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Feasibility of lung ultrasound for locating bronchial blockers in pediatric thoracic surgery: a retrospective analysis

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Abstract

Objective To identify the feasibility of using lung ultrasound to determine the position of bronchial blockers in pediatric patients.

Methods In this study, children aged 4–8 years who underwent elective right one-lung ventilation at our hospital between January 2019 and August 2022 were selected. We collected the results of lung ultrasound and fiberoptic bronchoscopy during the placement of bronchial blockers in these children. The accuracy, sensitivity, and specificity of lung ultrasound in determining the position of bronchial blockers were calculated. Additionally, the reproducibility of lung ultrasound in determining the appropriateness of bronchial blockers was also calculated. Furthermore, information regarding whether there were complications associated with lung ultrasound examination or fiberoptic bronchoscopy was also collected.

Results The accuracy of lung ultrasound for determining the position of bronchial blockers was 95.0%. When the position of BBs was appropriate, the sensitivity of lung ultrasound was 96.3% and the specificity was 88.9%. When the position of BBs was too shallow, the sensitivity of lung ultrasound was 75% and the specificity was 96.7%. The reproducibility test of lung ultrasound for determining the position of bronchial blockers had a weighted kappa value of 0.91, $P < 0.001$. In this study we found 6 children had hypoxemia and 6 children had airway mucosal bleeding during fiberoptic bronchoscopy. And no complications linked to lung ultrasound examination were observed.

Conclusion Lung ultrasound has high accuracy, sensitivity, specificity, and repeatability in determining the position of bronchial blockers. It is a new and safe method to determine the position of bronchial blockers.

Keywords Lung ultrasound, Fiberoptic bronchoscopy, Bronchial blockers, One lung ventilation

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Introduction

Bronchial blockers (BBs) play a critical role in thoracic surgery by enabling precise lung isolation during procedures, ensuring optimal surgical exposure and minimizing intraoperative complications [1]. Their flexibility in achieving selective one-lung ventilation enhances patient safety, particularly in complex cases or patients with compromised pulmonary function. Compared to traditional double-lumen tubes, bronchial blockers offer reduced airway trauma and faster postoperative recovery, making them indispensable for modern minimally invasive thoracic interventions. Therefore, determining whether the BBs are correctly positioned is particularly important. Currently, the commonly used methods for assessing the position of the BBs include auscultation and fiberoptic bronchoscopy (FOB). Due to sound transmission between tissues, auscultation may not accurately determine whether the BBs are in place. Fiberoptic bronchoscopy allows for direct visualization to assess the position of the BBs and is currently the gold standard for clinical evaluation of BBs placement [2]. However, FOB may damage the airway mucosa and reduce tidal volume during the examination, potentially causing hypoxemia and other respiratory-related adverse events. Additionally, due to the limitations imposed by the diameter of the tracheal tube, FOB may not be feasible in neonates. Therefore, finding a new method to assess the position of the BBs is of utmost importance.

Lung ultrasound has been widely used in clinical practice due to its advantages of being non-invasive, radiation-free, and portable [3]. Through different ultrasound signs, it is possible to determine whether a lung lobe is ventilated, providing a theoretical basis for clinically assessing the position of the BBs. Additionally, this method does not affect the patient's tidal volume or damage the airway mucosa, which is more advantageous compared to FOB. Currently, there are several studies focused on the use of lung ultrasound to assess the depth of tracheal intubation and the position of BBs in infants [4, 5]. However, there is a lack of studies focused on the accuracy of lung ultrasound for assessing the position of BBs in young children. Therefore, the study aims to explore the accuracy, sensitivity, and specificity of lung ultrasound in determining the position of BBs, and to provide a theoretical basis for clinical practice.

