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RESEARCH ARTICLE

To Investigate The Accuracy of Tube Selection According to Ultrasonographic Airway Measurements in Patients Undergoing OLV

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ABSTRACT

Objectives: Double-lumen endobronchial tubes (DLTs) are often used in one-lung ventilation (OLV). However, there is no optimal guide or parameter to estimate the accurate size of a DLT. The aim of this study was to investigate the role of ultrasonographic measurements—including tracheal width (TW), cricoid width (CW), lung offset, pulmonary pulse, and diaphragmatic motion—in selecting the correct DLT size.

Methods: Thirty-four patients undergoing thoracic surgery requiring OLV were included in the study. In the selection of DLT size, a scale based on sonographic tracheal width (TW) and the patient's height was used. Sonographic lung measurements (SLM), including lung offset, pulmonary pulse, and diaphragmatic motion, were also used to confirm the location of the DLT, as compared to fiberoptic bronchoscopy (FOB).

Results: The mean DLT size was 39 Fr, while the mean BCV was 2.5 mm. BCV was found to be suitable (successful intubation) in 29 patients (85.3%) and non-suitable (failed intubation) in 5 patients (14.7%). The three SLMs—lung shift, pulmonary pulse, and diaphragmatic movement—were 100% compatible with intubation and OLV.

Conclusion: The sonographic TW- and height-based scale had an 85.3% success rate in determining the appropriate DLT size. Sonographic measurements of the lung were also found to be 100% compatible with intubation and OLV. Despite these promising results, sonographic measurements seem unlikely to replace FOB in DLT positioning. However, they may be helpful for selecting DLT size and confirming its placement, especially in the absence of FOB, in the presence of mucous plaque, or during emergency surgery.

Keywords: Double-lumen endobronchial tube, lung ultrasonography, one lung ventilation, ultrasonographic airway measurements

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Introduction

One-lung ventilation (OLV), defined as providing oxygenation and carbon dioxide elimination by ventilating only one lung, is frequently used in thoracic surgery.[1] Double-lumen endobronchial tubes (DLT) are often preferred in OLV as they allow ventilation and aspiration of both lungs simultaneously and separately. A DLT should be in an appropriate size for the patient; namely, its main body should pass through the glottis without resistance, move easily into the trachea, and should be placed in the intended bronchus without difficulty. However, there is no optimal guide or parameter to estimate the appropriate size of DLT. Although different indicators and mathematical formulas have been recommended to date, the selection of DLT size is often based on the clinical experience of the anesthesiologist and various anthropometric measurements in routine practice.[2]

In OLV, obtaining the optimal DLT depth is as important as determining the appropriate DLT size. Optimal DLT depth is achieved by placing the blue endobronchial cuff just below the carina and not obstructing the trachea and main bronchus. DLT depth is directly proportional to height in both men and women. Average insertion depth for 170 cm height is 29 cm, and the tube is moved forward or backward

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approximately 1 cm for every 10 cm change in height.[3] This observational method can be helpful for DLT placement but does not provide certainty. Correct placement of DLT can be confirmed by various methods including observation of chest wall movements, auscultation of lung sounds, fiberoptic bronchoscopy (FOB), and ultrasonography (US). Watson et al.[4] first described the use of FOB to monitor tube position in lung isolation. Today, confirmation of the position of DLT by FOB has become the gold standard in OLV. Improper tube selection may lead to malposition and can cause serious injuries.

DLT malposition is defined as the placement of both lumens in the main bronchus or the trachea or the advancement of DLT into the opposite bronchus, resulting in impaired gas exchange. High cuff volume, surgical manipulation, and patient repositioning may also lead to malposition of DLT. Another undesirable situation associated with inappropriate size and positioning of DLT is bronchial rupture. Tension pneumothorax and pneumomediastinum may also occur due to high tidal volume as a result of excessive migration of the endobronchial portion of the small DLT. A narrow tube lumen may cause greater resistance to gas flow and auto positive end-expiratory pressure (PEEP).

