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Comparison of Lung Ultrasound to X-ray for Diagnosis of Pulmonary Complications after Cardiac Surgery in Children

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ABSTRACT

Background: The purpose of this study was to compare diagnostic performance of lung ultrasound in comparison to chest X-ray to detect pulmonary complication after cardiac surgery in children.

Methods: A prospective observational study was conducted in tertiary center of Nepal. 141 consecutive paediatric patients aged less than 14 years scheduled for cardiac surgery were enrolled during the 6 months period. Ultrasound was done on the first post-operative day of cardiac surgery and compared to chest X-ray done on the same day to detect pleural effusion, consolidation, atelectasis and pneumothorax.

Results: Sensitivity, specificity, positive and negative predictive values and diagnostic accuracy were calculated using standard formulas. lung ultrasonography had overall sensitivity of 60 %, specificity of 72.4%, positive predictive value of 31.9% and negative predictive value of 89.3% and diagnostic accuracy of 70.2% for diagnosing consolidation. Similarly, lung ultrasonography had overall sensitivity of 90%, specificity of 82.6%, positive predictive value of 46.1% and negative predictive value of 98% and diagnostic accuracy of 83.6 % for diagnosing pleural effusion. For atelectasis, ultrasonography had sensitivity of 50%, specificity of 76.9%, positive predictive value of 30.7% and negative predictive value of 88.2% and diagnostic accuracy of 72.3%. No pneumothoraxes were detected during our study period.

Conclusions: Lung ultrasound is an alternative non-invasive technique which is able to diagnose pulmonary complications after cardiac surgery with acceptable diagnostic accuracy with no proven complications but with decreasing exposure to ionizing radiation and possibly cost.

Keywords: Cardiac surgery; children; lung ultrasound; pulmonary complications

INTRODUCTION

Pulmonary complications are frequent in cardiac surgery, representing an important cause of morbidity, prolongation of hospital stay and need for repeated examinations.[1-2] Chest X-rays(CXR) are done routinely and even multiple times to detect such complications as it is the current standard diagnostic imaging. However, CXR exposes healthcare workers and the patients to ionizing radiations. Lung ultrasonography (LUS) is an alternative test to detect pulmonary complications that can be done easily on bedside. LUS is gaining popularity in recent years as a non-invasive, radiation-free tool for the diagnosis of various pulmonary diseases [3-6] due to its bedside convenience, accuracy, and easy availability. There is increasing evidence to support the use of LUS in acute care setting [7-9] and post-cardiac surgical patients are also considered critically ill. The purpose of this study was to compare diagnostic performance of LUS in comparison to CXR to detect pulmonary complication after cardiac surgery in children.

METHODS

Following institutional review board approval, a written informed consent was obtained from all the patient's guardians meeting the inclusion criteria before undergoing surgery on pre-operative visit. This is the prospective observational cohort study performed at a cardiac surgical intensive care unit (ICU) of a Heart Center. All consecutive pediatric patients aged less than 14 years scheduled for cardiac surgery during the 6 months period from October 2016 to April 2017 were enrolled in the study. The exclusion criteria included

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guardian's refusal;patient who died intra-operatively or before the examination period in the cardiac ICU and when ultrasound was not feasible due to logistics. Total of 160 patients were operated during this study period of which 141 patients were included. 19 were excluded as the patient died before the examination next day.

The patient's age, weight, height, diagnosis, operation, cardiopulmonary bypass time and aortic cross clamp time were recorded.

LUS was done on the first post-operative day of cardiac surgery and compared to CXR done on the same day for any pulmonary complications. LUS examination was performed by board-certified radiologist to detect pleural effusion, consolidation, pulmonary atelectasis and pneumothorax using Siemens AUCUSON Freestyle Diagnostic Ultrasound System and L13-5 linear probe. The trans-thoracic LUS approach was done in supine and both lateral decubitus positions of the anterior lung area (between the sternum and the anterior axillary line), lateral lung area (between the anterior and posterior axillary lines), and posterior lung area (between the posterior axillary line and the spine) in caudo-cranial direction and the probe was positioned perpendicular to the ribs for each intercostal space. The radiologist who performed the examination identified pleural line as a hyper-echogenic line between the two rib shadows. Also, lung sliding and comet tail artifacts were checked during respiration. Portable, anterior-posterior CXR were obtained in the supine position using portable X-ray unit before LUS evaluation. CXR were evaluated by anesthesiologists in ICU to detect pleural effusion, consolidation, pulmonary atelectasis and pneumothorax.

Pleural effusion:The ultrasound image of pleural effusion was measured by depth of echo-free space between the visceral and parietal pleura.

Pulmonary consolidation: The pulmonary ultrasonic signs of lung consolidation included a hypo-echoic area of varying shape and size with irregular margins of heterogeneous echogenicity.[10,11] Moreover, the ultrasound also included dynamic air bronchogram (multiple lentil-sized echoes within the lesion), visualization of intra-parenchymal pulmonary arteries and veins and motion with respiration.

