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SCIENTIFIC ARTICLE

Risk factors for intraoperative hypoxemia during monopulmonary ventilation: an observational study

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KEYWORDS
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Double lumen;
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Abstract
Background: Left double-lumen endotracheal tubes have been widely used in thoracic, esophageal, vascular, and mediastinal procedures to provide lung separation. Lacking clear objective guidelines, anesthesiologists usually select appropriately sized double-lumen endotracheal tubes based on their experience with 35 and 37 Fr double-lumen endotracheal tubes, which are the most commonly used. We hypothesized the patients with a left main bronchus of shorter length (<40 mm) had a greater chance of experiencing desaturation during one lung ventilation, due to obstruction in the orifice of the left upper lobe with the bronchial tube.
Methods: We included 360 patients with a left double-lumen intubated between September 2014 and August 2015. The patient's age, sex, height, weight, and underlying disease were recorded along with type of surgical procedure and the desaturation episodes. In addition, the width of the trachea and the width and length of the left bronchus were measured using computed tomography.
Result: Patients with a left main bronchus length of less than 40 mm who underwent intubation with a left double-lumen endotracheal tubes had significantly higher incidence of desaturation (Odds Ratio (OR: 8.087)) during one-lung ventilation. Other related factors of patients identified to be at risk of developing hypoxia were diabetes mellitus (OR: 5.368), right side collapse surgery (OR: 4.933), and BMI (OR: 1.105).
Conclusions: We identified that patients with a left main bronchus length of less than 40 mm have a great chance of desaturation, especially if other desaturation risk factors are present.

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PALAVRAS-CHAVE
Brônquio principal esquerdo;
Duplo lúmen;
Ventilação monopulmonar;
Dessaturação

Fatores de risco para hipoxemia intraoperatória durante ventilação monopulmonar: estudo observacional

Resumo
Justificativa: Os tubos endotraqueais de duplo lúmen (Double-lumen tubes – DLTs) para intubação seletiva esquerda têm sido amplamente utilizados em procedimentos torácicos, esofágicos, vasculares e mediastinais para proporcionar a separação dos pulmões. Com a falta de diretrizes claras, os anestesiologistas geralmente selecionam os tubos com base em sua experiência com os tubos endotraqueais de duplo lúmen de 35 e 37 Fr, que são os mais comumente usados. Nossa hipótese foi que os pacientes com um brônquio principal esquerdo de menor comprimento (<40 mm) apresentavam uma chance maior de sofrerem dessaturação durante a ventilação monopulmonar, devido à obstrução do orifício do lobo superior esquerdo com o tubo brônquico.
Métodos: No total, 360 pacientes submetidos à intubação seletiva esquerda mediante o uso de tubo de duplo lúmen foram incluídos no estudo entre setembro de 2014 e agosto de 2015. Idade, sexo, altura, peso e doença de base foram registrados, junto do tipo de procedimento cirúrgico e os episódios de dessaturação. Além disso, a largura da traqueia e a largura e comprimento do brônquio esquerdo foram medidos por meio de tomografia computadorizada.
Resultados: Os pacientes com comprimento do brônquio principal esquerdo inferior a 40 mm, submetidos à intubação seletiva esquerda com tubos endotraqueais de duplo lúmen, tiveram incidência significativamente maior de dessaturação (Odds Ratio – OR: 8,087) durante a ventilação monopulmonar. Outros fatores relacionados aos pacientes e identificados como risco de desenvolver hipoxemia foram diabetes *mellitus* (OR: 5,368), cirurgia de colapso direito (OR: 4,933) e IMC (OR: 1,105).
Conclusões: Identificamos que os pacientes com comprimento do brônquio principal esquerdo inferior a 40 mm apresentam grande chance de dessaturação, principalmente se outros fatores de risco para dessaturação estiverem presentes.