In recent years, US has been used to determine the appropriate DLT size and to confirm the position of the DLT.[1] DLT size can be estimated by sonographic measurement of tracheal width (TW). The size of both cuffed or uncuffed endotracheal tube can be accurately determined sonographically, and this method was found superior to age- and height-based formulas.[5] US is also used to confirm tube placement by providing dynamic visualization of lung sliding and diaphragmatic movements.

There are studies in the literature on both TW and CW in estimating tube size. Although we did not use CW in estimating the appropriate tube size in our study, we also measured CW to evaluate the correlation between CW and TW.

The primary aim of the study was to investigate the role of height-sonographic TW-based scala in determining the appropriate DLT size. Although CW was not used in estimating appropriate DLT size in the study, the correlation of TW and CW was also assessed.

The second endpoint of the study was to investigate the role of three sonographic measurements (lung sliding, pulmonary pulse, and diaphragmatic movement) on confirmation of DLT localization and lung isolation.

Methods

Study Design

The study was approved by Eskişehir Osmangazi University Clinical Research Ethics Committee (date: 09.02.2021 and protocol number: 02) and conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. The patients were informed in detail about the stages of the study, and written informed consent was obtained from all. Thirty-six patients, aged between 18 and 85 years, classified as The American Society of Anesthesiologists (ASA) physical status 1–3, and who were intubated using a DLT for a thoracic operation requiring OLV were included in the study. Patients below 18 years old, who did not approve the study design, had ASA status ≥4, had a disease that narrowed the trachea, had a history of tracheotomy or neck surgery, and received radiotherapy to the neck region were excluded from the study.

Primary and Secondary Endpoints of the Study

The primary aim of the study was to investigate the role of height- and sonographic TW-based scala in determining the appropriate DLT size. Although CW was not used in estimating appropriate DLT size in the study, the correlation of TW and CW was also assessed. The second endpoint of the study was to investigate the role of three sonographic measurements (lung sliding, pulmonary pulse, and diaphragmatic movement) in confirmation of DLT localization and lung isolation.

Anesthetic Management

The patients were taken to the operating room without premedication and placed on the operating table in the supine position. Standard monitoring included electrocardiogram, pulse oximetry, and non-invasive blood pressure. Intravenous (IV) access was provided using a 20-gauge cannula over the hand, and saline infusion was started to keep the vascular access open. Demographic data including gender, age, height, weight, ASA physical status, Mallampati score, type of surgery, and hemodynamic parameters were recorded.

Routine general anesthesia protocol was applied to the study population. The patients were first preoxygenated for three minutes. Induction was performed with lidocaine 1mg/kg, thiopental sodium 3–5mg/kg, remifentanil 0.5–1mcg/kg, and rocuronium 0.6mg/kg. All patients were intubated with video laryngoscope to facilitate intubation under the pandemic precautions.

Determining Tube Size

The tube size was selected by looking at the scale combining the patient's height and the TW measured by ultrasound. The self-styled DLT was placed in the oral cavity with its distal concave curve facing forward, in an appropriate size determined by the patient's TW and height (Fig. 1).[6] In extreme lengths and tracheal widths, the tube with the closest size was selected. When the tip of the DLT passed