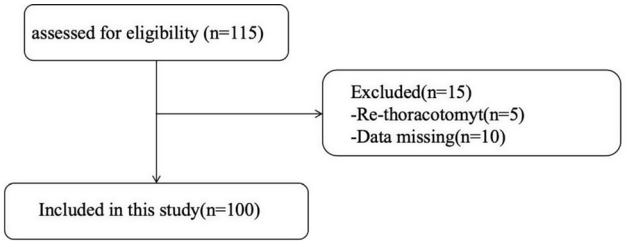

Fig. 1 Data screening

Materials and methods

This study was approved by the Ethics Committee of Children's Hospital of Nanjing Medical University (approval number: 202208159-1). Patients who underwent elective thoracic surgery requiring one-lung ventilation at our hospital from January 2019 to August 2022 were selected, with all data obtained from electronic anesthesia records (Fig. 1). Inclusion criteria: Patients undergoing elective right lung ventilation, ASA class I-II, aged 4–8 years. Exclusion criteria: (1) preoperative FEV1 < 79%, (2) re-thoracotomy (pleural adhesions), 3.pulmonary infection, 4.thoracic deformities or anatomical abnormalities, 5.tracheal or bronchial anatomical abnormalities, 6. preoperative SpO2 < 90%, 7.pulmonary edema, 8.pleural effusion, 9. data missing.

Anesthesia: Intravenous access was established before the child was admitted to the operating room. After entering, ECG, arterial blood pressure, central venous pressure, pulse oxygen saturation, and temperature were monitored. The induction drugs include midazolam 0.05 mg/kg, propofol 2–3 mg/kg, sufentanil 0.3–0.5 μg/kg, cis-atracurium 0.15 mg/kg, and the maintenance drugs include sevoflurane 2–3%, propofol 5 mg/kg/h and remifentanil 0.5 μg /kg/min. After 3–5 min of drug administration, the endotracheal tube was inserted and secured following bilateral breath sound confirmation. Then an experienced anesthesiologist inserted a bronchial blocker (Mode: Wellead, 5 F) and fixed it(Insertion depth: Calculate the distance from the teeth to the midpoint of the left main bronchus based on preoperative chest CT). After inflating the blocker's cuff, lung ultrasound was used to assess the position of the bronchial blocker (two anesthesiologists trained in lung ultrasound recorded their assessments separately), followed by FOB (Model: Youyi. Zhejiang, Video-assisted fiberoptic bronchoscopy, PLF–260, Diameter:2.6 mm) to verify the position of BBs and check for consistency between the two methods (Fig. 2). All findings were recorded in the electronic anesthesia record (The data collectors were blinded to the purpose of this study). During surgery, the children were ventilated using volume-controlled ventilation mode with a tidal volume of 6–8 ml/kg, and the respiratory rate was adjusted based on $PetCO_2$ to maintain $PetCO_2$ between 35–45mmHg.

Outcome measures

The primary outcomes were the results of lung ultrasound and fiberoptic bronchoscopy in determining the position of the bronchial blocker (appropriate, too deep, too shallow, or misdirected into the contralateral side) (Fig. 3). The secondary outcomes included whether the