Introduction

Monopulmonary ventilation using double-lumen endotracheal tubes (DLTs) is a method that facilitates relatively effective surgical exposure in lung cavities during thoracic procedures.[1] To achieve successful lung isolation and effective oxygenation, both the proper placement and appropriate size of the (DLT) are essential.[2–4] The choice of tube size has previously been determined through imaging and is based on the patient's height and tracheal or bronchial diameter to prevent airway injury or air leakage.[2,5,6] Patients with a height of <160 cm, tracheal diameter of <15 mm, or bronchial diameter of <10 mm were not recommended for intubation with a DLT larger than 35 Fr.[7,8] These studies have focused on the diameter of the trachea or bronchus.[9,10]

However, the Length of the Left Main Bronchus (LLMB) of the patient is also important. According to statistical data, the distance from the proximal bronchial cuff to the distal bronchial tip correlates with the size of the left-sided DLT (Fig. 1).[11] In patients with a very short left main bronchus, the cuff-tip length is longer than the length of the left bronchus, and the tip of the double-lumen tube will easily obstruct the orifice of the left upper lobe.[12,13] Even if the double-lumen tube is withdrawn, the bronchial cuff could still herniate to the carina. Either cuff leakage or excessive airway pressure could occur during one-lung ventilation. All these situations would lead to desaturation.

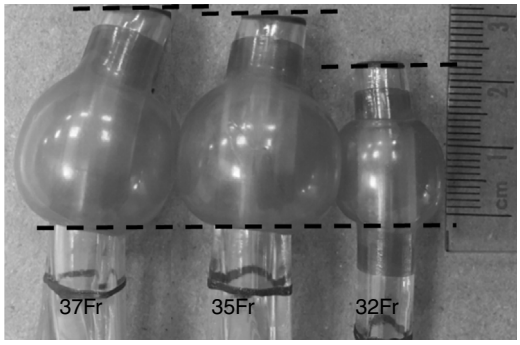

Figure 1 Cuff-to-tip difference of approximately 1 cm between 32 Fr and other DLTs due to different joint surfaces in the bronchial cuff.

The present study emphasized the length of the left main bronchus as an essential factor for successful monopulmonary ventilation. Patients with short left main bronchi had a tendency for hypoxia perioperatively because the tube obstructed the orifice of the left upper lobe. Based on this hypothesis, this study was designed to investigate whether the short left main bronchus affected the incidence of hypoxia during one-lung ventilation and to explore

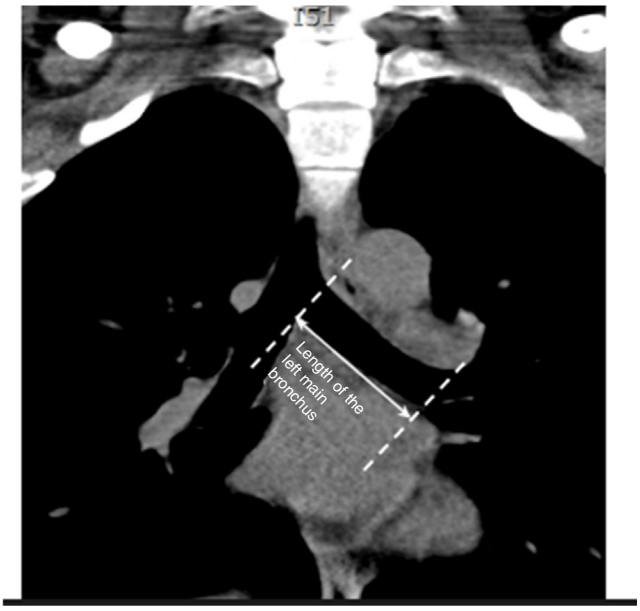

Figure 2 Length of the left main stem bronchus was measured from the tracheal bifurcation tip to inflection point of the left proximal bifurcation orifice.

related clinical variables that were predictive of desaturation events in thoracic surgery.

Methods

Patients who underwent thoracic surgery from September 2014 to August 2015, required intubation with left-sided DLTs (Bronchocath, Mallinckrodt, Athlone, and Ireland) and had chest computed tomography (CT) imaging within 1 month of the scheduled surgery were retrospectively studied. Patients were excluded from the study if they had already undergone tracheal intubation or if their CT image showed distorted anatomy of the tracheobronchial tree. If more than one thoracic surgical session was performed on a single patient, only the first session was adopted for outcome analysis. The study protocol was approved by the institutional review committee on human research, and the same committee also waived the requirement for written informed consent.

Computed tomography

All CT imaging was performed using 64 slice multidetectors and $\geq$1.25 mm thick sections in a single breath hold covering the whole lung. An anesthesiologist quantified the diameter of the trachea and the diameter of the left main bronchus as well as the length of the left main bronchus by using a Picture Archiving and Communication System program.