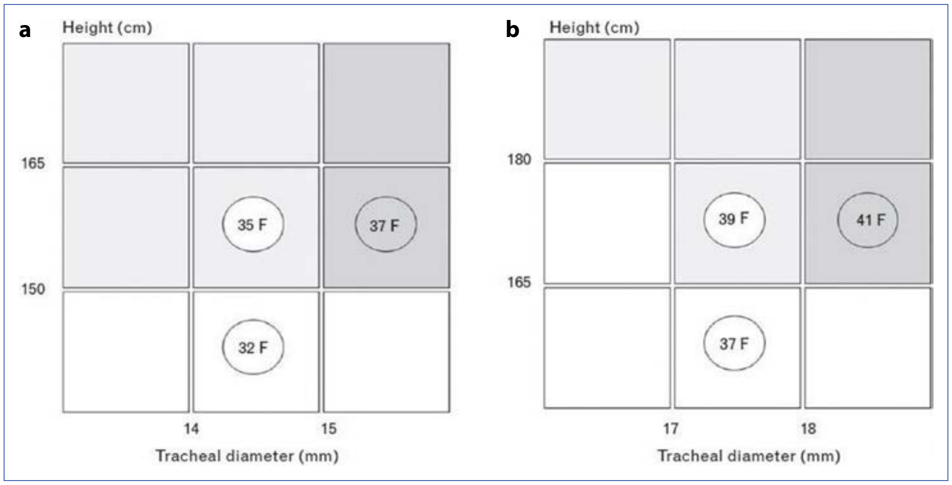

Figure 1. The scale based on height and sonographic TW for selection of the DLT size in women **(a)** and men **(b)**.

TW: Tracheal width; DLT: Double-lumen endobronchial tube.

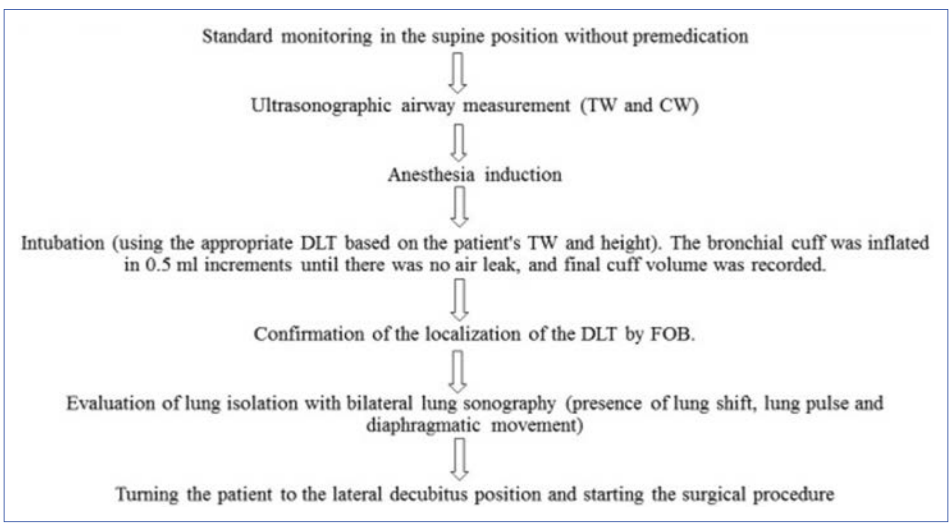

Figure 2. Flow chart of the study.

TW: Tracheal width; CW: Cricoid width; DLT: Double-lumen endobronchial tube; FOB: Fiberoptic bronchoscopy.

the vocal cords, the stylet was removed and the tube was rotated 90 degrees to the side of the main bronchus to be intubated. The tube was moved in the bronchus until resistance was encountered. Duration of intubation was noted as the unit of second.

After intubation, lung auscultation was performed. The intubation time was considered as the time from the end of mask ventilation and the placement of the D-blade in the oral cavity, until intubation was completed and the end-tidal carbon dioxide value appeared in 2 consecutive waves. The size and direction (right/left) of the DLT, the number of attempts for successful intubation, the presence or absence of resistance in intubation (absent/mild/moderate/severe), the calculated-applied depth distances of the DLT, and airway resistance were recorded.

After sonographic assessments and fiberoptic bronchoscopy (FOB), the patient was placed in the lateral decubitus position according to the side to be operated. Anesthesia was maintained with remifentanil (0.05–2mcg/kg/min) IV infusion, 4L/min 50% O_2/air mixture, and 2–3% sevoflurane with a MAC value of 1–1.3. Hemodynamic parameters were recorded at the 15th minute following OLV. The mechanical ventilator was set at 12–20/min, with tidal volume 6–8mg/kg, PEEP 4–6cmH_2O, and respiratory rate above SpO_2 92%. After opening the thorax, the surgeon's observation was asked. Lung collapse was evaluated as appropriate or inappropriate by the surgeon. All steps of the study are summarized in Figure 2.

Standard analgesia protocol with 1g paracetamol and 1mg/kg tramadol IV was administered to the patients. After extubation, the patients were transferred to the intensive care unit (ICU) and evaluated in terms of sore throat, hoarseness, and satisfaction at the postoperative 24th hour.