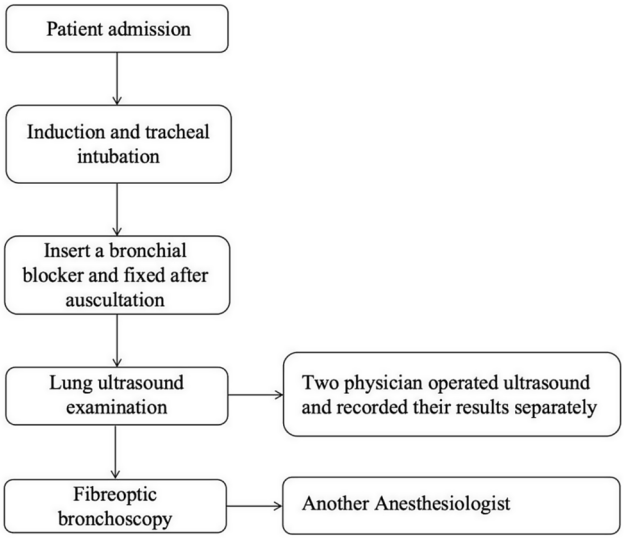

Fig. 2 Anesthesia、intubation and examination

two anesthesiologists' assessments using lung ultrasound to determine the position of the bronchial blocker were consistent (both anesthesiologists were unaware of each other's assessment results), the duration of ultrasound examination and FOB, as well as whether hypoxemia ($SpO_2 < 90\%$) or airway mucosal injury occur during the examination. Degree of mucosal bleeding classification: (1) No bleeding, (2) Mild bleeding that requires no treatment, (3) Excessive bleeding that requires hemostatic agents, (4) Severe bleeding that requires intervention.

Ultrasound examination: The lung ultrasound was performed by trained anesthesiologists using a Mindray ultrasound machine. A 4–10 MHz line array probe was selected and the lung ultrasound was performed in the supine position. The probe was placed in the 2nd–4th intercostal spaces along the midclavicular line on both sides and at the upper edge of the diaphragm along the midaxillary line on both sides(Fig. 4) to assess for the presence of pleural sliding sign and curtain sign. In M-mode, assess both lungs for the presence of the seashore sign (lungs with inflation) and the barcode sign (lungs without inflation) (Fig. 5).

Fiberoptic bronchoscopy procedure

The bronchoscope was advanced through the main airway to locate the carina. After identifying the carina, the positions of the left and right main bronchi were confirmed. The position of the BBs cuff was then visualized to determine if it was in the left main bronchus. If malpositioned, the BBs was adjusted under direct visualization. During the procedure, hypoxemia (SpO_2 <90%) prompted immediate withdrawal of the FOB and initiation of mechanical ventilation until SpO_2 normalized,

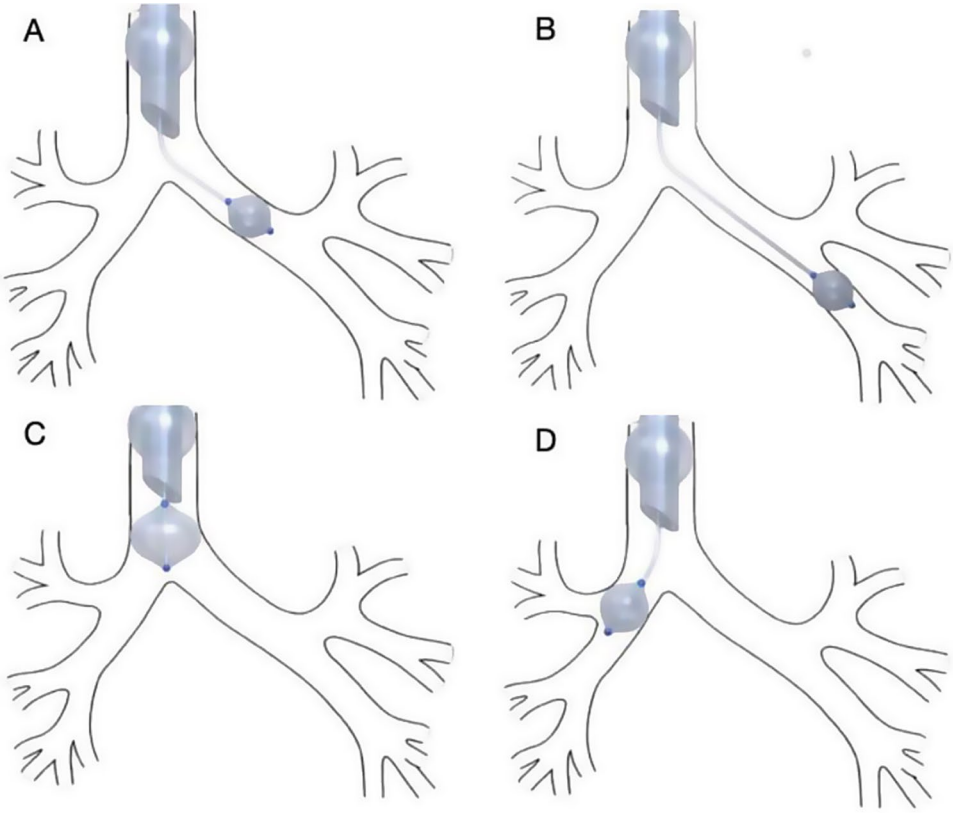

Fig. 3 The position of the bronchial blocker. (**A**: appropriate **B**: too deep **C**: too shallow **D**: misdirected into the contralateral side)

