Original Article

Lung Ultrasound as a Predictor of Fast Track Extubation in Pediatric Cardiac Surgery

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ABSTRACT

Background: Fast tracking in cardiac surgery refers to the early extubation, mobilization, and hospital discharge to reduce costs and perioperative morbidity. Lung ultrasound (LUS) can detect pulmonary congestion by assessing extravascular lung water. This study aims to show if immediate postoperative LUS together with the measurement of arterial blood gas at the end of pediatric cardiac surgeries can predict extubation within the next 6 h.

Patients and Methods: A prospective observational study in single center tertiary teaching hospital, where 45 pediatric patients undergoing elective repair of congenital acyanotic heart diseases with cardiopulmonary bypass. Patients were examined with arterial blood gases and LUS after induction of anesthesia and at the end of the surgery, and given a score according to the number of B lines in each region, the receiver operating characteristics curve was used to assess the predictive value of LUS score and PaO2/FiO2 (PF) ratio to predict early extubation in ventilated children at the optimal cutoff points.

Results: Thirty two (71%) children were extubated early, and 13 (29%) children experienced delayed extubation. Children with delayed extubation had significantly lower ages, and significantly higher LUS before extubation than those with early extubation. The LUS showed good discriminative power for the prediction of early extubation (area under the receiver operating characteristics curve 0.95 with sensitivity 93% and specificity 89% at cutoff point <13). The PF ratio was less sensitive (87%) but more specific (100%) for the prediction of early extubation at a cutoff point more than 230. The study showed a strong negative correlation between LUS and PF ratio (r=0.76, P<0.001). We found an adequate interobserver agreement for LUS (weighted kappa=0.94).

Conclusion: LUS is a simple, noninvasive, reproducible and reliable tool for predicting early extubation after pediatric cardiac surgery.

Trial registration: Clinical Trials.gov, NCT05317897, retrospectively registered on April 8, 2022.

Key Words: Congenital heart disease, extubation, lung, mechanical ventilation, prediction, ultrasound

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INTRODUCTION

In cardiac surgery, fast tracking refers to early extubation, mobilization, and hospital discharge to reduce costs and perioperative morbidity[1].

Early extubation from mechanical ventilation (e.g. in the operating room or shortly after arrival to the ICU) has become relatively common in pediatric cardiac surgery, which aids in the search for new modalities that encourage fast track strategies[2,3].

Factors that favor delayed extubation, are as follows: younger age (particularly neonates), longer cardiopulmonary bypass/aortic cross-clamp times, ventricular dysfunction necessitating a high dose of inotropes, pulmonary hypertension, unsatisfactory hemostasis, coagulopathy, pulmonary dysfunction impairing gas exchange, intraoperative fluid overload, and preoperative mechanical ventilation[3].

Lung ultrasound (LUS) can detect pulmonary congestion by assessing extravascular lung water, which is a risk factor for delayed extubation[4].

Furthermore, it is a noninvasive, radiation-free tool for diagnosing a variety of pulmonary diseases in both adults and children[5]. LUS performs similarly to computed tomography and exceeds that of chest radiograph in diagnosing lung pathologies such as consolidation, pleural effusion, pulmonary edema, and pneumothorax, which occur frequently after cardiac surgery[6].

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Given the increased sensitivity of pediatric patients to radiation hazards, position changes, and patient transfers, a LUS would be an excellent perioperative option in pediatric cardiac surgery. Nonetheless, there is little evidence in the literature to support the use of LUS in pediatric cardiac surgery.

The following study aimed to show if LUS together with arterial blood gas at the end of pediatric cardiac surgeries can predict early extubation within the next 6 h.

PATIENTS AND METHODS

Study design and participants:

After approval by the local ethical committee on the clinical investigation and the guardian's written informed consent, this study was carried out following the principles of the Helsinki Declaration. The study was conducted in the pediatric cardiothoracic operation rooms in a specialized pediatric hospital. The trial has been registered on the ClinicalTrials.gov platform with the identifier NCT05317897.

A prospective observational study of 45 children with congenital acyanotic heart disease. The study team evaluated patient eligibility and enrolled participants by approaching them individually before surgery. Pediatric patients aged 5 years or younger with acyanotic congenital heart disease who were scheduled for cardiac surgery were eligible. Exclusion criteria included previous thoracic surgery, upper or lower airway infection, pulmonary disease, airway anomaly, genetic disease, and abnormal preoperative chest radiograph findings such as atelectasis, pneumothorax, pleural effusion, or pneumonia.