The tracheal diameter was measured at the interclavicular level.[10] The diameter of the left main bronchus was measured 2 cm below the carina (Fig. 2),[14] and the lengths of the left main bronchi were defined as the distance between the carina and the left bronchus bifurcation in the coronal views of the CT scan (Fig. 2). To minimize errors, all measurements were performed on an image enlarged by 300% for the trachea and 150% for the left main bronchi.

The distances from the proximal edge of the bronchial cuff to the tips of the bronchial tubes were generally more than 3 cm for 35 Fr and 37 Fr left-sided Mallinckrodt DLTs but substantially less than 3 cm for the 32 Fr DLT.[4] We assumed that the bronchial tip permits a 1 cm safety range that is movable during one lung ventilation. When patients have a short left main bronchus (i.e., <4 cm), the tubes have a greater chance of obstruction in the left upper lobe.

Clinical parameters

All clinical data of these patients were obtained from hospital admission notes and anesthetic records. The preoperative factors, namely, baseline demographics and comorbid illnesses, were recorded. Intraoperative factors were recorded, including the type of surgery, the size of the left-sided DLTs, and the side of the collapsed lung.

After induction of general anesthesia, the patients were intubated with a 32–37 Fr double-lumen endobronchial tube. The correct position of the endotracheal tubes were confirmed through auscultation and fiberoptic bronchoscopy.

Definition of perioperative desaturation

A hypoxemic event was defined as a reduction in peripheral oxygen saturation (SpO_2) to less than 93% or arterial partial pressure of oxygen (PaO_2) to less than 69 mmHg, measured through pulse oximetry analysis or arterial blood gas, with 100% oxygen during monopulmonary ventilation.

Statistical analysis

Continuous variables were expressed as the mean (SD). Univariate followed by multivariate logistic regression analysis were used to identify independent correlations among hypoxemic events. The independent variables enrolled for regression analysis were categories of demographic characteristics, comorbid illnesses, and operative and anesthetic parameters. The variables were tested in a conditioned multivariate logistic regression model to assess whether their univariate *p*-values were less than 0.05, which was defined to indicate statistical significance. The Odds Ratios (ORs) and 95% Confidence Intervals from the logistic regression analysis were used as estimates of relative risk. All analyses were performed using SPSS software version 22.0 (SPSS, Chicago, IL).

Results

From September 2014 to August 2015, 360 patients (207 male, 153 female) without preoperative oxygen desaturation were enrolled from the database. The demographic, coexisting disease, type of surgery, and side of the collapsed lung data are shown in Table 1.

A 9.2% incidence of desaturation was observed during monopulmonary ventilation in our study. Hypoxemic events were observed in 4.7% of the patients who experienced a decrease in PaO_2 to $\leq$69 mmHg and 8.3% of the patients who

Table 1 Demographic characteristics and comorbidities of chest surgery patients with a double-lumen endotracheal tube.

Age (years)	57.6 ± 13.7
BMI (kg.m^{-2})	23.9 ± 4
Male, n (%)	207 (57.5%)
Age group, n (%)	
<65 years	241 (66.94%)
65–74 years	83 (23.1%)
≥75 years	36 (10%)
Coexisting diseases, n (%)	
HT	111 (30.8%)
DM	36 (10%)
CAD	11 (3.1%)
COPD	17 (4.7%)
HF	7 (1.9%)
Creatinine >2.0 mg.dL^{-1}	3 (0.8%)
CVA	5 (1.4%)
Types of surgery, n (%)	
Mediastinotomy, pleurodesis or others	13 (3.6%)
Decortication of pleura	15 (4.2%)
Open esophagectomy	28 (7.8%)
Thoracoscopic surgery	248 (68.9%)
Open thoracotomy	55 (15.3%)
Right lung collapse	140 (38.9%)

CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; HF, heart failure; CVA, cerebrovascular accident; BMI, body mass index; HT, hypertension; DM, diabetes mellitus.

Table 2 Incidence of desaturation duration monopulmonary ventilation.