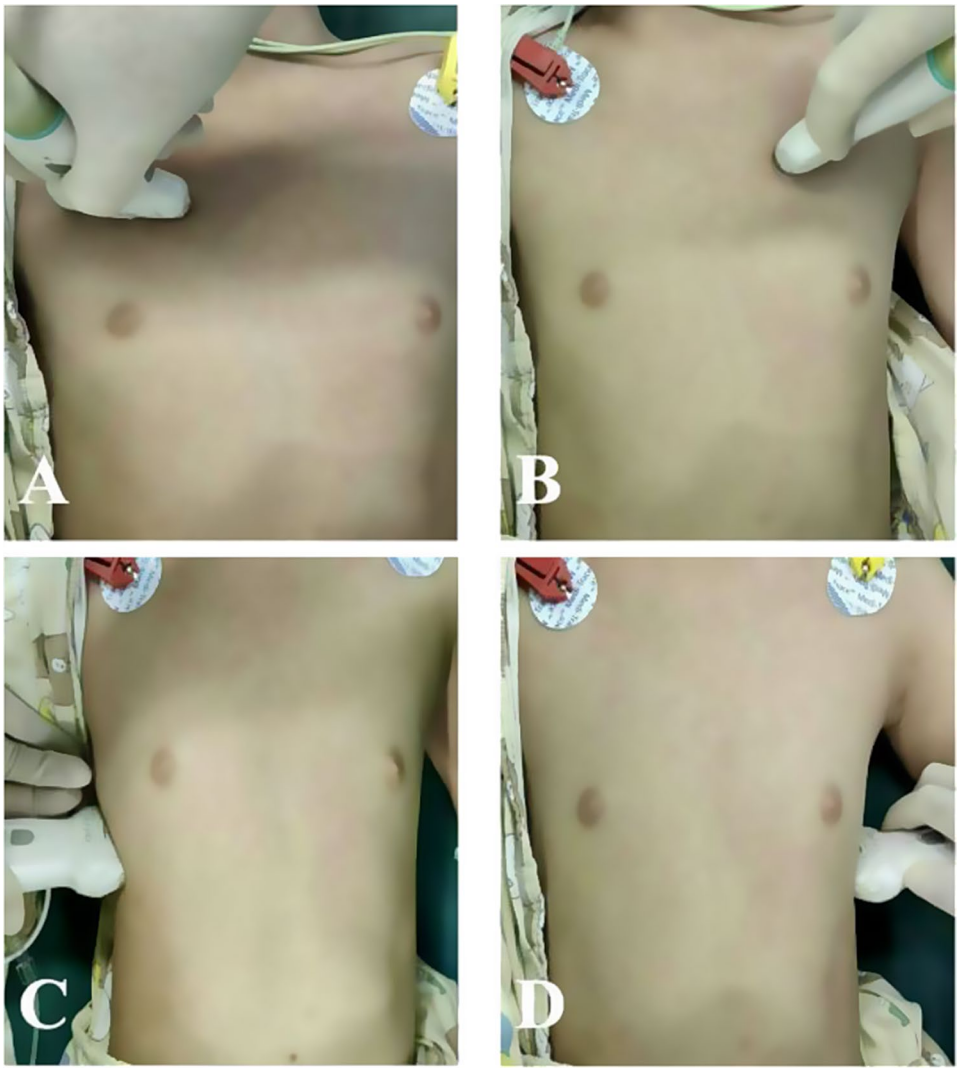

Fig. 4 Probe placement during lung ultrasound examination. (**A** 2nd–4th intercostal spaces along the right midclavicular line, **B** 2nd–4th intercostal spaces along the left midclavicular line, **C** the upper edge of the diaphragm along the right midaxillary line, **D** the upper edge of the diaphragm along the left midaxillary line)