Atelectasis: The main features of atelectasis on LUS included lung consolidation and static air bronchograms.[12,13] The presence of a dynamic air bronchogram can rule out atelectasis.[12,13] The edges of wide local atelectasis were quite regular.

Pneumothorax: The ultrasound findings of pneumothorax included absent lung sliding and "B lines" with the presence of "A lines". This is due to air in between the parietal and visceral pleura, preventing lung from sliding. "B-lines" or "comet-tail artifacts" are reverberation artifacts that appear as hyperechoic vertical lines that extend from the pleura to the edge of the screen without fading. These artifacts are lost due to air accumulating within the pleural space. "A lines" are also reverberation artifacts appearing as equally spaced repetitive horizontal hyperechoic lines reflecting off of the pleura that are characteristic of pneumothorax. Visualizing the junction between sliding lung and absent sliding is known as the lung point sign and is near 100% specific for pneumothorax. The "lung pulse" is a result of cardiac vibrations being transmitted to the lung pleura in poorly aerated lung. Cardiac activity is essentially detected at the pleural line when there is absent lung sliding.

Both the radiologist and anesthesiologists were blinded to each other's findings. Comparison of the findings was done at the end of study. The anesthesiologists and radiologist who performed the LUS examination and X-ray interpretation filled out a data form asking for his/her determination of the absence or presence of pulmonary complications in all examined lung fields.

Collected data were analyzed by means of statistical software SPSS-16. Descriptive statistics were expressed in frequency, percentages and and mean ± standard deviation. Chest radiograph was considered as the reference standard for calculations.Sensitivity, specificity, positive and negative predictive values, and diagnostic accuracy were calculated using standard formulas.

RESULTS

Total of 160 patients underwent cardiothoracic surgery during the study period and we recruited 141 patients of which 58.9% were male and 41.1% female. Table 1 below shows the demographic data and clinical characteristics of patients studied. As shown in table 2, lung ultrasound diagnosed more patients with pulmonary complications compared with chest X-ray.The incidence of consolidation was 47 while chest x-ray detected only 25 patients. Similarly, pleural effusion was detected in 39 patients by LUS as compared to 20 patients by CXR. Also, atelectasis was diagnosed in 39 patients by LUS while CXR detected only 24 cases. No pneumothoraxes were detected during our study period.

Table 1. Patients' demographic profile (n= 141).

Characteristics	Frequency	Percent	Mean ± SD
Age (years)			
<1year	15	10.6	6.3 ± 4.7
1 to 5 years	59	41.8	
>5 years	67	47.6	
Gender			
Male	83	58.9	
Female	58	41.1	
Height (cm)			
50 to 80	33	23.4	
80 to 110	44	31.2	105.6±28.4
110 to 140	48	34	
140 to 170	16	11.4	
Surgeries			
Simple Congenital heart diseases repair	79	56	
Complex Congenital heart diseases repair	37	26.2	
Valve repair	13	9.2	
Others	12	8.5	
Cardiopulmonary bypass time	119	84.4	84.99
Aortic cross-clamp time	116	82.2	56.31

Table 2. Distribution of lung complications detected by LUS as compared to CXR (n= 141).

Charateristics	LUS n(%)	CXR n (%)
Consolidation	47(33.3)	25(17.7)
Pleural effusion	39(27.7)	20(14.2)
Atelectasis	39(27.7)	24(17)

Table 3 shows the sensitivity, specificity, PPV,NPV and diagnostic accuracy for lung ultrasound in comparison with chest X-ray in detecting common postoperative pulmonary complications.The sensitivity,specificity and diagnostic accuracy was higher for lung ultrasound for detecting pleural effusion as compared with CXR. Similarly,specificity and diagnostic accuracy was higher and sensitivity was comparable for consolidation and atelectasis by lung ultrasound in comparison to CXR.No cases of pneumothorax were detected during the study period as shown in Table 3 below.

Table 3. Sensitivity, specificity, PPV, NPV and DA of LUS to diagnose pleural effusion, consolidation and atelectasis as compared to CXR (n= 141).

Lung ultrasound	Sensitivity	Specificity	PPV	NPV	Diagnostic accuracy
Pleural effusion	90.0	82.6	46.1	98	83.6
Consolidation	60.0	72.4	31.9	89.3	70.2
Atelectasis	50.0	76.9	30.7	88.2	72.3

DISCUSSION

In this study, we evaluated the diagnostic accuracy of LUS so that we can reduce the number of CXRs and relative hazards associated with it. We found that LUS in post-cardiac surgery patients have relatively high sensitivity, specificity and diagnostic accuracy in comparison to CXR to detect common pulmonary complications.