Monopulmonary ventilation PaO_2 (mmHg)	165.9 ± 91.6
Monopulmonary ventilation SpO_2 (%)	97.9 ± 3.1
Desaturation duration monopulmonary ventilation, n (%)	
$PaO_2 \leq 69$ mmHg during monopulmonary ventilation	17 (4.7%)
$SpO_2 \leq 93\%$ during monopulmonary ventilation	30 (8.3%)
$PaO_2 \leq 69$ mmHg or $PaO_2 \leq 93\%$ during monopulmonary ventilation	33 (9.2%)

Some patients had both monopulmonary ventilation $PaO_2 \leq 69$ mmHg and monopulmonary ventilation $SpO_2 \leq 93\%$.
PaO_2, partial pressure of oxygen; SpO2, oxyhemoglobin saturation by pulse oximetry.

had SpO_2 of ≤93%, even when ventilated with an inspired oxygen fraction (FiO_2) of 1.0 (Table 2).

The parameters of the airway dimensions, including the diameter of the trachea and the diameter of left main bronchus as well as the length of left main bronchus, are presented in Table 3.

Patients with a left main bronchus less than 4 cm were classified as having a short left main bronchus according to our hypothesis in this study. Multiple logistic regression analyses revealed that the presence of a short left main bronchus (OR = 8.087), diabetes mellitus (OR = 5.414), right lung collapse (OR = 5.062), and high BMIs (OR = 1.106) are predictors of hypoxia (Table 4).

Table 3 Tracheal A-P diameter, left main bronchus diameter, and left main bronchus length measured using computed tomography.

CT tracheal A-P diameter (cm)	1.7 ± 0.3
CT left main bronchus diameter (cm)	1.3 ± 0.2
CT left main bronchus length (cm)	4.8 ± 0.5
CT left main bronchus length (cm), n (%)	
≤4 cm	21 (5.8%)
>4 cm, ≤4.5 cm	97 (26.9%)
>4.5 cm, ≤5 cm	147 (40.8%)
>5 cm	95 (26.4%)

CT, computed tomography.

Table 4 Multivariate logistic regression analysis for the factors that predict hypoxia during one-lung ventilation.

Multivariate mode	Odds Ratio	95% CI	*p*
LLMB ≤4 cm	8.087	2.537–25.778	<0.001[a]
Right lung collapse	5.062	1.796–14.262	0.002[a]
BMI	1.106	1.009–1.212	0.031[a]
DM	5.414	2.128–13.769	<0.001[a]

CI, confidence interval; LLMB, Length of the left main stem bronchus; BMI, Body Mass Index; DM, diabetes mellitus.
[a] $P < 0.05$.

Table 5 Multivariate Logistic regression analysis for the factors that predict left main bronchus length less than 4 cm.

Multivariate mode	Odds Ratio	95% CI	*p*
Sex	0.148	0.028–0.794	0.026[a]
Height	0.915	0.845–0.992	0.030[a]

CI, confidence interval.
[a] $P < 0.05$.

In addition, multiple logistic regression analyses found that sex (OR = 0.148) and short stature (OR = 0.915) are predictors of short left main bronchus (Table 5).

Discussion

To prevent mechanical injury of the airway, anesthesiologists usually choose the DLT based on the diameter of the trachea or left main bronchus. However, in our study, we emphasized the importance of the length of the left main bronchus. Patients with short left bronchi who are intubated using common-sized left-sided DLTs had an independent risk of intraoperative desaturation.

Hypoxia incidence and risk factors during monopulmonary ventilation

Intraoperative desaturation is an undesirable complication of one-lung ventilation. The incidence of hypoxic events in our study was 9.2%, as defined by PaO_2 less than 69 mmHg or

SpO_2 less than 93%. This finding was compatible with another study that found an incidence of 4 - 10% since they defined hypoxis event by PaO_2 less than 70 mmHg or SpO_2 less than 90%.[15]

Several patient factors, like, morbid obesity, previous lobectomy in the contralateral lung, low preoperative PaO_2, high or normal Forced Expiratory Volume in 1 second (FEV1), perioperative left-sided ventilation, and the supine position, were considered significant risk factors for hypoxia.[16,17] In this study, we demonstrated that a BMI of more than 30 $kg.m^{-2}$ and perioperative left-sided ventilation are also risk factors. In addition, our statistics showed that diabetes mellitus and short left main bronchus are key hypoxia predictors.

