Diagnostic accuracy of auscultation and lung ultrasound in the assessment of adequate double lumen tube position for anesthetic trainee doctors – a single center, prospective study

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Lung ultrasound can be used to assess adequate regional ventilation, similar to auscultation. Therefore, we evaluated whether the diagnostic accuracy of lung ultrasound was superior to that of auscultation in the assessment of proper double lumen tube (DLT) position, which were performed by anesthetic trainees. We conducted a single-center, prospective study of 69 patients. DLT insertion, auscultation, lung ultrasound, and fiberoptic bronchoscopy were sequentially conducted in the same patients in the supine and lateral positions. During lung ultrasound, the proper DLT position was defined when the lung pulse and barcode sign were visible on the non-ventilated lung, and lung sliding and seashore sign were observed in the ventilated lung. Fiberoptic bronchoscopy was performed for final verification of the DLT position as a standard test. Contingency tables were plotted to determine accuracy, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) for each method. The primary outcome of this study was the accuracy of each method. Accuracy (60.9%), sensitivity (100%), specificity (12.9%), PPV (58.5%), and NPV (100%) of ultrasound were equal to those of auscultation in the supine position. Accuracy (89.9%), sensitivity (100%), specificity (36.4%), PPV (89.2%), and NPV (100%) of ultrasound were equal to that of auscultation in the lateral position. The prevalence of proper lung isolation was 55.1% in the supine position, and it increased to 84.1% in the lateral position. Lung ultrasound is not superior to auscultation for determination of the proper DLT position in both the supine and lateral positions.

Keywords: Accuracy; Auscultation; Double lumen tube; Fiberoptic bronchoscopy; Lung ultrasound

INTRODUCTION

One-lung ventilation (OLV) has been successfully achieved with double lumen tubes (DLTs) in most thoracic or abdominal surgeries requiring lung isolation [1]. However, pre-

cise positioning of DLT is essential for facilitating surgical exposure with successful lung isolation for thoracic surgery [1]. The auscultation method has been commonly used to evaluate regional ventilation and lung collapse, but it has low accuracy for confirmation of the optimal DLT position

[2]. Therefore, direct visual confirmation using fiberoptic bronchoscopy (FOB) was considered a standard method [2]. Currently, a combination technique of auscultation and FOB is commonly used to determine adequate positioning of DLT. However, FOB examination is an invasive, time-consuming technique, and it requires an experienced operator to confirm the adequate DLT positioning. In addition, some institutions still do not perform FOB.

Recently, ultrasound examination has been used increasingly in various aspects of airway management. Ultrasound has been studied to evaluate its efficacy for determining adequate endotracheal intubation in the presence of an endotracheal cuff, airway extension, or lung-sliding sign in the thoracic region [3-6]. It has been suggested that ultrasound is useful to detect whether endotracheal intubation is adequate. Pneumothorax can also be diagnosed with high specificity and sensitivity based on lung ultrasound findings (absence of lung sliding and seashore sign with M-mode, or presence of lung pulse) [7-9]. Based on the concept that the non-ventilated thoracic condition after OLV is similar to that with pneumothorax, the proper lung isolation was evaluated with ultrasound findings used in patients with pneumothorax. Several investigators have suggested that lung ultrasound is a noninvasive, effective, and simple technique that is superior to auscultation in determining the proper DLT position, but both methods were not ensured in confirming the misplacement [10-13]. However, there is still a lack of evidence for the usefulness of lung ultrasound in determining proper DLT positions.

This study compared the diagnostic accuracy of auscultation and lung ultrasound in the assessment of proper DLT position, which anesthetic trainee doctors performed in patients who underwent thoracic surgeries. The primary outcome of this study was the overall accuracy of each method.

MATERIALS AND METHODS

This prospective, randomized, controlled, and investigator-blinded study was approved by the Institutional Review Board of Chosun University Hospital (Chosun 2018-11-008-001) and was registered with the Clinical Research Information Service (CRIS: <https://cris.nih.go.kr/>, ref: KCT0003881) on May 3, 2019. This study was conducted according to the Declaration of Helsinki 1964 and all subsequent revisions.

