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FACTORS AFFECTING THE OCCURRENCE OF HYPOXEMIA DURING ONE-LUNG VENTILATION

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ABSTRACT

Introduction: Hypoxemia that occurs during one-lung ventilation (OLV) in thoracic surgery increases the risk of perioperative and postoperative complications, affecting mortality and morbidity. The aim of this study is to analyze the occurrence of perioperative hypoxemia ($SpO_2 \leq 90\%$) and to determine whether preoperative spirometry results and arterial blood gas analyses influence its development.

Materials and Methods: In this retrospective study, we evaluated 80 elective patients who underwent lung resection (segmentectomy, lobectomy, bilobectomy, pneumonectomy) due to malignancy under one-lung ventilation. The patients had ASA I-III, EF >50%, FEV_1 >40%, and PaO_2 >60 mmHg. We administered anesthesia in accordance with a standard protocol. We excluded patients under the age of 18, those with pathological arrhythmias, metastatic changes in the contralateral lung, endocrine disorders, renal or hepatic dysfunction, coagulation disorders, or those who had previously undergone radiotherapy or chemotherapy. We evaluated demographic, clinical, and surgical data, with a special focus on the results of preoperative spirometry and blood gas analyses and their correlation with the occurrence of desaturation (SpO2 ≤ 90%), which was measured every 10 minutes from the start of OLV.

Results: Desaturation had the highest percentage of occurrences 20 minutes after the initiation of OLV (27.5%). It was more common in patients with right-sided surgery, patients with $FEV_1\% \geq 70$ and FVC%≥70, and in overweight patients (BMI ≥ 25).

Conclusion: The risk factors for hypoxemia during one-lung ventilation in thoracic surgery include right-sided surgery, which poses higher anatomical challenges for oxygenation, and pulmonary function values such as FEV and FVC at or above 70 percent. Additionally, a higher body mass index (BMI) is a key predictor of oxygen saturation drops. These factors highlight the need for careful preoperative assessment to manage oxygenation effectively.

Keywords: blood gas analyses, hypoxemia, one-lung ventilation, spirometry

INTRODUCTION

Anesthesia in thoracic surgery is inconceivable without the use of one-lung ventilation (OLV), which facilitates optimal surgical exposure. The insertion of a double-lumen endotracheal tube or a bronchial blocker typically achieves OLV, allowing ventilation of only one lung while both lungs remain perfused. This creates a mismatch in the ventilation/perfusion (V/Q) ratio, leading to shunting and, consequently, impaired oxygenation [1]. A drop in the arterial oxygen saturation (SpO_2), measured by pulse oximetry, below 90% in patients who are ventilated with an inspired oxygen fraction greater than 0.5 can happen during OLV. This is called perioperative hypoxemia [2].

The occurrence of hypoxemia during OLV is influenced by a variety of factors, including the proper placement of the double-lumen tube, the use of a bronchoscope, the patient's underlying medical condition, body positioning during surgery, the type of surgical procedure, ventilator settings, and the experience of the anesthesiologist in thoracic surgery [3,4].

During general anesthesia, it is not possible to precisely determine the degree of acceptable hypoxia for individual patients [5-7]. Patients with a functionally intact cardiopulmonary system generally exhibit relatively high tolerance to hypoxemia. However, a significant proportion of thoracic surgery patients are heavy smokers with chronic heart failure, coronary or cerebrovascular disease, or anemia. In such patients, the reduction in the oxygen delivery caused by hypoxemia may result in myocardial depression, atrial fibrillation, renal insufficiency, cognitive dysfunction, and pulmonary hypertension, all of which can significantly compromise postoperative outcomes [8]. This highlights the importance of preoperative risk assessment to identify patients who may be at increased risk of developing perioperative hypoxemia [9].

Spirometry and preoperative arterial blood gas analysis are fundamental tests that assess the functional capacity of the lungs. A number of studies have investigated which factors are critical in predicting perioperative hypoxemia during OLV. However, there is a degree of inconsistency across studies regarding the predictive value of spirometric parameters and blood gas measurements, including forced expiratory volume in one second (FEV_1), forced vital capacity (FVC), their ratio (FEV_1/FVC), partial pressure of oxygen in arterial blood (PaO_2), and partial pressure of carbon dioxide in arterial blood ($PaCO_2$) in relation to perioperative hypoxemia. Nevertheless, it is generally accepted that preoperative pulmonary function tests, including spirometry and arterial blood gas analysis, are essential for patients undergoing lung resection [10-12].

The objective of this study is to analyze the occurrence of perioperative hypoxemia (SpO_2 $\leq$ 90%) and to determine whether preoperative spirometry results and arterial blood gas analysis influence its development.