Anesthesia and perioperative ventilatory settings:

The anesthesiologist interviewed and took a history from the parents, examined the patients, and all routine investigations, such as a complete blood count, coagulation profile, liver function tests, renal function tests, chest radiograph, echocardiography, and angiography, were reviewed.

After placement of standard monitors, including ECG, pulse oximetry, and noninvasive blood pressure cuff, inhalational induction with sevoflurane in 50% oxygen was used on all patients, followed by the placement of a peripheral intravenous cannula. Fentanyl (1–2 μg/kg) and atracurium (0.5 mg/kg) administration aided oral endotracheal intubation. Anesthesia was maintained with 1% end-tidal sevoflurane, 0.5 mg/kg/h atracurium infusion, and fentanyl in divided doses up to 10 μg/kg.

Mechanical ventilation was maintained in a pressure-controlled mode with a FiO2 of 50%, a positive end-expiratory pressure of 3 cmH2O, an I : E ratio of 1 : 2, and a peak inspiratory pressure adjusted to deliver a tidal volume of 6–8 ml/kg and a respiratory rate ranging from 15 to 35 cycles per minute, depending on age, to keep $EtCO_2$ between 30 and 35 mmHg.

Lung ultrasound examination:

LUS examination and arterial blood gases were performed twice, after induction of anesthesia and at the end of surgery.

Radiologists who were blinded to the study performed LUSs. The multifrequency superficial linear probe (6–12 MHz) installed on the Siemens Acuson X300 ultrasound machine was used to examine the lungs (Siemens Health Care GmbH, Erlangen, Germany). The presence of B lines in the lungs was determined using ultrasound[4,7–9]. The presence of B lines indicates a loss of air per volume of lung tissue, with an increase in extravascular lung water as a result[10].

Lung ultrasound score:

To standardize the examination for all patients, the LUS score proposed by Bouhemad *et al.*[11] was used. Images and videos were saved for offline analysis later.

LUS was obtained by scanning 12-rib interspaces with a probe held perpendicular to the wall. Each hemithorax was divided into six sections: two anterior sections, two lateral sections, and two posterior sections. The results of each scanning site produced a score indicating the extent of the pulmonary interstitial status[4,7–9].

Different lung aeration patterns were identified as follows: lung sliding with only A lines indicating normal aeration was assigned a score of 0, three or more separated well-defined B lines indicating moderate loss of lung aeration was assigned a score of 1, coalescent or crowded B lines with or without consolidation limited to the subpleural space indicating severe loss of lung aeration was assigned a score of 2, and the appearance of extensive consolidations indicating lung consolidation was assigned a score of 3 Figure 1. The summation of this B lines from the 12 regions yields a score from 0 to 36[4,7–10].

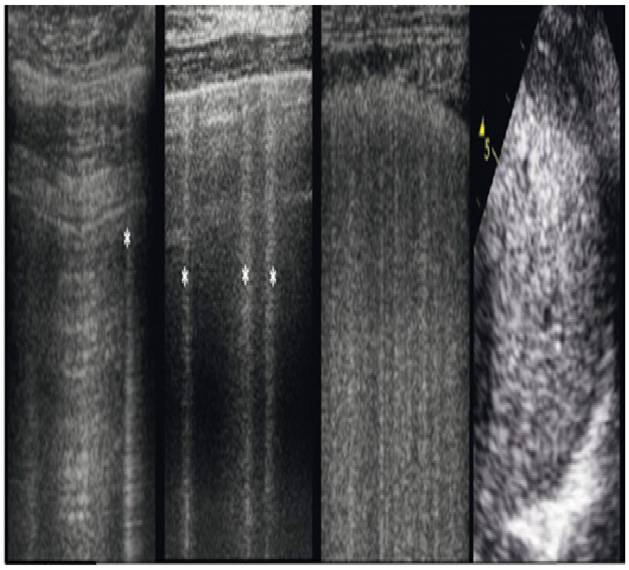

Fig. 1: Different lung aeration patterns. (score 0: A lines; score 1: three or more well-spaced B lines; score 2: coalescent B lines; score 3: lung consolidation)

Patients were transferred to the cardiac surgical ICU for postoperative care following surgery. Before weaning and extubation, patients were mechanically ventilated using assisted controlled ventilation and then switched to SIMV. The treating intensivist, who was blinded to the study, decided on extubation based on the ICU policy, which was being hemodynamically stable, ventilatory rate less than 25 cycle/min, peak inspiratory pressure at 16–18 cmH2O with adequate chest expansion, acceptable blood gases, PaO2 more than or equal to 60 mmHg on positive end-expiratory pressure less than or equal to 5 cm, FiO2 less than or equal to 0.4, PaO2 : FiO2 more than or equal to 150–300, and Glasgow coma score more than or equal to 13 without sedation. Following extubation, patients were placed on nasal noninvasive ventilation or nasal cannula based on their rate, pattern, and work of breathing. To assess postextubation failure, the patient was monitored for 24 h after extubation (EF). EF is defined as the need for reintubation or invasive ventilatory support within 24 h of extubation.