The subjects included patients aged over 18 years with an American Society of Anesthesiologists (ASA) physical status I-III and who were scheduled to undergo elective thoracic surgery requiring one-lung ventilation with DLT. We excluded patients <18 years of age, those with anticipated difficult airways or a tracheostomy tube in situ, and those diagnosed with pleural effusion, pleurodesis or post-inflammatory pleural adhesions, chronic obstructive pulmonary disease, or mesothelioma.

Patients were screened a day before surgery, and written informed consent was obtained from all participants or a legal surrogate, after a thorough explanation of the purpose of this study. A total of 69 patients were included in the study from August 6, 2019 to April 13, 2020, but they were not randomized.

The attending anesthesiologist was responsible for obtaining consent, managing anesthesia, and determining the size and side of DLT (Mallinckrodt Endobronchial Tube, Covidien, USA). After premedication with intramuscular midazolam (0.05 mg/kg), the patients were transported to an operating room. Before the anesthesia was induced, the principal investigator (PI) or other investigators evaluated whether the patients had intact breathing sounds and lung sliding. We excluded patients without lung sliding before anesthesia induction. They did not participate in the auscultation, lung ultrasound, or FOB. Auscultation and lung ultrasound were performed at the same points as follows: 1) the point at which the second intercostal space meets the midclavicular line and 2) the point at which the fifth intercostal space meets the midclavicular line.

Following total intravenous anesthesia induction with propofol, remifentanyl, and rocuronium, the attending anesthesiologist performed bronchial intubation and recorded the initial intubation depths at the central incisor level. During two-lung ventilation (TLV), the tidal volume was 8 mL/kg (ideal body weight), with the oxygen-air mixture in a 1:1 ratio. During OLV, the tidal volume was 6 mL/kg with 100% oxygen. The end-tidal carbon dioxide and oxygen saturation were maintained between 30 and 35 mmHg and 93-100%, respectively.

In the supine position, auscultation, lung ultrasound, and FOB were performed sequentially to assess whether the DLT position was proper. The investigators were randomly assigned as the examiner of either auscultation, lung ultra-

sound, or FOB. Randomization was performed using a computer-generated random table with the randomly permuted block method (1:1:1 allocation ratio).

First, auscultation was performed as follows: 1) at both lung points during TLV, 2) at the points of the ventilated lung during OLV, and 3) at non-ventilated lung points during OLV. We defined the proper DLT position as follows: intact breathing sound at two points of the ventilated lung, and absence of breathing sound at two points in the non-ventilated lung.

Next, lung ultrasound examiners performed the examination of lung ultrasound during OLV using an M-Turbo Ultrasound system (SonoSite Ltd., UK) with a 13-6 MHz linear transducer. We placed this transducer sagittal at pre-defined measurement points in both midclavicular lines. If lung sliding with 2D mode and seashore sign with M-mode were shown in the non-ventilated lung, we defined it as an improper DLT position. If the lung pulse with 2D mode and barcode sign with M-mode were visible, it was defined as the proper DLT position.

Finally, FOB examiners determined whether the proximal part of the blue cuff was located just below the carina without obstruction of the opposite bronchus (proper DLT position), with FOB (intubation fiberscope 3.7×65, Karl Storz, Germany). If the blue cuff of the DLT was located deep in the main bronchus, we defined it as a suboptimal position. If the blue cuff of the DLT was not located in the main bronchus of the nonsurgical lung or in the trachea, we defined it as malposition.

After FOB, the principal investigator adjusted the depth of DLT with FOB results and recorded the adjusted intubation depths. The principal investigator gathered all data reported as 'correct' or 'incorrect' from each investigator in the case record form, and each investigator did not share results until the final analysis was completed. After the lateral decubitus position, this evaluation process was repeated in the non-ventilated lung during OLV.

