of cardiac chambers and operative results, detection of residual defects, evaluation of position and function of valvular prosthesis, and estimation of pressures inside cardiac chambers.[35] The intensivist in PCICU is not always a cardiologist, so it is advised for the intensivist to perform a quick informative US screen to assess at least cardiac function and to rule out PE that may lead to respiratory or hemodynamic failure in many occasions.

Pericardial effusion

The incidence of PE was reported 10%–13.6% for all cardiac surgeries in the recent studies.[36,37] PE occurs most commonly after corrective cardiac surgeries but may be observed in all types of surgeries involving the pericardial sac.[38,39] It contributes to postoperative morbidity and mortality, hence to be a risk for hemodynamic compromise. PE was reported to occur more commonly after Fontan-type procedures and the Ross procedure.[36,37] Residual shunts and valvular dysfunctions may interfere with the occurrence of postoperative PE.[37] The role of ECHO is extremely important in atypical clinical presentations such as in patients in the postoperative period after cardiac surgery.

Quick informative ECHO can rule out PE mainly in the apical four chambers view [Figure 11]. Moreover, drainage of the effusion is mandatory in the presence of cardiac tamponade, and in this regard, ECHO-guided pericardiocentesis is the gold-standard method.[40]

Depressed cardiac function

A degree of heart dysfunction is expected after pediatric cardiac surgery in up to 25%[41] and is related to multiple factors such as the complexity of surgery performed, degree of ventricular muscle incision, placement of corrective patches, CPB time, aortic clamping, and intraoperative complications.[41] Poor cardiac function can lead to significant respiratory distress and pulmonary congestion that can be detected on CXR and lung US. In addition, it can lead to cardiogenic shock with hemodynamic embarrassment.

2D and M-mode ECHO are simple tools to assess cardiac function through acquired recordings mainly from parasternal long access view to estimate and calculate ventricular ejection and shortening fractions, respectively, for proper titration of vasoactive medications postcardiac surgery [Figure 12].

Residual lesions

Residual lesions postpediatric cardiac surgery can occur and may affect negatively the respiratory system and/or hemodynamics. It is not easy to perform detailed ECHO study after cardiac surgery due to many factors such as surgical dressing, adhesions postoperation, and open sternum in critical cases. In addition, it needs experience and good training. Hence, it can be arranged simultaneously with cardiology support to detect the residual lesions such as mitral regurgitation or stenosis postmitral valve repair [Figure 8d], or narrowing of the baffle after total anomalies of pulmonary veins drainage repair, or residual patch leak after surgical closure of a ventricular septal defect.

Abdominal ultrasound

Abdominal distention is a frequent finding after pediatric cardiac surgery and is still considered a

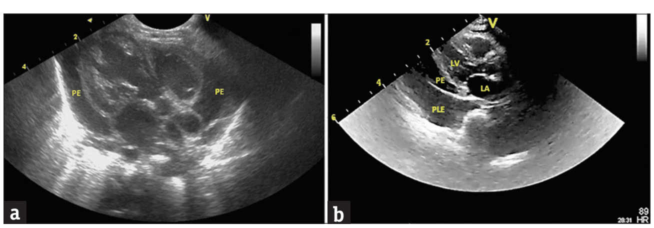

Figure 11: A 6-week neonate on day 3 postpulmonary artery band operation developed sudden hemodynamics instability and respiratory compromise: (a) Apical ultrasongraphic view of the heart shows pericardial effusion. (b) Parasternal long axis ultrasongraphic view of the heart shows pleural and pericardial effusions; LA: Indicates left atrium, LV: Left ventricle; PLE: Pleural effusion; PE: Pericardial effusion.

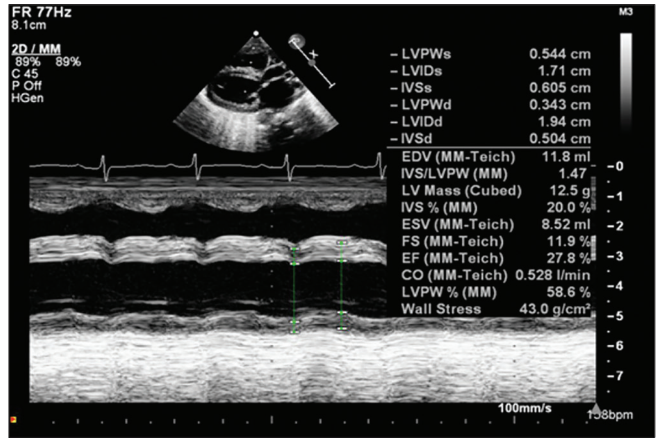

Figure 12: A 6-year-old child postmitral valve repair with congested chest X-ray and dyspnea: two-dimensional echocardiography and M-mode tracing in the parasternal long-axis view show dilated left chambers and depressed cardiac function with an estimated ejection fraction of 27.8% and fractional shortening of 11.9%.