Outcome variables:

Demographic data: age, sex, weight, diagnosis, aortic cross-clamp, and bypass times. Assessment data: baseline arterial blood gases and LUS score after induction of anesthesia and at the end of surgery.

The primary outcome was to assess the predictive value of LUS to predict early extubation within the first 6 h in the ICU after pediatric cardiac operation at the optimal cutoff point. Secondary outcomes were to assess the predictive value of PaO2/FiO2 (PF) ratio to predict early extubation within the first 6 h in the ICU after pediatric cardiac operation at the optimal cutoff point and the correlation between LUS and PF ratio at the end of the operation.

Sample size:

The sample size was calculated using a value of 0.78 for the area under the curve (AUC) of LUS to predict weaning success in ventilated children [12]. Based on this calculation, we found that a sample of 27 from the early extubation group and 13 from the delayed extubation group with a total number of 40 children would be needed to achieve 80% power to detect a difference of 0.25 between AUC at a significance level of 0.05, 45 patients were enrolled to avoid dropout.

Statistical analysis:

The Statistical Package for Social Sciences (SPSS) (IBM Corp., Armonk, NY), version 24 was used for data management and statistical analysis. Means and SDs were used to express continuous variables. Categorical data were summarized as numbers and percentages. The Student t test was used to compare the means of continuous variables between the two groups of failed and successful early extubation. The χ^2 test or Fisher exact test was employed to compare categorical variables in the two groups.

The receiver operating characteristics (ROC) curve was used to assess the predictive value of LUS and PF ratio in ventilated children at optimal cutoff points for early extubation success. To predict successful extubation, we created a binary logistic regression model with LUS and PF ratio as independent variables. The Spearman rank correlation was done to analyze the correlation between LUS and PF ratio. P values less than or equal to 0.05 were considered significant. The interobserver reliability in this study was assessed between the ultrasound measurements performed by two different radiologists. The quadratic-weighted kappa coefficient (which is comparable to interclass correlation coefficient) and their 95% confidence intervals (CI) were calculated to assess the degree of reliability.

RESULTS

The study was conducted in the pediatric cardiothoracic operation rooms in specialized pediatric hospital. This study involved 45 patients with acyanotic heart disease who have repaired cardiac defects, 32 (71%) of them were early extubated within 6 h and 13 (29%) of them were extubated later. There was only one (3.1%) patient from the early extubated group that is reintubated for hemodynamic instability.

Patients with delayed extubation had significantly lower ages than those with early extubation (13.2±3.2 vs. 16.2±4.5 months, *P*=0.02). LUS before extubation at end of the operation was significantly higher in patients with delayed extubation than in those with early extubation (17±5.2 vs. 9±3.9, *P*=0.001). However, there was no significant difference between the two groups as regards sex, weight, diagnosis, aortic cross-clamp and bypass times, baseline blood gas, or baseline LUS (Table 1).

Table 1: Variables in children with early and delayed extubation:

Variables	Early extubation (N=32)	Delayed extubation (N=13)	*P*
Age (months)	16.2 ± 4.5	13.2 ± 3.2	0.02*
Sex (male : female)	18 : 14	8 : 5	0.85
Weight (kg)	15.7 ± 14.26	12.25 ± 12.96	0.47
Diagnosis			
VSD	15 (47)	6 (46)	0.97
ASD	7 (22)	3 (23)	
PAVC	10 (31)	4 (31)	
Cross-clamp time (min)	50 ± 21	52 ± 28	0.84
CPB time (min)	71 ± 25	74 ± 33	0.89
LUS after induction	14.2 ± 4.5	15.1 ± 3.2	0.44
LUS at the end	9 ± 3.9	17 ± 5.2	0.001*

Data are presented as mean±SD or the number of patients or percentage.
ASD, atrial septal defect; CPB, cardiopulmonary bypass; LUS, lung ultrasound; PAVC, partial atrioventricular canal; VSD, ventricular septal defect.
Values marked with an asterisk are statistically significant.