We recorded demographic data, such as age, sex, height, weight, body mass index (BMI), ASA physical status, diagnosis, side of DLT, and type of operation. We calculated the true positive (TP), true negative (TN), false positive (FP), and false negative (FN), sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of each method, with fiberoptic bronchoscopy findings as

standard test results. Sensitivity, specificity, PPV, NPV, and accuracy were calculated as follows: Sensitivity (%) = $TP / (TP + FN) \times 100$, specificity (%) = $TN / (TN + FP) \times 100$, PPV (%) = $TP / (TP + FP) \times 100$, NPV (%) = $TN / (TN + FN) \times 100$, and accuracy (%) = $(TP + TN) / (TP + TN + FP + FN) \times 100$.

Statistical analysis

The primary outcomes of this study were accuracy of auscultation and lung ultrasound to determine the proper DLT position. SPSS software (Windows ver. 26.0, IBM Corp., Armonk, NY, USA) was used for all statistical analyses, which were performed by an independent researcher who did not participate in the examinations and data collection.

Based on a previous report, [10,13,14] we assumed that lung ultrasound would be superior to auscultation to determine the proper DLT position. We calculated the sample size with a significance level (α) of 5%; power (1- β), 90%; expected accuracy of auscultation, 60%; and expected accuracy of lung ultrasound, 85%, via a website for sample size calculation (<https://www.sealedenvelope.com/power/binary-superiority/>). We finally decided on a sample size of 69 patients, considering a dropout rate of approximately 10%, because we designed the study with the sequential tests in the single group.

All data are presented as means (95% confidence intervals [CI]), number (percentage) of patients (n [%]), or percentage (%). An analysis of the contingency table was used to calculate the accuracy, sensitivity, specificity, PPV, and NPV for each method. The contingency table data were analyzed using the chi-square test or Fisher's exact test, and were also analyzed with McNemar's test to examine the extent of disagreement between each method. p values <0.05 were considered statistically significant.

RESULTS

A total of 69 patients were finally enrolled in both auscultation and lung ultrasound groups (Fig. 1). Table 1 shows the demographic data of the participating patients.

The main results of this study were as follows: accuracy, sensitivity, specificity, PPV, and NPV of ultrasound were equal to that of auscultation, regardless of the position change. However, the accuracy, specificity, and PPV of both methods were increased in the lateral decubitus position

Fig. 1. CONSORT diagram for patient recruitment.

Table 1. Demographic data

Variables	Cohort (n=69)	Variables	Cohort (n=69)
Age (yr)	46.3 (41.5–51.2)	Types of surgeries	
Sex (M/F)	15 (21.7)/54 (78.3)	Biopsy	9 (13.0)
Height (cm)	168.1 (165.8–170.4)	Lobectomy	12 (17.4)
Weight (kg)	61.3 (58.8–63.8)	Mass removal	2 (2.9)
BMI (kg/m ²)	21.6 (21.0–22.3)	Rib fixation	6 (8.7)
ASA-PS		Sympathectomy	4 (5.8)
I	30 (43.5)	Wedge resection	36 (52.2)
II	36 (52.2)	Diagnosis	
III	3 (4.3)	Chest wall mass	1 (1.4)
Side of DLT used		Hyperhidrosis	4 (5.8)
Left DLT	66 (95.7)	Lung mass	22 (31.9)
Right DLT	3 (4.3)	Pneumothorax	35 (50.7)
		Rib fracture	6 (8.7)
		Thymoma	1 (1.4)

Values are expressed as mean (95% confidence intervals) or number (percentage) of patients. ASA-PS: American Society of Anesthesiologists physical status, BMI: body mass index, DLT: double lumen tube.

after correction of DLT depth according to FOB findings, as shown in Tables 2, 3, and 4.

In determining the appropriate DLT position in a supine position, the accuracy of lung ultrasound was equal to that of auscultation, which was 60.9% (48.4%–72.4%) (Table 4). The sensitivity and specificity of lung ultrasound were equal to those of auscultation, which were 100% (88.6%–100.0%) and 12.9% (4.2%–30.8%), respectively (Table 4). The PPV and NPV of lung ultrasound were equal to those of auscultation, which were 58.5% (45.6%–70.3%) and 100% (39.6%–100.0%), respectively (Table 4).