MATERIALS AND METHODS

This retrospective/prospective observational study was conducted at the Clinic for Thoracic and Vascular Surgery in Skopje, over a period of one year (2022-2023).

The study included 80 elective patients who underwent standard lung resection procedures for the treatment of lung malignancies (segmentectomy, lobectomy, bilobectomy, and pneumonectomy) under general anesthesia with a double-lumen tube (DLT). Inclusion criteria consisted of patients classified as ASA I-III according to the American Society of Anesthesiologists (ASA) classification, patients with an ejection fraction (EF) > 50%, hemoglobin levels greater than 90 g/L, preoperative PaO_2>60 mmHg, and those without prior cycles of chemotherapy or radiotherapy. Exclusion criteria included patients under 18 years of age, those with preoperative FEV_1< 40%, patients with pathological arrhythmias, metastatic changes in the contralateral lung, or endocrinopathies. After receiving approval from the clinical ethics council, the study was carried out, and each subject gave their informed consent.

The anesthetic protocol was standardized for all patients. A comprehensive preoperative evaluation was performed, including patient history, clinical examination, with particular focus on cardiovascular and respiratory systems. Body weight, height, non-invasive blood pressure (NIBP), and calculation of the ideal body mass index (BMI) were measured for all patients. Additionally, a 12-lead electrocardiogram (ECG), preoperative echocardiography, standard laboratory tests, spirometry, arterial blood gas analysis, hemostasis tests, and computed tomography (CT) of the lungs were performed. Following the evaluation, the patients were prepared for surgery according to the standard preoperative protocols, which included fasting and premedication with 5 mg of diazepam tablets.

Intraoperatively, all patients were monitored using standard parameters, including ECG, pulse oximetry, NIBP, and an arterial line. The postoperative analgesia was managed through the placement of an epidural catheter. The induction of anesthesia followed a standardized protocol. After pre-oxygenation with 100% oxygen, general anesthesia was induced with 2 mg of midazolam, 3 µg/kg of fentanyl, and 1-2 mg/kg of propofol. For intubation and placement of the double-lumen tube (DLT), rocuronium bromide (0.6 mg/kg) was used as a muscle relaxant. After mask ventilation with 100% oxygen, the double-lumen tube was inserted. For patients undergoing left-sided lung surgery, a right-sided double-lumen tube was placed, and for those undergoing right-sided lung surgery, a left-sided double-lumen tube was used. The proper positioning of the DLT was confirmed by auscultation and bronchoscopy.

During the procedure, the anesthesia was maintained with a continuous infusion of propofol (6-7 mg/kg/h), intermittent fentanyl (2 µg/kg), and rocuronium (0.3 mg/kg/h) for muscle relaxation. Crystalloid solutions were infused at a rate of 8 ml/kg/h throughout the procedure. Ventilation was controlled using a pressure-controlled ventilation mode with volume guarantee (PCV-VG). During the ventilation of both lungs, the tidal volume was set at 7 ml/kg of ideal body weight, with PEEP set to 5 cmH_2O. The gas mixture consisted of 50% of oxygen and 50% of air (FiO_2 0.5), with an inspiratory-to-expiratory ratio of 1:2. The respiratory rate was adjusted according to $PaCO_2$ levels, maintaining a target range between 35-45 mmHg. During one-lung ventilation, the tidal volume was reduced to 5 ml/kg of predicted body weight (PBW), while the other ventilatory parameters remained unchanged.

In the perioperative period, all patients were continuously monitored using electrocardiography (ECG), heart rate (HR), non-invasive blood pressure (NIBP), mean arterial pressure (MAP), peripheral oxygen saturation (SpO_2) via pulse oximetry (SAT%), capnography (end-tidal carbon dioxide, $ETCO_2$), and the fraction of inspired oxygen (FiO_2).

Postoperatively, all patients received analgesia through an epidural catheter, complemented by paracetamol for pain management.

During the perioperative period, we closely monitored oxygen saturation (SAT%) every 10 minutes throughout the one-lung ventilation (OLV) procedure. Hypoxemia was defined as a reduction in peripheral oxygen saturation (SpO_2) to less than 90%, as measured by pulse oximetry, with a FiO_2 of 0.5.

In this study, we performed an analysis and comparison of the spirometry parameters, including forced expiratory volume in 1 second (FEV_1%), forced vital capacity (FVC%), and the FEV_1/FVC ratio, expressed as percentages. Additionally, we evaluated the partial pressure of oxygen in arterial blood (PaO_2) in relation to changes in oxygen saturation levels.