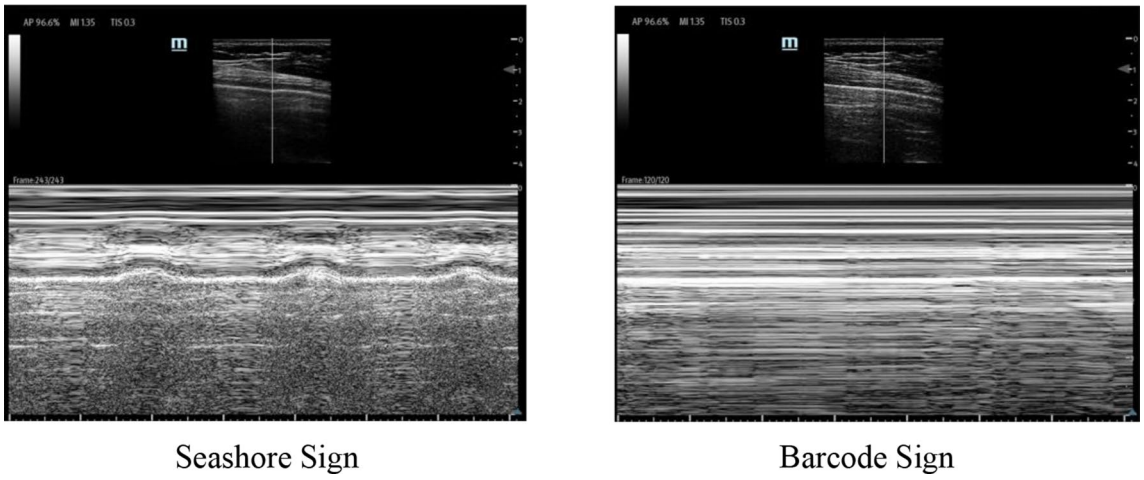

Fig. 5 Different signs of lung lobes in M-mode.

Table 1 Lung ultrasound determining the position of the bronchial blocker

Blocker position	Left lung sliding sign/ seashore sign	Left lung barcode sign	Right lung sliding sign/seas hore sign	Right lung bar-code sign	Left lung curtain sign	Right lung curtain sign
A	-	+	+	-	-	+
B	+	-	+	-	-	+
C	-	+	-	+	-	-
D	+	-	-	+	+	-

A: appropriate, B: too deep, C: too shallow, D: misdirected into the contralateral side, + indicates the presence of the sign; - indicates the absence of the sign

Table 2 Baseline information of the children

	Baseline information
Gender	
Male n(%)	53 (53%)
Female n(%)	47 (47%)
Age (y)	5.52 ± 1.45
ASA Classification	
II n(%)	85 (85%)
III n(%)	15(15%)
Height (cm)	114.15 ± 11.26
Weight (kg)	20.67 ± 4.93
Types of thoracoscopic surgery	
Left lung lobectomy n(%)	40(40%)
PDA ligation n(%)	12 (12%)
Mediastinal tumor resection n(%)	48 (48%)
Anesthesia time (min)	164.30 ± 43.36
Surgery time (min)	128.00 ± 41.46

(ASA: American Society of Anesthesiologists, I) Normal healthy patient, 2) Patient with mild systemic disease, 3) Patient with severe systemic disease, 4) Patient with severe systemic disease that is a constant threat to life, 5) Moribund patient not expected to survive without the operation, 6) Declared brain-dead patient whose organs are being removed for donor purposes)

after which FOB was reattempted. In cases of bleeding, blood and secretions were aspirated, and topical epinephrine (1:10,000) was applied under direct visualization to achieve hemostasis.