In determining the appropriate DLT position in a lateral position, the accuracy of lung ultrasound was equal to that of auscultation, which was 89.9% (80.2%–95.8%) (Table 4). The sensitivity and specificity of lung ultrasound were equal to those of auscultation, which were 100% (92.3%–100.0%) and 36.4% (12.4%–68.4%), respectively (Tables 2–4). The PPV

Table 2. Contingency table for auscultation and lung ultrasound

Group		DLT position by FOB in supine position		p values	DLT position by FOB in lateral position		p values
		Correct	Incorrect		Correct	Incorrect	
Auscultation	Correct	38 (55.1)	27 (39.1)	0.316*, <0.001 [†]	58 (84.1)	7 (10.1)	<0.001*, 0.016 [†]
	Incorrect	0 (0)	4 (5.8)		0 (0)	4 (5.8)	
Lung ultrasound	Correct	38 (55.1)	27 (39.1)	0.316*, <0.001 [†]	58 (84.1)	7 (10.1)	<0.001*, 0.016 [†]
	Incorrect	0 (0)	4 (5.8)		0 (0)	4 (5.8)	

Values are expressed as number (percentage) of patients n (%). DLT: double lumen tube, FOB: fiberoptic bronchoscopy. *Analysis using Fisher's exact test.

[†]Analysis using McNemar's test.

Table 3. Correlated proportion comparison of lung ultrasound to auscultation for DLT position

		Lung ultrasound (n=69)		p value
		Correct	Incorrect	
Supine position				
Auscultation (n=69)	Correct	65 (94.2)	0 (0)	<0.001*, 1.000 [†]
	Incorrect	0 (0)	4 (5.8)	
Lateral position				
Auscultation (n=69)	Correct	65 (94.2)	0 (0)	<0.001*, 1.000 [†]
	Incorrect	0 (0)	4 (5.8)	

Values are expressed as number (percentage) of patients n (%). DLT: double lumen tube. *Analysis using Fisher's exact test. [†]Analysis using McNemar's test.

and NPV of lung ultrasound were equal to those of auscultation, which were 89.2% (78.5%–95.2%) and 100% (39.6%–100.0%), respectively (Tables 2–4).

Table 2 shows a statistically significant difference in the contingency table for auscultation and lung ultrasound in the supine and lateral positions, with fiberoptic bronchoscopy as the standard test. The auscultation and lung ultrasound showed a statistically significant disagreement with FOB ($p < 0.001$ in the supine position and $p = 0.016$ in the lateral position, Table 2), but lung ultrasound did not show a statistically significant disagreement with auscultation in either the supine or lateral positions ($p = 1.000$ in both the supine and lateral positions, Table 3).

The prevalence of proper lung isolation was 55.1% (42.7%–66.9%) in the supine position, and it increased to 84.1% (72.8%–91.4%) in the lateral decubitus position after correction of DLT depth according to FOB findings (Tables 2, 5).

Adjustments in the DLT position were required because of either suboptimal position with OLV or malposition with

Table 4. Accuracy, sensitivity, specificity, PPV, and NPV of auscultation and lung ultrasound in determining proper DLT positioning

Outcomes	Auscultation (n=69)		Lung ultrasound (n=69)	
	Value (%)	95% CI	Value (%)	95% CI
Supine position				
Accuracy	60.9	48.4–72.4	60.9	48.4–72.4
Sensitivity	100.0	88.6–100.0	100.0	88.6–100.0
Specificity	12.9	4.2–30.8	12.9	4.2–30.8
PPV	58.5	45.6–70.3	58.5	45.6–70.3
NPV	100.0	39.6–100.0	100.0	39.6–100.0
Lateral position				
Accuracy	89.9	80.2–95.8	89.9	80.2–95.8
Sensitivity	100.0	92.3–100.0	100.0	92.3–100.0
Specificity	36.4	12.4–68.4	36.4	12.4–68.4
PPV	89.2	78.5–95.2	89.2	78.5–95.2
NPV	100.0	39.6–100.0	100.0	39.6–100.0

Values are expressed as percentage 95% confidence intervals (CI). NPV: negative predictive value, PPV: positive predictive value.