Sonographic Assessment

Sonographic measurement of TW was performed to determine the appropriate DLT size. Although we did not use CW in estimating the appropriate tube size in our study, we also measured CW to evaluate the correlation between CW and TW.

After the tube was placed, the following were performed to verify its location: lung sliding, pulmonary pulse, and diaphragmatic movement.

Airway US (Samsung-HS50, 3–16MHz high-frequency linear probe) was performed by a single anesthesiologist just before induction. First, in the transverse section, the probe was placed perpendicular to the neck just above the sternoclavicular joint. To minimize measurement errors, TW outer diameter was measured three times. Then, the US probe was shifted upwards longitudinally in the midline, and the cricoid width (CW) inside diameter was measured three times. Lung isolation was checked by bilateral US after intubation and just before surgery. A linear high-frequency transducer was used longitudinally in the 2nd–8th intercostal spaces in the midaxillary line in B (brightness) and M (motion-motion) modes. Lung sliding, pulmonary pulse, and diaphragm movements were examined to evaluate DLT localization and lung isolation.

Fiberoptic Bronchoscopy

Before lateral decubitus positioning, the localization of the DLT was evaluated by FOB. First, the fiberoptic bronchoscope was passed through the tracheal lumen to confirm the side, and then the bronchial cuff was placed just below the carina. It was aimed for the balloon to completely close the lumen of the main bronchus without herniation into the trachea. Cuff pressure could not be measured because there was no cuff pressure gauge in our hospital. Positive pressure ventilation was applied to the patient with a tidal volume of 6–8ml/kg according to weight. The bronchial cuff was inflated in 0.5ml increments until there was no air leak by visual assessment during FOB. Tracheal and bronchial cuff volumes were recorded in milliliters. In our study, bronchial cuff volume was evaluated as suitable (1–3.5mL) and unsuitable (<1mL large tube and >3.5mL small tube), and was used to determine whether "improper tube selection" was performed.

In patients with right DLT, it was definitely seen that the right upper lobe mouth was open from Murphy's eye. Subsequently, the secondary carina was seen by passing through the lumen of the bronchus with the FOB. The appropriate tube depth was decided by FOB. The patients with suitable fiberoptic evaluation were given to the surgical team.

Statistical Analysis

A power analysis (G Power version 3.01) based on the study by Sustić et al.[7] showed that a sample size of at least 24 patients was required to achieve an 80% power with a 5% significance level (effect size: 0.8 and the degree of freedom: 1). IBM SPSS 26 package program was used to analyze the data. Frequency analysis was performed in order to obtain information about the participants and research variables. Fisher's Exact test was used to compare categorical data. In addition, Mann-Whitney-U test, correlation analysis, and regression analysis were used. While creating the research report, 95% confidence interval was used for the significance level.

Results

Thirty-five patients who underwent thoracic surgery under OLV were included in the study. One patient who could not tolerate OLV was excluded from the study because of the lack of follow-up data. Of the 34 patients whose data were evaluated, 24 (70.6%) were male and 10 (29.4%) were female. The mean age of the patients was 50.7 years. The most common types of surgery were lobectomy (38.2%) and wedge resection (29.4%). The basic clinical characteristics were presented in Table 1.

All patients were evaluated by US in terms of TW and CW. Thereafter, the patients were intubated using DLT according to the scale based on the patient's TW and height. The mean DLT size was 39Fr. The mean tracheal cuff volume was 4.9mm, while the mean bronchial cuff volume was 2.5mm.

Three sonographic measurements of the lung, including lung sliding, pulmonary pulse, and diaphragmatic movement, confirmed the proper intubation and OLV in all patients. All sonographic examinations were presented in Table 2.

In the correlation analysis performed to determine whether there was a relationship between TW and CW, a positive moderate correlation was found between the two variables ($r=0.474$, $p=0.005$).