Method of determining the position of the blocker

A schematic diagram of the position of the blocker and the diagnostic criteria used by lung ultrasound are presented in Fig. 3; Table 1 respectively.

Statistics

SPSS 25 software and R version 4.4.3 were used for analysis, and normally distributed continuous data were expressed as mean ± standard deviation, and paired t-test was used for intra-group comparison. Regarding categorical data in the intra - group comparison, the McNemar or McNemar Chi-square test was utilized. The reproducibility of lung ultrasound operation was evaluated via the weighted kappa test. In addition, the accuracy, sensitivity, and specificity of lung ultrasound for determining the position of BBs were computed. $p < 0.05$ was considered statistically significant.

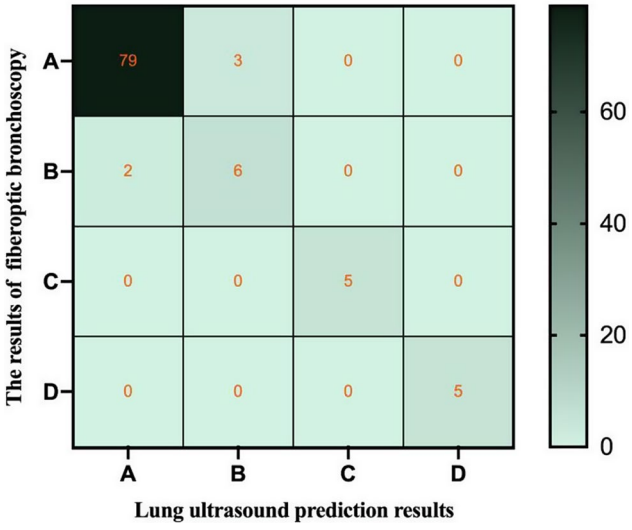

Fig. 6 Confusion matrix of lung ultrasound in determining the position of the BBs. (**A**: appropriate, **B**: too deep, **C**: too shallow, **D**: misdirected into the contralateral side)

Results

Baseline information of the children is detailed in Table 2. In three patients, lung ultrasound suggested that the blocker was in the right position but FOB suggested that the blocker was too deep. In two patients, lung ultrasound suggested that the blocker was too deep, but FOB suggested that the blocker was appropriately positioned. The results of lung ultrasound examinations and FOB of all patients are presented in the form of a confusion matrix in Fig. 6.

The accuracy of lung ultrasound in determining the position of BBs was 95%. When the position of BBs was appropriate, the sensitivity of lung ultrasound was 96.3% and the specificity was 88.9%. When the position of BBs was too shallow, the sensitivity of lung ultrasound was 75% and the specificity was 96.7%. When the position of BBs was too deep or the BBs entered the contralateral side, both the sensitivity and specificity of lung ultrasound were 100%.

The reproducibility of lung ultrasound for determining the position of the blocker was assessed by the weighted Kappa consistency test, with a kappa value of 0.91, $P < 0.001$. The duration of lung ultrasound examination

was 84.61 ± 9.56 s, while that of bronchoscopy was 82.29 ± 10.02 s, There was no statistically significant difference between the two durations ($p = 0.057$).

In this study, six children developed mucosal bleeding, and six experienced hypoxemia. Among them, two children developed hypoxemia due to mucosal bleeding. The incidence of complications in bronchoscopy examination was 10% (Table 3).

Table 3 Complications associated with examination

	Lung ultrasound	FOB	*P*-value
Hypoxemia during the examination, n(%)	0(0%)	6(6%)	0.041
Airway mucosal injury, n(%)	0(0%)	6(6%)	0.041
1	0	0	
2	0	4	0.133
3	0	2	0.480
4	0	0	

(1. No bleeding, 2. Mild bleeding that requires no treatment, 3. Excessive bleeding that requires hemostatic agents, 4. Severe bleeding that requires intervention)