Table 5. Analysis of proper DLT position depending on patient positions

	Supine position	Lateral position*
Correct position (No change)	38 (55.1)	58 (84.1)
Incorrect position	31 (44.9)	11 (15.9)
Causes of incorrect position		
Suboptimal position (One-lung ventilation)	28 (40.6)	6 (8.7)
Malposition (Two-lung ventilation)	3 (4.3)	5 (7.2)

Values are expressed as number or number (percentage) of patients. DLT: double lumen tube, FOB: fiberoptic bronchoscopy. *Lateral position changed after correction of DLT depth according to FOB findings.

TLV (Table 5). The suboptimal position and the malposition were 40.6% and 4.3% of patients in the supine position, whereas they were 8.7% and 7.2% of patients in the lateral position. Both auscultation and lung ultrasound did not reveal an inappropriate DLT position in 39% of patients in

a supine position, and in 10% of patients in the lateral position (Table 2).

DISCUSSION

This study compared the diagnostic accuracy of lung ultrasound and auscultation, which anesthetic trainee doctors performed for the determination of proper DLT positions in patients undergoing thoracic surgeries. We demonstrated that lung ultrasound was not superior to auscultation, with equal diagnostic accuracy in the supine (60.9%) and lateral positions (89.9%). In the lateral position after correction of DLT depth according to FOB findings in a supine position, the specificity, PPV, and accuracy were increased, but the sensitivity and NPV did not change.

We commonly evaluate the proper DLT position with two steps: confirmation of regional ventilation distribution by auscultation (functional lung isolation) and precise DLT position with FOB (anatomical lung isolation) [11]. However, previous studies showed a wide range of sensitivity (47%-100%), low sensitivity (18%-56%), and moderate accuracy (42%-70%) [10-14]. Furthermore, de Bellis et al. [15] showed that the misplacement and critical malposition of DLT was confirmed in 32% and 5% of patients with FOB, even though the anesthesiologist considered to be in a proper DLT position under the clinical evaluation in a supine position. This study also showed 100% sensitivity, 13% specificity, and 61% accuracy in the supine position. In addition, the misplacement and critical malposition of DLT was confirmed in 40.6% and 4.3% of patients with FOB. Therefore, our results support the evidence that auscultation is unreliable for choosing the proper DLT position, and FOB is frequently required for adequate placement [2,15]. Ultimately, FOB is required for confirmation of proper placement of DLTs if available. However, in the situation where the FOB cannot be available, we do not have a choice to rely on auscultation.

Recently, lung ultrasound has been suggested as a useful tool in airway management to confirm the correct position of endotracheal tubes, and it has also been a method to confirm adequate regional ventilation similar to auscultation [16-19]. However, a few studies have been conducted to evaluate the efficacy of lung ultrasound to confirm the proper DLT positions for OLV [10-14]. These studies sug-

gested that lung ultrasound was superior to auscultation in the determination of DLT position, with a more concise range of sensitivity (70%-95%), higher specificity (55.6%-94.7%), and higher accuracy (71%-89%) compared with those of auscultation [10,11,13]. In addition, the combination of lung ultrasound and clinical assessment was useful to ensure more precise DLT placement than with clinical assessment alone [12,14]. However, this study did not show the superiority of lung ultrasound over auscultation in the supine position, in which the sensitivity, specificity, and accuracy of lung ultrasound were equal to those of auscultation. Compared with previous studies, this study showed lower specificity and accuracy.