Bronchial cuff volume was the primary independent variable in terms of feasibility of DLT, complications, and patient satisfaction. Bronchial cuff volume was first classified as small, suitable, and large; however, in order to ensure homogenization between categories, small and large categories were gathered under the title of "unsuitable". Bronchial cuff volume was found suitable and non-suitable in 29 (85.3%) and 5 (14.7%) patients, respectively. Statistically,

Table 1. Basic clinical characteristics of the patients (n=34)

Characteristics	n	%
Age (year)	50.7±2.9 (20–77)	
Gender		
Female	10	29.4
Male	24	70.6
BMI (kg/m^2)	25.5±0.8 (16–35)	
ASA physical status		
ASA 1	7	20.6
ASA 2	20	58.8
ASA 3	7	20.6
Mallampati score		
Mallampati 1–2	23	67.7
Mallampati 3–4	11	32.3
Type of surgery		
Lobectomy	13	38.2
Wedge resection	10	29.4
Hydatid cyst	2	5.9
Diafragmatic hernia	2	5.9
Mediastinal mass	2	5.9
Others	5	14.7

Age and BMI was presented as mean±SD (minimum-maximum); other variables were presented as number. BMI: Body mass index; ASA: American society of anesthesiologists.

there were no significant relationships between bronchial cuff volume and gender, intubation-related parameters, anesthesia-related complications, postoperative sore throat, and postoperative hoarseness (Table 3).

The relationship between DLT size and some parameters, including anesthesia-related complication (p=0.285), postoperative sore throat (p=0.690), postoperative hoarseness (p=0.661), and patient satisfaction (p=0.771), were evaluated with the Mann-Whitney-U test and no statistical difference was found.

Table 2. Intubation parameters and airway sonographic measurements of the patients (n=34)

Characteristics	n (%)
TW (mm)	18.4±0.4 (13.9–25)
CW (mm)	13.3±0.3 (9.5–17.9)
DLT size (Fr)	39±0.3 (35–41)
Number of attempts	1.1±0.06 (1–2)
Duration of intubation (sec)	46.6±5.3 (13–160)
Tracheal cuff volume (mm)	4.9±0.3 (2–10)
Broncheal cuff volume (mm)	2.5±0.1 (1–6)

TW: Tracheal width; CW: Cricoid width; DLT: Double-lumen endobronchial tube; mm: millimeter; Fr: French; sec: second.

Discussion

Selection of the appropriate size of DLT is one of the most critical stages in anesthesia management requiring OLV. The blind method based on the height and gender of the patient is the most frequently used technique in routine practice. However, previous studies showed that 41Fr DLT can be used for most of the men regardless of their height and weight, whereas height- or weight-based methods are not completely reliable in predicting airway dimensions for women.[8] Slinger recommended measuring the diameter of the left main bronchus from direct radiographs as a guideline.[9] Nevertheless, the fact that left bronchus outlines can be clearly seen in only

Table 3. The association between bronchial cuff volume and intubation-related parameters

Parameters	Nonsuitable BCV (n=5)	Suitable BCV (n=29)	p
Gender (female/male)	1/4	9/20	0.535
Intubation side (right/left)	1/4	10/19	0.471
Intubation time	34±13.02	48.8±33.04	0.318
Resistance			0.225
Absent	3	9	
Present	2	20	
Airway pressure (post-intubation)	18.8±4.3	15.3±6.2	0.571
Heart rate (post-intubation)	89.9±5.3	86.3±2.7	0.571
Mean arterial pressure (post-intubation)	89.2±5.9	92.3±3.6	0.888
Oxygen saturation (post-intubation)	99.4±0.5	97.1±3.4	0.099
Carbondioxide (post-intubation)	33.2±4.4	36.1±1.1	0.508
Anesthesia-related complication	5	25	0.512
Postoperative sore throat	2	9	0.529
Postoperative hoarseness	0	4	0.512

BCV: Bronchial cuff volume.

half of chest radiographs limited the use of this method. Brodsky et al.[10] measured the tracheal diameter from the chest radiograph at the level of the clavicle, and used a 41Fr left DLT if it was≥18mm, 39Fr if it was≥16mm, 37Fr if it was≥15mm, and 35Fr if it was<15mm. In the same study, it was found that the ratio of left bronchus diameter to tracheal diameter was always 0.68 despite the differences in tracheal and bronchial widths between individuals. As a result of this groundbreaking study, it was realized that the measurement of tracheal width is sufficient to predict bronchial width when determining DLT size.

