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Article

Study on the Consistency of Point-of-Care Ultrasound and Chest X-ray in the Diagnosis of Postoperative Thoracic Abnormalities in Children with Congenital Heart Disease

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Abstract

Objective: This study aimed to explore the consistency of point-of-care ultrasound (POCUS) and chest X-ray in the diagnosis of postoperative thoracic abnormalities in children with congenital heart disease. **Methods**: The clinical data of 68 children with congenital cardiosurgery in our hospital from January 2021 to August 2024 were retrospective analyzed. Six children were excluded, and 62 cases were finally included. POCUS was performed 24 hours after surgery. After the examination of POCUS, chest X-ray examination was conducted. The results of POCUS and chest X-ray examinations in children, as well as the clinical incidence of postoperative thoracic abnormalities were recorded. The effect of POCUS and chest X-ray in the diagnosis of postoperative thoracic abnormalities was compared. **Results**: POCUS had slightly higher diagnostic sensitivity of pleural effusion and atelectasis than chest X-ray. The sensitivity of POCUS in diagnosing pulmonary edema was consistent with that of chest X-ray. However, POCUS had slightly lower sensitivity in diagnosing pneumothorax than chest X-ray. The specificity of POCUS in diagnosing pneumothorax and atelectasis was consistent with that of chest X-ray. However, POCUS had slightly higher specificity in the diagnosis of pleural effusion and pulmonary edema than chest X-ray. The kappa values of POCUS and chest X-ray in diagnosing pleural effusion, pneumothorax, atelectasis and pulmonary edema were 0.546, 0.565, 0.502 and 0.701, respectively. **Conclusion**: POCUS and chest X-ray examinations have good consistency in the diagnosis of postoperative thoracic abnormalities in children with congenital heart disease.

Keywords

point-of-care ultrasound; chest X-ray; congenital heart disease; sensitivity; specificity

Introduction

Congenital heart disease is the most common type of congenital birth defects [1], which is a major public health problem affecting children's survival and health. With the rapid development of medical technology, surgery of congenital heart disease has been widely carried out. However, postoperative recovery in children with heart disease is hampered by pulmonary complications, such as pneumothorax, pleural effusion, interstitial edema, and pulmonary consolidation [2]. These complications need to be detected and treated in a timely manner through detailed examination and diagnosis to avoid health problems.

Traditional imaging examinations of chest mainly include computed tomography (CT), X-ray, and ultrasound. Characterized by the high density and high spatial resolution [3], CT is the gold standard for the diagnosis of most chest diseases. Due to high price, large radiation, and inability to perform bedside examinations, CT is limited as a routine clinical examination. Chest X-ray examination is a fast and cheap examination [4], which has become one of the most common methods in diagnostic radiology. This technology can help radiologists identify patients with potential risks of heart and lung disease [5]. However, the examination of chest X-ray has limited diagnostic accuracy, and is prone to subjective variability [6], which cannot obtain high-quality images and get the results immediately.

Ultrasonography is a surface technique that can accurately diagnose the pathological process near the pleural line [7]. Point-of-care ultrasound (POCUS) is increasingly used at the bedside to integrate clinical assessment of critically ill patients [8]. Ultrasound is an ideal diagnostic tool for pediatric patients with high spatial and temporal resolution, real-time imaging, lack of ionizing radiation and availability of bedside [9]. POCUS examination of chest includes indicative assessment of cardiac function and assessment of lung parenchyma, and contains the exclusion of pericardial effusion, pneumothorax or liquid thoracic cavity [10]. However, any ultrasound technology is dependent on the operators and requires high-level training. At present, the study of POCUS in most hospitals of China is still in its infancy. Taking clinical diagnosis as the standard, this study compared the consistency of POCUS and chest X-ray in the diagnosis of postoperative thoracic abnormalities in children with congenital heart disease.

Materials and Methods

Research Subjects

A total of 68 children with congenital cardiosurgery from January 2021 to August 2024 were included. Children received regular imaging examination of chest, and the surgical effect and complications were monitored. Six children (2 critically ill children, 2 children with septic shock, 1 child with short-term death, and 1 child with tumor disease) were excluded, and 62 children were finally included. This study has obtained the informed consent from the family members of children. This study conformed to the Declaration of Helsinki (2013) [11].

This study has been approved by the medical ethics committee of Shijiazhuang People's Hospital (approval No.: 2023079).

Inclusion and Exclusion Criteria

Inclusion criteria. (1) Children conformed to the diagnostic criteria of congenital heart disease [12]. (2) Children received the surgery of congenital heart disease in our hospital. (3) Children had thoracic abnormalities after surgery. (4) Children underwent open heart surgery under general anesthesia, hypothermia and extracorporeal circulation.