Discussion

One-lung ventilation, a technique commonly used in thoracic surgery, is achieved by placing a blocker in the main bronchus of the affected lung, leading to the collapse of the affected lung. However, due to the short length of the main bronchus, multiple adjustments of the blocker's position are required to place it correctly. Currently, the commonly used methods for determining whether the position of the blocker is appropriate mainly include auscultation and fiberoptic bronchoscopy. However, auscultation has a high margin of error, and fiberoptic bronchoscopy may damage the patient's airway mucosa and affect the patient's tidal volume. Therefore, finding a new method to assess the position of bronchial blocker is particularly important. This study found that lung ultrasound, by observing specific signs in different lung areas, can determine whether the position of the bronchial blocker is appropriate, and it has high accuracy, sensitivity, and specificity, while not affecting the perioperative safety of the patient. This suggests that lung ultrasound is a new method for clinically assessing the appropriateness of the bronchial blocker's position.

Lung ultrasound has been widely used in clinical anesthesia due to its advantages of non-invasiveness, non-radiation exposure, and real-time monitoring. When the probe is placed in the 2nd – 4th intercostal space along the midclavicular line on both sides of the patient, the pleura appears as a bright linear echo under ultrasound. During respiratory movements, the sliding between the parietal and visceral pleura can be observed, which is a phenomenon known as the pleural sliding sign [6, 7]. When the ultrasound probe is positioned in the diaphragm's upper intercostal space along the mid-axillary line on both sides, the sliding lobe of the lung is seen to partially obscure the liver or spleen with respiratory movement, sliding like a curtain, which is called the curtain sign, and if the curtain sign is not observed, it indicates that the lung on that side is not ventilated [8, 9]. In M-mode [10–12], as breathing continues, the lung appears as a seashore sign under ultrasound, when the lung is not aerated, it appears as a barcode sign. The recognition of these phenomena provides a theoretical basis for using ultrasound to determine whether the position of the bronchial blocker is appropriate. Chenkin J [13] et al. found that through their study on the learning curve of using lung ultrasound to assess the position of endotracheal intubation, physicians could accurately identify lung images under ultrasound after only two practice sessions, with an overall error rate of just 0.9%. Moreover, the training model for lung ultrasound is not limited to online or offline settings. Previous literature [14] reported that when anesthesiologists were divided into online and offline groups and underwent four weeks of training, both groups were able to proficiently master the operational skills of lung ultrasound, indicating that the use of lung ultrasound to assess blocker positioning is easy to learn and can be promoted in clinical practice.

In this study, it was found that the accuracy of lung ultrasound in determining the position of the bronchial blocker was 95%, indicating a high level of accuracy. Prior studies [5] reported that the accuracy of lung ultrasound in determining the position of blockers in infants (< 2 years old) was 88%, which is similar to our result. However, the accuracy in this study is higher, possibly because this study combined the assessment of the pleural sliding signs, the curtain signs, the seashore sign or the barcode sign for a comprehensive judgement. While in the literature, researchers only combined pleural sliding sign and curtain sign to determine the position of the BBs, which uses one sign less than our method. Therefore, the accuracy improves when we combine as many signs as possible. Adam C et al. [15] reported a successful case of extraluminal bronchial occlusion guided by lung ultrasound. By observing the presence or absence of pleural sliding sign and lung pulse, they successfully confirmed that the position of the bronchial blocker was appropriate and the effect of lung collapse was satisfactory. In this study, the operating time for ultrasound was 84.61 s, with no statistical difference compared to the time of FOB. In Wang et al.'s [5] study, the total observation time at six observation points was 86.2s, which was consistent with this study. These literature indicate that lung ultrasound has high accuracy in determining the position of bronchial blockers and does not increase the examination time [16]. Furthermore, to assess the reproducibility of lung ultrasound operations, two physicians with similar

experience sequentially used lung ultrasound to determine the position of the bronchial blocker in the same patient and recorded their findings separately. The results showed a high consistency between the two physicians (Kappa value of 0.91, $P<0.01$), indicating that the reproducibility of lung ultrasound for determining the appropriateness of blocker position is strong, making it easy to promote in clinical practice.