To further assess the factors influencing oxygen desaturation, we conducted comparative analyses of several independent variables, including: gender, body mass index (BMI), type of surgery (segmentectomy, lobectomy, bilobectomy, pneumonectomy), ASA classification, surgical side (left or right lung), and smoking history.

RESULTS

A total of 80 patients were included in the study, of which 81.25% were male and 18.75% were female, with an average age of over 62 years. The majority of the patients (56.25%) had a body mass index (BMI) of 25 or higher, categorizing them as overweight or obese. Smoking history was present in 71.25% of the patients. A larger proportion of the patients underwent right thoracotomy (58.75%), and 90% of the patients were classified as ASA ≥ II. The most common surgical procedure performed was lobectomy, which was conducted in 71.25% of the cases (Table 1).

Table 1. *Patient Characteristics*

Variable	Number	Percentage (%)
Gender		
Male (m)	65	81.25
Female (f)	15	18.75
Type of Surgery		
Lobectomy	57	71.25
Bilobectomy	7	8.75
Pneumonectomy	11	13.75
Segmentectomy	5	6.25
Age		
≤ 60 years	30	37.5
> 60 years	50	62.5
BMI		
< 25.0	35	43.75
≥ 25.0	45	56.25
ASA Classification		
< II	8	10.0
≥ II	72	90.0
Smoking Status		
Yes	57	71.25
No	23	28.75
Side of Surgery		
Right	47	58.75
Left	33	41.25

Table 2. *The average values of hematocrit and hemoglobin are within the reference range*

Variable	N	Mean	Median (Me)	Minimum	Maximum	Lower Quartile	Upper Quartile	Std. Dev.
Hematocrit	80	0.40	0.40	0.28	0.50	0.36	0.43	0.04491
Hemoglobin	80	132.3	133.0	89.0	174.0	120.5	145.0	17.35174

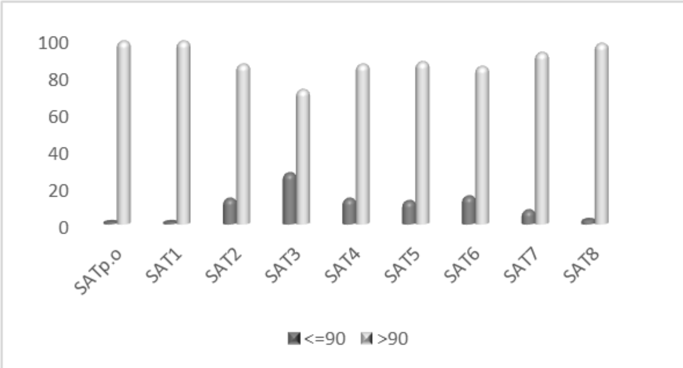

Figure 1. *Representation of the prevalence of SAT ≤ 90% and > 90% at 10-minute intervals from the start of one-lung ventilation (OLV).*

The percentage of values for SAT ≤ 90% is highest 20 minutes after the initiation of one-lung ventilation (OLV) (SAT3), with 27.5%, and gradually decreases to 2.5% at SAT8 (Figure 1).

We statistically analyzed the preoperative spirometry results, including FEV1%, FVC%, and the FEV1%/FVC% ratio.

A forced expiratory volume in the first second (FEV1%) greater than or equal to 70 is observed in 77.5% of patients, a forced vital capacity (FVC%) greater than or equal to 70 is found in 80.0% of patients, and the FEV1%/FVC% ratio is greater than or equal to 60 in all patients (Table 3).

Table 3. Prevalence of FEV1%, FVC%, and FEV1%/FVC%

Variable	Number	%
FEV1%		
< 70	18	22.5%
≥ 70	62	77.5%
FVC%		
< 70	16	20.0%
≥ 70	64	80.0%
FEV1%/FVC%		
≥ 60	80	100.0%

This table presents the distribution of FEV1%, FVC%, and FEV1%/FVC% ratios in the study population.

We also performed a statistical analysis of the arterial blood gas values (PaO_2 and $PaCO_2$). The partial pressure of oxygen in arterial blood (PaO_2) in the patients was greater than or equal to 8 kPa (Table 4).