According to a previous study, diabetic patients had basement membrane thickening induced by hyperglycemia that led to decreased diffusing capacity and restrictive lung pathology.[18,19] Then, the impaired pulmonary function resulted in poor alveolar gas exchange, and the ventilation or perfusion mismatch may explain why patients with diabetes mellitus are commonly affected by perioperative desaturation.

Next, we hypothesized that the mechanic airway obstruction caused by an endotracheal tube explains the increase in the possibility of inadequate oxygenation during the surgery. According to a cadaver study, the mean left bronchus lengths range from 3.8 to 4.6 cm, with an average length of 4.2 cm, which is similar to the average of 4.8 ± 0.5 cm obtained from our data.[20] In our study, for patients with a left main bronchus shorter than 4 cm, 32 Fr endotracheal tubes were considered the best fit because tubes of this size have a significantly shorter distance from the distal tip of the bronchus tube to the proximal edge of bronchus cuff than the 35 and 37 Fr left-sided tubes (Fig. 1).[21] Because of this difference, the 35 Fr and 37 Fr left-sided tubes, which are commonly used, have the disadvantage of being difficult to position with partial or total obstruction the bronchial cuff in the orifice of the left upper lobe, especially in patients with short left main bronchi.

Traditional size selection by diameter of the trachea or left main bronchus

Lacking clear objective guidelines, anesthesiologists usually choose the appropriate size of DLT based on the diameter of the trachea or left main bronchus. An oversized DLT can easily cause airway damage during advancing, whereas an undersized DLT can lead to bronchus injury from over inflation of the bronchial cuff.[22] The diameter of the trachea or left main bronchus can be measured directly through chest CT or Chest X-Ray (CXR). Studies have indicated that when a chest CT image is unavailable and the left main bronchus is not identified using CXR, the width of the main bronchus can be indirectly evaluated according to the diameter of the trachea or the height of the patient.[23] Through CT-based measurements of the diameter of the trachea and left bronchus, we can choose a suitable DLT according to the size of its outside diameter.

Size selection by the length of the left main bronchus

If patients with short left main bronchi are intubated with large-sized double lumen tubes, obstruction of the left upper lobe bronchial orifice could easily occur at the tip of the bronchus lumen. Four lengths (28 Fr, 32 Fr, 35 Fr, and 37 Fr) of the bronchial cuff and tip were tested and revealed that the patients in the 28 Fr and 32 Fr groups were substantially shorter than the patients in the 35 Fr and 37 Fr groups.[11] Lee et al. found that patients of short stature have a greater chance of having a short left main bronchus and should be intubated with a DLT smaller than 35 Fr to prevent desaturation.[13] Further, we directly found that patients with left main bronchi <4 cm who were intubated with a double-lumen tube larger than 32 Fr may easily experience desaturation during monopulmonary ventilation.

Factors affecting left main bronchus lengths of less than 4 cm

The incidence of short left main bronchus was 5.8% in our study. Being female and having a short stature are independently correlated with a left main bronchus length of <4 cm. This result is consistent with the article from Lee et al., which claimed that sex and height may have a collateral relationship with the patient's LLMB. To prevent desaturation, we suggested that LLMB measurements by chest CT imaging should be performed preoperatively, especially in females with short stature. If the LLMB was less than 4 cm, then the patient was recommended to be intubated with a DLT smaller than 35 Fr during thoracic surgery.

Limitations

Patients using other lung isolation devices preoperatively, such as a right-sided DLT or bronchial blocker, were not included in this paper. Thus, the short length of the left main bronchus in relation to the desaturation from other devices requires further data to be discussed.

Conclusion

Hypoxemia during monopulmonary ventilation could jeopardize the surgical procedure and patient safety. Therefore, the prediction, prevention or treatment of risk factors of hypoxemia during monopulmonary ventilation is important.

The length of the left main bronchus is vital for successful monopulmonary ventilation. To choose an appropriate DLT, both the diameter of the trachea and the left main bronchus along with the length of the left main bronchus are essential factors to ensure that the patient's airway is kept intact and oxygenated. To achieve successful ventilation, a 32 Fr DLT should be chosen for lung isolation in patients with a left main bronchus length <4 cm.

Conflicts of interest

The authors declare no conflicts of interest.

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