Currently, the commonly used methods for determining the position of BBs in clinical practice are auscultation and fiberoptic bronchoscopy. Due to the typically thin chest walls of pediatric patients, which allow for good interstitial conduction, auscultation often has a significant margin of error. In contrast, fiberoptic bronchoscopy allows direct visualization of whether the blocker is in place, making it the gold standard for assessing blocker position in clinical settings [17]. Patients undergoing thoracic surgery often have severe pulmonary disease and poor tolerance to hypoxia [18]. The internal diameter of the tracheal tube in pediatric patients is relatively small, and the fiberoptic bronchoscope occupies space within the tube during examination, which can affect the patient's tidal volume and lead to hypoxemia. Two retrospective studies [19, 20] found that the probabilities of hypoxemia in patients undergoing fiberoptic bronchoscopy were 3.6% and 2.6% respectively. In our trial, six patients experienced a decrease in SpO2 to below 90% during the fiberoptic bronchoscopy, resulting in an incidence rate of 6%, which is similar to the aforementioned studies. Although no severe complications occurred after management, further attention from clinicians is still warranted. Additionally, during fiberoptic bronchoscopy, the bronchoscope may damage the airway mucosa, causing bleeding and increasing the risk of postoperative asphyxiation and pulmonary infection. Previous literature [19] has reported that four ICU patients experienced severe bleeding during fiberoptic bronchoscopy, with an incidence rate of 1.2%. In another study, the bleeding incidence was 2.6%. In this study, a total of six patients experienced bleeding during the fiberoptic bronchoscopy, with two patients experiencing significant bleeding that was managed with adrenaline nebulization, and no severe complications occurred following treatment. For patients with normal preoperative cardiopulmonary function, airway mucosal bleeding associated with SpO2 < 90% may not pose significant risks; however, in critically ill children admitted to the cardiac care unit (CCU) or those with severe conditions, FOB-related complications could jeopardize patient safety. Therefore, ultrasound may offer greater advantages in this specific population.

There are several limitations in this study: 1. Patient collection bias: patients with severe preoperative upper respiratory tract infections were excluded because excessive inflammation could lead to pleural adhesions, which may disrupt pleural sliding and interfere with clinical evaluations. The accuracy of lung ultrasound in determining the position of bronchial blockers (BBs) in this specific patient population needs further investigation. 2.Age limitation: The patients in this trial were aged between 4 and 8 years. The effectiveness of lung ultrasound in determining the blocker's position in younger children remains to be explored. 3. Physician variability: The training levels of different physicians in ultrasound and fiberoptic bronchoscopy (FOB) may influence the accuracy, sensitivity, and specificity of lung ultrasound for determining the position of BBs. Larger, multi - center studies are required to draw more accurate conclusions. 4. Setting limitation: This study was conducted in an operating - room setting. The accuracy of ultrasound in determining the position of BBs in critical emergency and intensive care unit (ICU) scenarios needs further investigation.

Lung ultrasound has high accuracy, sensitivity, and specificity in determining the position of bronchial blockers. It is simple, reproducible, and easy for clinicians to master. Moreover, lung ultrasound does not affect the child's tidal volume and does not increase perioperative injury to the child. Therefore, it is a new and safe method to determine the position of bronchial blockers. In scenarios where fiberoptic bronchoscopy (FOB) is not feasible, lung ultrasound (LUS) may serve as a viable alternative.

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Not applicable.

Author contributions
Weiwei Cai is the first author, and he designed this trial, collected data, performed statistical analyses and wrote the paper. Wei Gu was responsible for data analysis. Yuting Song and Huanhuan Ni were responsible for data collection. Hongqiang Huang and Huiying Shao were correspondence authors.

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Data availability
The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The experimental protocol was established, according to the ethical guidelines of Helsinki Declaration and was approved by the Ethics Committee of the Children's Hospital of Nanjing Medical University (approval number: 202208159–1).Written informed consent was obtained from guardian participants.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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