Hannallah et al.[11] determined the DLT size by measuring the diameters of the left bronchus from the computed tomography (CT), based on the idea that it showed the bronchial anatomy better. Similarly, Shiqing et al.[12] used tomographic measurements of the cricoid ring, the narrowest part of the upper airway, and left main bronchus diameter to determine the most appropriate size of DLT. Although there are cadaveric studies describing the cricoid ring and its shape in the literature, the "best fit" study is the first to use CT scans in adult patients *in vivo*.

However, this was a limited study as multiplane reconstruction of thoracic CT scans was required, few patients were studied, and their hospital did not have a 41Fr DLT. The authors found that the size and shape of the cricoid ring were very different between the sexes, and claimed that cricoid diameter measurement is more suitable for women than men. Although CT-based methods are correct, they could not be used in routine practice because they always require an experienced radiologist. US, another imaging method, has some advantages over its competitors, since it is widely available, portable, reproducible, inexpensive, painless, reliable, and does not require complete immobility. The trachea can be examined at high resolution with ultrasound probes due to its superficial location.

In the study of Sustić et al.,[7] a strong correlation was found between the tracheal outer diameter measured by US and the inner tracheal diameter and the left main bronchus diameter measured by CT. However, sonographic measurements are alone insufficient in estimating the diameter of the left main bronchus. Roldi et al.[6] improved left DLT selection by combining clinical parameters, including height and gender, with left main bronchus diameter, and reduced the frequency of oversized DLT placement. The other study reported by Shiqing et al.[13] was the first to use US and cricoid ring diameter measurement in the evaluation of DLT compliance. The authors demonstrated a good correlation between CT and US measurements of the cricoid diameter. In another study conducted on Asian women, the appropriate size of DLT was found to be estimated by ultrasonographic measurement of the cricoid diameter.[14]

We used ultrasonographic airway measurement of TW with the height of the patient in determining the DLT size. For extreme lengths and tracheal widths, on the other hand, the smallest possible DLT is selected. In our study, we also used this approach and aimed to investigate the effectiveness of ultrasonographic airway measurement of TW with the height of the patient in determining the DLT size. We first found a statistically significant positive correlation between sonographic measurements of TW and CW. As the primary endpoint, our work demonstrated that the appropriate DLT size for the patient can be determined by TW measured by US.

In DLT placement, the practitioner has two options while advancing the selected tube into the trachea: to advance blindly until resistance is felt or to advance visually with the aid of FOB. Studies have found that both methods are successful, but the FOB-directed method requires more time. In the study of Boucek et al.,[15] the blind approach took 88 seconds and the FOB-directed approach took 181 seconds. We found the mean intubation time was 71 seconds, consistent with the literature.

DLT placement depth is another issue where there is no consensus. Various methods and formulas have been proposed to estimate the depth of DLT. In our study, the 0.1×patient height+12.5cm formula recommended by Chow et al.[16] was preferred because it is easy to perform and has a high success rate. It should be noted that this kind of formula may only give an idea of the initial insertion depth, and the final DLT insertion depth should be decided by FOB. In our study, we did not find statistically significant differences between calculated and applied depths or appropriate and inappropriate DLTs. The reason for this situation might be related to the fact that we decided the final appropriate tube depth of the patient with FOB.

Auscultation is one of the oldest clinical methods and is indispensable for clinicians despite developing technology. Álvarez-Díaz et al.[17] reported that lung US was clinically superior to auscultation in confirming the left DLT position, whereas there was no difference between the two methods in confirming tube misplacement. Less experience, high ambient noise, and emergencies reduce the success of auscultation. In a prospective study by Parab et al.,[18] they found that the addition of lung US increased accuracy in estimating left DLT position compared to clinical methods alone. Tracheal US is a quick and simple method to evaluate the accuracy of intubation.[19] Thoracic or lung ultrasound, on the other hand, requires more experience and knowledge to interpret imaging artifacts specific to the lung and pleura.