Chest radiograph on first post-operative day is standard of care after cardiac surgery. Lung ultrasound is a non-invasive technique without any proven complications. If lung ultrasound proves to be superior or equivalent to chest radiograph, then this may change the approach of managing post cardiac surgical patients in terms of decreasing exposure to ionizing radiation, time and cost.

We have shown that LUS had high overall sensitivity, specificity, diagnostic accuracy for diagnosing pleural effusion. In the bedside assessment of effusion on critically ill patients done by Kocijancic et al., LUS showed a better sensitivity and reliability than CXR, which is highly dependent on the necessity of the upright view.[14] In another study by Balik et al. bedside CXR rarely detects small effusions and can also miss effusions of up to 500 ml.[15] On the other hand, the sensitivity and specificity of LUS for the detection of PLE are as high as 93%, compared with computed tomography (CT) [16] in a study done by Lichtenstein et al.This suggests that lung ultrasound might perform better than CXR in detecting pleural effusionwhich is in line with our study.

Similarly, we have found that LUS had high specificity and diagnostic accuracy for diagnosing consolidation. There were two published meta-analyses conducted by Hu et al and Chavez et al which evaluated the diagnostic accuracy of ultrasound for detecting pneumonia with very high sensitivity (97% and 94%) and specificity (94% and 96%).[17,18] In a study done by Xiong Ye in patients

with community acquired pneumonia, LUS had a pooled sensitivity of 0.95 (0.93-0.97) and a specificity of 0.90 (0.86 to 0.94), CXR had a pooled sensitivity of 0.77 (0.73 to 0.80) and a specificity of 0.91 (0.87 to 0.94).[19] A meta-analysis showed that LUS had a high sensitivity (94%) and specificity (96%) for diagnosing pneumonia in adults and was superior to CXR.LUS also had a consistently high diagnostic accuracy of pneumonia when compared with chest CT scan as the gold standard.[20,21] Of note, previous research has shown that lung ultrasound potentially facilitates prompt diagnosis of pulmonary complications,it might be used as a primary imaging technique to screen for complications after cardiac surgery.

Our study also found that for atelectasis, ultrasonography had high diagnostic accuracy. Yu et al found that in some cases with total or near-total opacification of the hemithorax, LUS has a high sensitivity in differentiating between consolidation of atelectasis and pleural effusion, whereas CXR is unable to make this distinction.[22] LUS has been used in diagnosing atelectasis in children, and its sensitivity was 100% in research conducted by Lichtenstein et al.[23]

No pneumothorax was detected during our study period. However,in the study done by W Abdalla, lung ultrasound showed a considerable higher sensitivity (86.1% vs. 52.7%) and diagnostic accuracy against CXR (95.3% vs. 90.6%).[24] Study done by Reissig et al showed that CXR has low sensitivity for the diagnosis of post-procedural pneumothorax.[25] LUS revealed an optimal diagnostic accuracy, with superior sensitivity and similar specificity to CXR, for the detection of pneumothorax in the emergency department.[26,27] In Volpicelli study, however, its use in cardiac surgery remains extremely limited, and only one paper reporting on a few pediatric clinical cases can be found in the recent literature.[28]

Our study has some limitations. We could not compare our results with thoracic CT scan which is considered the gold standard for thoracic imaging. Analysis of LUS was done by qualified radiologist however CXR were done by the different anesthesiologists which may be the potential source of bias. To reduce the selection bias we enrolled all the patients during our study period except those pediatric patients who died before the examination. Since previous studies have found that lung ultrasound diagnosed more pulmonary complications as compared to CXR,the use of a CXR as a reference standard with potentially worse accuracy than the lung ultrasound(index test) makes it difficult to interpret our results.

CXR are done routinely post- cardiac surgery not only for pulmonary complications but also to detect position of central venous catheters, endotracheal tubes and position of chest tubes. We cannot completely eliminate CXR from our daily practice, however, we can reduce the number of use of CXR. Considering the aforementioned, we suggest using lung ultrasound as a complementary tool in patients after cardiothoracic surgery. We have shown that lung ultrasound is a very useful tool for diagnosis of pulmonary complications in pediatric patients after cardiothoracic surgery in view of limitations of CXR.The limitations of CXR will be clear in ICU settings where patients can be examined only in supine positions. Future perspective should include need for multicenter studies on larger sample to investigate the cost effectiveness, ease of implementation. There also should be clear guideline regarding the protocols to be adopted and transducer to be employed according to the patient's ages and body sizes. Also further studies are needed for quantification of pulmonary complications. Thepossibility of using LUS instead of CXR as a primary diagnostic tool in the setting of cardiac surgery has not been explored yet.

CONCLUSIONS

Lung ultrasound done routinely is an alternative non-invasive, reliable and accurate tool for diagnosing common pulmonary complications in paediatric patient post-cardiac surgery as compared to chest X-raywith acceptable diagnostic accuracy thereby decreasingexposure to ionizing radiation, time and costs.

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