frequent challenge in critically ill patients. US helps in differentiating ascites (abdominal fluid collection in the peritoneal cavity) from distended bladder, hepatosplenomegaly, edematous intestine, or mass [Figure 13a and c]. Ascites is a well-known sign of the right heart failure, especially in cases of pulmonary hypertension and Tetralogy of Fallot. Significant accumulation of intra-abdominal fluid is a part of extravascular fluid overload and capillary leakage and may decrease respiratory system compliance, impair gas exchange, alter hemodynamics, and delay metabolic recovery.[42] Significant abdominal fluid collection may push up the diaphragm in the chest cavity; increase the intraabdominal pressure which may have a negative effect on lung function and urine output. Accordingly, removal of extravascular fluid in this patient population is expected to help improving lung compliance and gas exchange.[42] There is a paucity of data on using US to quantify ascites after pediatric cardiac surgery. However, US could help to decide cost and time effectively whether or not to perform a peritoneal drainage [Figure 13a and b]. US-guided paracentesis of ascites will most likely reduce the rate of complications. Most of our patients are critical and lying in supine position, so US represents an optimal tool to guide the centesis that is often performed below the umbilicus in the right or left iliac fossae.

Limitations

Despite the proven diagnostic ability of critical care US and its influence on decision-making and therapeutic management, there are significant barriers to the widespread use of this pragmatic, noninvasive bedside tool. The fact that the interpretation of US

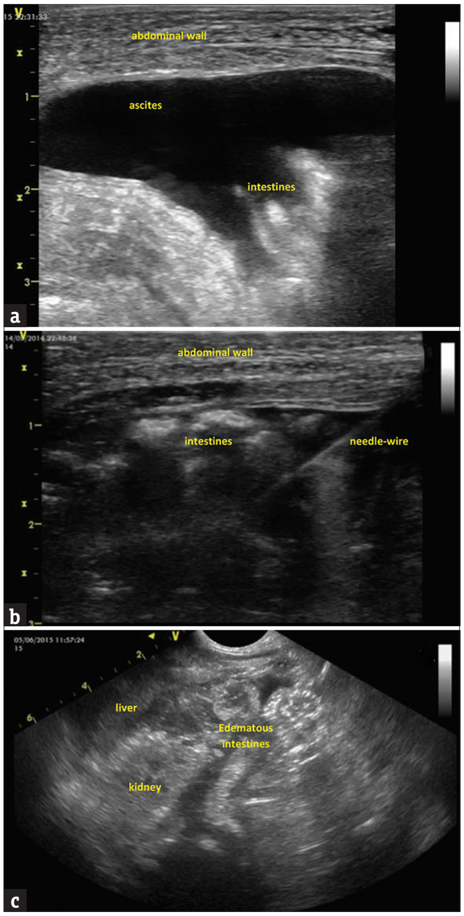

Figure 13: Two infants known to have right ventricle diastolic dysfunction posttetralogy of Fallot repair, presented with abdominal distention. Ultrasound differentiates the causes of abdominal distention in these 2 cases: (a) Sonographic appearance of free abdominal fluid collection (ascites). (b) Ultrasound-guided abdominal paracentesis for same patient shown in the above image. There is minimal fluid collection after paracentesis and the intestines become closed to the abdomen wall. (c) Edematous intestinal loops only with no clear ascites in the second case.

findings is heavily dependent on operator experience represents one important limitation. In most of the studies that show a high diagnostic accuracy of US, experts in the field have performed the scans themselves, thus this may limit the generalization of results for all ICUs.[4]

On the other hand, detailed educational protocols to achieve competence in general critical care US have not been fixed yet to spread the proper use of US in critically ill patients.[4]

Conclusions

US in PCICU stands as a quick, non-invasive, and reproducible practical tool for the diagnosis and management of common respiratory difficulties in the early postoperative period that often associated with weaning difficulties or extubation failure after cardiac surgery.

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Conflicts of interest

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