Even though the DLT position has been optimized in the supine position by correction according to FOB findings, the optimized DLT positions may be changed after moving from the supine to the lateral position. Therefore, we evaluated the proper DLT position using auscultation and lung ultrasound in both the supine and lateral positions. Hu et al. [13] showed that the overall sensitivity and accuracy of lung ultrasound decreased after moving from the supine to the lateral position, while the overall specificity was increased. However, the positioning of the left and right DLTs differs significantly due to anatomical differences. Hu et al. [13] showed that the accuracy and sensitivity were increased in patients with the left DLT, and the specificity was decreased, while they were opposite in patients with right DLT. This study showed that the overall accuracy increased in the lateral position after the readjustment of DLT depth according to FOB findings. This discrepancy can be explained by the different proportions of right and left DLTs. In this study, 4.3% of enrolled patients had right-sided DLT, while the study by Hu et al. [13] consisted of 44.7% of patients with right-sided DLT.

During the lung ultrasound evaluation, lung sliding and lung pulse are commonly used to distinguish the adequately ventilated lung with a homogenous movement below the pleural line [20-23]. In particular, lung pulses have been demonstrated to have high sensitivity (93%) and specificity (100%) as a sign for adequate lung isolation in a non-ventilated lung [20,24]. While the ventilated lung shows lung sliding in B-mode and sea-shore sign in M-mode, the non-ventilated lung shows the lung pulse (pulsatile movement of the lung) in B-mode and bar-code sign in M-mode [24,25].

Therefore, an adequate DLT position can be assumed if there is lung sliding in the ventilated lung and lung pulse in the non-ventilated lung. In this study, we used these two ultrasound modes (B-mode and M-mode) to confirm lung ventilation. We first confirmed lung ventilation with B-mode and finally with M-mode because the examiners were the anesthetic trainee doctors and the M-mode was easier than the B-mode to confirm ventilation for beginners.

Overall examination of lung ultrasound also requires a learning curve of 7 months with a linear trend for reporting accuracy and quality of lung ultrasound [26]. However, Rouby et al. [27] suggested that trainees without expertise in lung ultrasound acquired skills in lung ultrasound to monitor lung aeration, with a rapid learning curve as 25 ultrasound examinations under the supervision of expert anesthesiologists in lung ultrasound. In particular, skills in lung ultrasound can be easily acquired and retained for a long time by a brief tutorial to determine the presence or absence of specific sonographic findings such as lung sliding and lung pulse sign [28]. Therefore, we first trained lung ultrasound and FOB investigators for 6 months before the enrollment of the first patient.

There are a few limitations to this study. First, instead of randomization of patients in two groups, we conducted auscultation, lung ultrasound, and FOB in the same patients (single group). Second, the choice of optimal DLT size is important to reduce the displacement or the malposition of DLTs because the inappropriately sized DLTs can be placed into the main bronchus too far distally or proximally. However, we did not record or analyze this data, even though we used 35 Fr, 37 Fr, and 39 Fr DLTs. Finally, lung ultrasound is unreliable in cases that can abolish the lung sliding sign, such as in patients with surgical pleurodesis or post-inflammatory pleural adhesions, chronic obstructive pulmonary disease, or mesothelioma [11]. Such conditions must be taken into account before using lung ultrasound. In this study, we excluded these patients during preanesthetic evaluation and by rechecking the absence of lung sliding before anesthesia induction. Therefore, further studies are required for the evaluation of lung ultrasound to determine the proper DLT position in patients with conditions excluded in this study.

In conclusion, we cannot suggest that lung ultrasound is superior to auscultation for determination of the proper DLT

position because of the equal results of accuracy, sensitivity, specificity, PPV, and NPV in both the supine and lateral positions. Lung ultrasound has high sensitivity to detect the proper DLTs, but low sensitivity to detect the misplacement of DLTs in both positions. Changing to the lateral position after adjustment of intubation depth with FOB findings in the supine position increased the accuracy of both methods, but it increased the malposition of DLTs while decreasing the misplacement of DLTs. Therefore, we additionally recommend that FOB reassessment be performed to reduce the risk of DLT malposition.

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CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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