The causes of delayed extubation were three cases with ventricular dysfunction, four cases with pulmonary dysfunction, and sex cases with both pulmonary and ventricular dysfunction.

Figure 2 showed a strong negative correlation between LUS and PF ratio ($r = -0.76$, $P<0.001$).

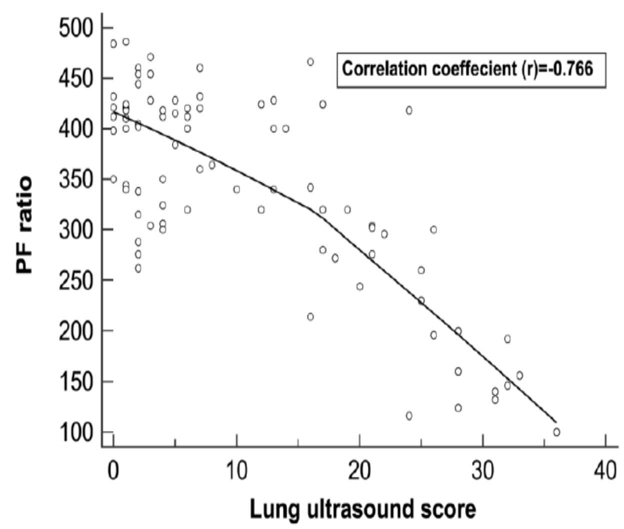

Fig. 2: Scatter plot for correlation between LUS and PF ratio. LUS, lung ultrasound; PF, PaO2/FiO2.

Figure 3 demonstrated the AUC for both LUS and PF ratio (sensitivity and specificity) for the prediction of early extubation within 6 h.

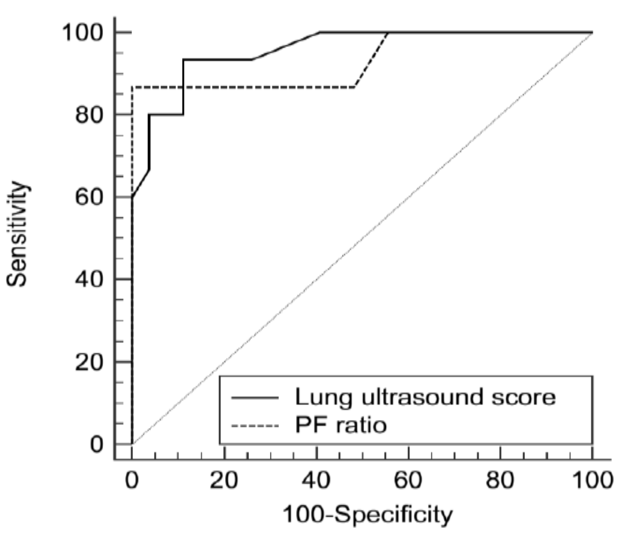

Fig. 3: Receiver operating characteristics curve for LUS and PF ratio for prediction of early extubation. LUS, lung ultrasound; PF, PaO2/FiO2.

The previous Figure 3 and Table 2 demonstrated that LUS showed sensitivity (93%) and specificity (89%) for prediction of early extubation [AUROC (95% CI): 0.95 (0.84–0.99); $P<0.001$], at a cutoff point less than 13.

Table 2: Predictive ability for lung ultrasound and PaO2/FiO2 ratio for early extubation within 6 h

	LUS	PF ratio
AUROC (95% CI)	0.95 (0.84–0.99)	0.93 (0.80–0.98)
Sensitivity	93%	87%
Specificity	89%	100%
PPV	96%	100%
NPV	69%	71%
Cut off value	<13	>230

AUROC, area under the receiver operating characteristic curve; CI, confidence interval; LUS, lung ultrasound; NPV negative predictive value; PF, PaO2/FiO2; PPV, positive predictive value.

The PF ratio showed sensitivity (87%) and specificity (100%) for the prediction of early extubation [AUROC (95% CI): 0.93 (0.80–0.98); $P<0.001$], at a cutoff point more than 230.

In the interobserver agreement, the quadratic weighted kappa value for LUS was 0.94 (95% CI: 0.91, 0.97), which shows almost perfect interobserver agreement.

DISCUSSION

According to our results, the study found significant interobserver agreement in their scoring system for B-line assessment of LUS consistent with the reproducibility of the technique. They can then further expand to the prediction of early extubation after pediatric cardiac surgery for congenital heart disease.