Exclusion criteria. (1) Children aged $\geq$18 years old. (2) Children failed to complete the examination due to critical illness or short-term death. (3) Children had endotoxic shock. (4) Children had other tumor diseases.

Methods

All patients underwent POCUS examination after surgery, and the examination was performed by an emergency physician trained in ultrasound. SonositeM-Turbo ultrasonic machine and abdominal micro-convex array probe were adopted, with the frequency of 1–5 MHz. L12-3 linear array probe was used, with the frequency of 3–12 MHz. The child was in a supine or semi-supine position, with the scan up to the subclavicular place, and down to the diaphragm. The detection site was each intercostal space of the midclavicular line, anterior axillary line, midaxillary line and paravertebral line. The image of each rib was recorded.

POCUS had diagnostic criteria for different thoracic abnormalities. (1) Pleural effusion showed the echoless area of pleural cavity, with a depth of more than 1 cm, which was displayed by the phased array probe. The trace pleural effusion could be displayed by the linear array probe. (2) Pneumothorax showed the disappearance of pulmonary sliding sign, without B line. The junction of gas in the pleural cavity and the pleural line with sliding sign was the lung point sign. (3) Atelectasis showed equal low echo, but the shape of lobe was complete, without fragmentation sign. (4) Pulmonary edema showed multiple B lines in bilateral chest walls and smooth pleural line.

All children underwent chest X-ray (MUX-100DJ mobile X-ray machine; tube voltage: 120 kV; exposure volume: 1.8–2.0 mAs; focal-screen distance: 25 cm; irradiation field: 35 cm $\times$ 43 cm) and chest CT examination (64-row GE Lightspeed VCT; end inspiratory scan in supine position for pediatric patients; tube voltage: 120 kV; tube current: 300–320 mAs; pitch: 1; matrix: 512-512; layer thickness: 0.625 mm) within 24 hours. The diagnostic results were obtained by the same radiologist. CT combined with clinical diagnosis was used as the final diagnostic criteria for thoracic abnormalities.

Chest X-ray had diagnostic criteria for different thoracic abnormalities. (1) Pleural effusion was manifested as blunted costo-phrenic angle, showing the effusion shadow on the outer and upper edge of arc. The effusion was scattered when patients were in horizontal position, which reduced the transmittance of whole lung field. (2) The typical manifestation of pneumothorax was a thin line shadow with convex arc shape (pneumothorax line). The outside line had increased brightness, no lung texture, and the inside line was compressed lung tissues. Massive pneumothorax showed that the lung retracted to the hilum of lung, manifested as a spherical shadow, and the mediastinum and heart moved to the healthy side. (3) Atelectasis was manifested as increased density of the affected lung field, lack of normal lung texture, reduced volume of lung, and clear boundary with surrounding normal lung tissues. (4) Pulmonary edema showed extensive cloud-like blurred shadows in bilateral lung fields, and blurred edges. The X-ray of severe cases showed honeycomb or reticular shadows.

Observation Indicators

General Clinical Data

The baseline data and clinical characteristics of the enrolled children were recorded and analyzed.

Diagnosis of Thoracic Abnormalities

The results of POCUS and chest X-ray examination within 24 hours after surgery were compared.

Analysis on Clinical Diagnostic Efficacy of Thoracic Abnormality

The diagnostic accuracy of POCUS, chest X-ray and clinical diagnosis of thoracic abnormalities within 24 hours after the surgery of congenital heart disease was compared.

Table 1. General clinical data.

Characteristics		Values
Sex [n, (%)]	Male	39.00 (62.90)
	Female	23.00 (37.10)
Age [years old, mean ± SD]		7.56 ± 3.31
Body mass index [kg/m^2, mean ± SD]		16.09 ± 1.38
Types of disease [n, (%)]	Atrial septal defect	13.00 (20.97)
	Ventricular septal defect	14.00 (22.58)
	Double outlet of right ventricle	6.00 (9.68)
	Tetralogy of fallot	12.00 (19.35)
	Coarctation of aorta	10.00 (16.13)
	Other complex abnormalities	7.00 (11.29)
Duration of ECC [min, mean ± SD]		125.95 ± 35.07
Aortic clamping time [min, mean ± SD]		89.42 ± 27.45
Duration of mechanical ventilation in ICU [h, mean ± SD]		6.89 ± 1.15
Treatment time in ICU [h, mean ± SD]		86.02 ± 43.73
Complications	Neurodevelopmental disorders	7.00 (11.29)
	Immunodeficiency	9.00 (14.52)
	Hypoevolutism	17.00 (27.42)

Notes: ECC, extra corporeal circulation; ICU, intensive care unit.