In our clinic, the multiple fixation technique was used to confirm the DLT location. In this technique, bilateral lung US was performed on patients who were evaluated by clinical methods, and then the final position was determined by FOB. In our study, lung collapse was evaluated by confirming with lung US parameters including lung sliding, pulmonary pulse, and diaphragmatic movement in all patients. We did not see a negative result in the US evaluations. There was no significant difference between the right and left DLTs. This situation may be associated with the small scale of the study, multiple fixation technique, and the completely operator-dependent nature of US assessments.

Of 34 patients, four were intubated with small DLT and one with large DLT. Many different bronchial cuff volumes have been used in the literature.[20] Roldi et al.[6] accepted 0.5–2.5ml of bronchial cuff volume to be sufficient, while Liu et al.[14] considered tubes requiring >4ml volume as small. The bronchial cuff volume and pressure required during OLV may change after opening of the chest. There is no published article on this subject.

There is no consensus for the estimation of DLT position. Parab et al.[18] stated in their study that DLT position was satisfactory if airway pressure was under 35cmH_2O and oxygen saturation was above 93% during OLV. In our study, there was a statistically significant difference between the post-intubation oxygen saturation of suitable DLTs and the post-intubation oxygen saturation of unsuitable DLTs. This difference may be explained by the fact that the tube moves too far, crossing the secondary carina and causing insufficient oxygenation. Visual confirmation of DLT position with FOB is currently the gold standard.[6,7,12–14] Routine FOB is recommended after intubation and patient positioning.[21–23] In our study, the bronchial cuff was considered suitable (91.2%) in a visible position without herniation to the carina.

As known, both lungs are perfused in OLV, leading to transpulmonary shunt, impaired oxygenation, and ultimately hypoxemia. Hypoxemia is defined as a decrease in arterial oxygen saturation below 90%. In the study of Karzai et al.,[22] it was stated that hypoxemia could be seen in 4% of the patients with OLV. During OLV, it is important to predict hypoxemia, to prevent it if possible, and to intervene promptly when it occurs. In our study, the mean value of SpO_2 was 94.7%, and there was no statistically significant difference between suitable and unsuitable DLTs.

The most common complication in DLT placement is malposition.[24] Wrong bronchial intubation was observed in two patients; both were detected and corrected early. Airway trauma associated with DLT is a rare situation. The most serious injury is tracheobronchial rupture, usually caused by overinflation of the cuff.[23] In our study, we deflated the bronchial cuff after positioning the patient and when OLV was not required, to reduce the risk of injury. Thus, we did not experience any airway injury.

Sore throat and hoarseness are possible postoperative complaints after the use of DLT. A large DLT can cause mucosal ischemia and damage as it passes through the cricoid ring, increasing the incidence of these complications.[13] The incidence of sore throat after intubation ranges from 12% to 70%.[24] In our study, 11 patients had mild to moderate sore throat and one patient had hoarseness. There was no statistically significant difference between DLT size and sore throat, which was possibly related to individual differences in pain assessments. Hoarseness developed in one patient who could be intubated on the second attempt due to cricoid stenosis.

Conclusion

According to the results obtained from the study, sonographic TW measurement and height-based scale had an 85.3% success rate in determining the appropriate DLT size for patients undergoing thoracic surgery requiring OLV. Sonographic measurements of the lung, including lung sliding, pulmonary pulse, and diaphragmatic movement, were also found to be 100% compatible with intubation and OLV. Despite all these promising results, sonographic measurements seem unlikely to replace FOB examination in the DLT placement. However, sonographic measurements may be helpful to anesthesiologists for the selection of DLT size and confirmation of DLT placement, especially in situations such as the absence of a fiberoptic bronchoscope, presence of mucous plaque, and emergency surgery.

Disclosures

Ethics Committee Approval: The study was approved by the Osmangazi University Non-interventional Clinical Research Ethics Committee (no: 02, date: 09/02/2021).

Informed Consent: Informed consent was obtained from all participants.

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