Pulmonary complications following cardiac surgeries remain one of the main causes of delayed extubation and prolonged hospital stay, 29% of pediatric cardiac surgical patients in our study had delayed extubation which was following the results of other studies[3]. Moreover, we found that pediatric cardiac surgical patients with delayed extubation had significantly lower ages compared with those with succeeded early extubation. This was in agreement with the results of other investigators[3].

Recent research has looked into the use of LUS in children undergoing congenital heart surgery. These studies have demonstrated the diagnostic accuracy of LUS for postoperative pulmonary complications. Furthermore, there is some evidence that LUS provides not only diagnostic but also prognostic information in pediatric cardiac surgery, suggesting that it may offer a new tool that advocates for rapid extubation[13]. LUS was significantly higher in patients with delayed extubation compared to those with successful early extubation in this study due to decreased lung aeration. The findings for LUS were consistent with previous findings in adults[14].

The accuracy of LUS to validate the readiness for extubation is coming from its ability to identify pulmonary edema with 97% sensitivity and 95% specificity as reported by Lichtenstein and Mezière[9]. Another previous study found that B lines seem to be more correlated with extravascular lung water with a sensitivity of 81%, and specificity of 90% than with pulmonary capillary wedge pressure[10]. Adults use either the sum of B lines in each area or the number of areas with more than three B lines to classify lung congestion in heart failure; however, in children, we use simplified scores; either qualitative or semiquantitative scores have been adopted. Pulmonary atelectasis is common after pediatric surgery and/or in the ICU, and it is difficult to distinguish from severe pulmonary congestion if scanned during postoperative recovery. Characteristic B lines aid in distinguishing cardiogenic lung congestion from other types of lung deaeration[14].

Regarding the predictive accuracy of LUS for early extubation, in our study, LUS shows sensitivity (93%) and specificity (89%) for the prediction of early extubation [AUROC (95% CI): 0.95 (0.84–0.99); $P<0.001$], the cut off value is LUS less than 13, the less the pulmonary congestion detected by LUS the higher the incidence of early extubation.

Similarly, Soummer *et al*.[15] reported that in ventilated adults, LUS less than 13 is associated with extubation success, but LUS greater than 17 is associated with extubation failure.

Moreover, several studies in adults revealed that LUS has excellent predictive power for predicting extubation success at various cutoff levels ranging from 10 to 14, depending on sample size, homogeneity of included patients, the definition of extubation failure, exclusion of deceased patients, and time between LUS and extubation[16–19].

In our study, there is a significant negative correlation between LUS for pulmonary congestion and PF ratio (Spearman correlation $r=-0.76$), the increase in pulmonary congestion worsens the PF ratio which is getting along with another study in 2018 by Ciumanghel *et al*.[20] that has showed a linear correlation between the baseline B line score and PF ratio in ICU patients with acute kidney injury where B line score more than 17 can predict PF ratio less than 300 with specificity 85% and sensitivity 80% with AUC 0.733.

Our results were found to be consistent with a study by Bilotta *et al*.[21] who demonstrated a significantly negative correlation ($r = 0.8$, $P<0.04$) between the B line score and PF ratio in neurocritical care patients.

Contrary to our study, the data collected by Engelhard and colleagues in their study showed a significant but weak correlation between LUS and PF ratio (Spearman's $r = -0.34$, $P=0.02$) but this study may be different from our study as they only scanned four lung zones, the authors claimed that a four-sector approach provided similar accuracy compared with more complex protocols in predicting extravascular lung water and this might be of value because rapid decision making is key in the emergency and ICU setting but no further studies applied this protocol[22].

Although the PF ratio is thought to be a cornerstone in predicting successful extubation, the difficulty of invasive arterial line insertion in children, and as an invasive maneuver with the possibility of complications such as accidental removal, hematoma formation, vasospasm, or thrombosis. The importance of LUS emerges here as a simple, reliable, reproducible, and noninvasive technique to aid in the prediction of successful extubation, the reduction of extubation failure, and the early detection of postoperative respiratory complications.

Limitations of the study:

The number of children included in this study was relatively small, as this was a single center study with strict inclusion criteria. Our findings might need to be validated by a larger multicentric study with different types of patients like children with congenital cyanotic heart diseases, and because this was an observational study, no causal association could be established.

CONCLUSION

This study showed a strong negative correlation between LUS and PF ratio, the ability of LUS to predict the success of early extubation after pediatric cardiac surgery was comparable to that of PF ratio with more sensitivity and less specificity, and LUS was reproducible with a good interobserver agreement.

CONFLICTS OF INTEREST

There are no conflicts of interest.

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