Based on the actual diagnosis of patients, clinical diagnosis included but not limited to the evaluation of symptoms and signs, laboratory examination, imaging examination and invasive examination (such as thoracentesis) when necessary.

Test of Clinical Diagnosis

This study evaluated the consistency of POCUS and chest X-ray in different detection results of clinical diagnosis.

Statistical Analysis

SPSS25.0 software (manufacturer: International Business Machines Corporation; origin: Armonk, NY, USA) was used for processing the data. The accuracy of POCUS and chest X-ray examination in detecting clinical thoracic abnormalities was manifested as sensitivity, specificity, positive and negative predictive values, and diagnostic accuracy.

Sensitivity = cases of true positive/cases of (true positive + false negative). Specificity = cases of true negative/cases of (true negative + false positive). Positive predictive value = cases of true positive/cases of (true positive + false positive). Negative predictive value = cases of true negative/cases of (true negative + false negative).

The consistency of examination methods was detected by Cohen's kappa test. The kappa value of 0–0.20 showed very poor consistency, 0.21–0.40 was poor consistency, 0.41–0.60 was medium consistency, 0.61–0.80 was good consistency, and 0.81–1.00 was excellent consistency. $p < 0.05$ indicated the statistically significant difference.

Results

General Clinical Data

A total of 68 children with congenital heart disease who underwent surgery were included. Six children were excluded, and 62 children were finally included. The baseline characteristics and clinical characteristics of children are shown in Table 1.

Diagnosis of Thoracic Abnormalities

The identified thoracic abnormalities were diagnosed as pleural effusion, pneumothorax, atelectasis and pulmonary edema. The total incidence of thoracic abnormalities under actual clinical diagnosis, POCUS, chest X-ray examination is shown in Table 2.

Analysis of Clinical Diagnostic Efficacy of Thoracic Abnormalities

Taking the actual diagnosis as reference, POCUS had slightly higher diagnostic sensitivity of pleural effusion and atelectasis than chest X-ray, and its diagnostic sensitivity of pulmonary edema was consistent with that of chest X-ray. However, POCUS had slightly lower diagnostic sensitivity of pneumothorax than chest X-ray. The diagnostic specificity of POCUS for pneumothorax and atelectasis was consistent with that of chest X-ray. However, POCUS had slightly higher diagnostic specificity of pleural effusion and pulmonary edema than chest X-ray, as shown in Tables 3,4.

Table 2. Comparison of detection rate of thoracic abnormalities [n, (%)].

Thoracic abnormalities	POCUS	Chest X-ray	Clinical diagnosis
Total incidence	36 (58.06)	38 (61.29)	23 (37.10)
Pleural effusion	16 (25.81)	17 (27.42)	11 (17.74)
Pneumothorax	9 (14.52)	10 (16.13)	6 (9.68)
Atelectasis	6 (9.68)	5 (8.06)	3 (4.84)
Pulmonary edema	5 (8.06)	6 (9.68)	3 (4.84)

POCUS, point-of-care ultrasound.

Table 3. Analysis of clinical diagnostic efficacy of thoracic abnormalities by POCUS.

Actual diagnostic results		POCUS examination		Positive predictive values	Negative predictive values	Sensitivity (%)	Specificity (%)
		Positive	Negative				
Pleural effusion	Positive	9	2	56.25	95.65	81.82	86.27
	Negative	7	44				
Pneumothorax	Positive	3	3	33.33	94.34	50.00	89.29
	Negative	6	50				
Atelectasis	Positive	2	1	33.33	98.21	66.67	93.22
	Negative	4	55				
Pulmonary edema	Positive	2	1	40.00	98.25	66.67	94.92
	Negative	3	56				

Test of Clinical Diagnosis

The kappa values of POCUS and chest X-ray in diagnosing pleural effusion, pneumothorax, atelectasis and pulmonary edema were 0.546, 0.565, 0.502 and 0.701, respectively, suggesting that the diagnostic results of two methods were consistent ($p < 0.001$), as detailed in Table 5.

Discussion

Congenital heart disease usually requires surgical intervention, sometimes accompanied by life-threatening postoperative complications [13]. Therefore, early identification of chest abnormalities is extremely important for intervention or monitoring the prognosis of children with congenital heart disease. This study showed that the sensitivity and specificity of POCUS and chest X-ray in the diagnosis of pleural effusion, pneumothorax, atelectasis, pulmonary edema and mediastinal pericardial effusion in children with congenital heart disease were comparable, and the diagnostic results of two methods were consistent.

Compared with the actual diagnosis, POCUS had slightly higher diagnostic sensitivity of pleural effusion and atelectasis than chest X-ray, and its diagnostic sensitivity of pulmonary edema was consistent with that of chest X-ray. This is consistent with the conclusion of Danish Mohammad *et al*. [14] that 6-Point lung ultrasonography can be a useful diagnostic tool and is better than chest X-ray in diagnosing respiratory pathologies in critically ill patients. This is because of the low visual contrast between normal and abnormal areas and the deformation caused by other overlapping tissues, making it challenging to identify and locate diseases in chest X-rays [15]. Ultrasound can clearly distinguish the two. The ultra-portability of POCUS makes them essential for bedside assessment [16]. Due to the high resolution of linear array probe, ultrasound is easy to find small consolidation in patients with fibrosis, showing a low echo area with irregular boundaries. When ultrasonic testing of fibrosis with small consolidation, other examinations and clinical manifestations of patients should be considered to determine whether the disease is an infectious disease. Because non-infectious diseases have different degrees of inflammation and fibrosis, characterized by consolidation. Ultrasound diagnosis of consolidation is more in line with the results of clinical diagnosis.

POCUS had slightly lower diagnostic sensitivity of pneumothorax than chest X-ray, and its diagnostic specificity was consistent with that of chest X-ray. Because pneumothorax represents the accumulation of air in the pleural cavity [17], and it is mainly diagnosed by the disappearance of pulmonary sliding sign, and lung point. Pneumothorax on chest ultrasound is defined as the absence of lung sliding and comet-tail artifacts, and is confirmed by stratospheric markers in M mode [18]. This sign is not as obvious as consolidation, effusion or B-line, which requires the careful scan of chest wall to observe the lung sliding between each rib. In terms of small range of pneumothorax, ultrasound is difficult to detect the location of lesions. When patients have both pneumothorax and severe emphysema, the pulmonary sliding sign will overtly reduce. At this time, the differential diagnosis needs to find the lung point. Pulmonary sign point is usually considered as a characteristic diagnostic sign [19], and the specificity of this sign in the diagnosis of pneumothorax is 100% [20,21].

Table 4. Analysis of clinical diagnostic efficacy of thoracic abnormalities by chest X-ray.

Actual diagnostic results		Chest X-ray examination		Positive predictive values	Negative predictive values	Sensitivity (%)	Specificity (%)
		Positive	Negative				
Pleural effusion	Positive	8	3	47.06	93.33	72.73	82.35
	Negative	9	42				
Pneumothorax	Positive	4	2	40.00	96.15	66.67	89.29
	Negative	6	50				
Atelectasis	Positive	1	2	20.00	96.49	33.33	93.22
	Negative	4	55				
Pulmonary edema	Positive	2	1	33.33	98.21	66.67	93.22
	Negative	4	55				

Table 5. POCUS and chest X-ray for different test results of clinical diagnosis.

Clinical diagnosis	Kappa values	*p* values
Pleural effusion	0.546	$<$0.001
Pneumothorax	0.565	$<$0.001
Atelectasis	0.502	$<$0.001
Pulmonary edema	0.701	$<$0.001

This study confirmed that the kappa values of POCUS and chest X-ray in the diagnosis of pleural effusion, pneumothorax, atelectasis and pulmonary edema were 0.546, 0.565, 0.502 and 0.701, respectively, suggesting that the diagnostic results of two methods were consistent. Because their technical principles are similar. Both methods are the imaging examination methods of detecting lung and pleural lesions, and have high sensitivity and specificity for common lesions, which are non-invasive and convenient, and require the experience and skills in clinical operation. These factors jointly ensure the complementarity and consistency of two examination methods in practical applications.

This study has some limitations. (1) This study is a single-center retrospective study, and the sample size is relatively small, which may lead to biased research data. (2) This study does not compare POCUS with multi-position chest X-ray. (3) This study does not rule out the influence of experience differences of operators on POCUS and chest X-ray. (4) This study does not assess the effects of different levels of exposure to confounding variables. In the future, more rigorous prospective studies with large sample size will be carried out to compare the effects of two diagnostic methods.

Conclusion

In summary, POCUS and chest X-ray, as non-invasive, rapid and effective examination methods, are consistent in diagnosing postoperative thoracic abnormalities in children with congenital heart disease, and have clinical promotion value.

Availability of Data and Materials

The datasets used and/or analyzed during the current study were available from the corresponding author on reasonable request.

Author Contributions

XW, YH and YZ designed the research study. DJ and XY performed the research. DJ and XY analyzed the data. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study has been approved by the Medical Ethics Committee of Shijiazhuang People's Hospital. Approval No.:2023079. Informed consent was obtained from the patients.

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Conflict of Interest

The authors declare no conflict of interest.

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