This table shows the results of the preoperative arterial blood gas analysis, including the partial pressures of oxygen (PaO_2) and carbon dioxide ($PaCO_2$) in the study cohort. A significant moderate negative indirect correlation was observed between the values of the SAT3 variable and BMI (r = -0.294, p = 0.004). A significant moderate negative indirect correlation was also observed between the values of the SAT3 variable and FEV% (r = -0.235, p = 0.018). A significant moderate negative indirect correlation was found between the values of the SAT3 variable and FVC% (r = -0.288, p = 0.005). An insignificant moderate weak positive direct correlation was noted between the values of the SAT3 variable and PaO_2 (r = 0.117, p = 0.150), indicating that as PaO_2 values decrease, SAT3 values also decrease in parallel. An insignificant greater decrease in saturation was registered during

Table 4. *Preoperative Arterial Blood Gas Analysis: PaO_2 and $PaCO_2$*

Variable	N	Mean	Median (Me)	Minimum	Maximum	Lower Quartile	Upper Quartile	Std. Dev.
PaO_2	80	10.35	10.14	8.00	21.67	9.205	10.91	1.81
$PaCO_2$	80	4.78	4.71	3.45	6.34	4.36	5.09	0.53

right-sided surgery compared to left-sided surgery, with SAT% values being lower on the right side than on the left. The remaining correlations were found to be insignificant (Table 5).

Table 5. *Correlation of SAT3 with the examined variables*

Variable	SAT3	p-value
SAT3	1.000	.
Gender	-0.194	0.042
Age	-0.054	0.317
BMI	-0.294	0.004
Type of Surgery	-0.013	0.456
Side of Surgery	0.112	0.161
ASA Classification	-0.058	0.304
FEV1%	-0.235	0.018
FVC%	-0.288	0.005
FEV1/FVC	0.049	0.333
PaO2	0.117	0.150
PaCO2	0.133	0.120
Complications	-0.087	0.221
Length of Stay (LOS)	0.114	0.156
Smoking	0.106	0.175
Time to Collapse	0.210	0.031
DM (Diabetes Mellitus)	-0.042	0.716

With the analysis of individual variables, it was concluded that only BMI has a significant influence, i.e., it is a significant predictor of SAT3 (Table 6).

DISCUSSION

This study, conducted with 80 participants, demonstrated that the highest percentage of the patients (28.75%) exhibited desaturation below or equal to 90% ($SpO_2 \leq 90\%$) 20 minutes after the initiation of one-lung ventilation (OLV), with saturation levels increasing after 30 minutes. This can be explained by hypoxic pulmonary vasoconstriction (HPV), which peaks within 20-30 minutes of lung collapse, thereby reducing the size of the intrapulmonary shunt and subsequently alleviating hypoxemia during OLV [13]. The literature reports similar findings regarding the time of onset of desaturation during OLV; however, the percentage of patients experiencing desaturation varies significantly across studies. This discrepancy can be attributed to differences in methodology and definitions of desaturation.

In the study by Yao et al., the incidence of desaturation during OLV was reported to be 9.2%, with desaturation defined as a drop in $SpO_2<93\%$ while ventilating with $FiO_2 = 1.0$. This contrasts with our study, where desaturation was defined as a decrease in $SpO_2<90\%$ during ventilation with $FiO_2 = 0.5$ [14]. A similar finding was reported by Karzai et al. and Schwarz-

Table 6. *Predictors of SAT3 Values*

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
	(Constant)	99.790	11.875		8.403	.000
	Gender	-1.220	1.184	-.113	-1.030	.307
	Age	-.119	.070	-.230	-1.710	.092
	BMI	-.371	.125	-.395	-2.973	.004
	Surgery	.350	.976	.045	.358	.721
	Side	1.235	.967	.144	1.278	.206
	ASA	1.172	.920	.172	1.273	.207
	FEV%	.001	.108	.006	.012	.990
	FVC	-.057	.099	-.249	-.575	.567
	FEV/FVC	.001	.088	.003	.010	.992
	PaO2	.037	.271	.016	.137	.891
	PaCO2	1.558	.950	.194	1.640	.106

kopf et al., where the incidence of desaturation ranged from 4% to 10%. However, in their study, hypoxemia was defined as PaO_2<70 mmHg or SpO_2<90%, whereas the previously mentioned study defined hypoxemia as SpO_2<93% [3]. This variation in the definition and assessment of desaturation underscores the importance of standardized criteria for evaluating oxygenation status during OLV in future studies.

One of the significant factors influencing the occurrence of desaturation during one lung ventilation (OLV) is the side of the surgical procedure [9,15,14]. It has been established that hypoxemia occurs less frequently during left thoracotomy, as the right lung is larger than the left [16]. Using regression analysis, Slinger et al. also confirmed that the side of surgery is a crucial predictive factor for hypoxemia during OLV [9]. Considering these findings, we can explain the higher incidence of desaturation observed in our study. Specifically, 58.75% (47 patients) underwent right-sided thoracotomy, and the side of surgery is therefore a risk factor for the occurrence of desaturation. However, we recorded a nonsignificant greater drop in oxygen saturation during right-sided surgery compared to left-sided surgery.

Preoperative functional test results also serve as markers that may help explain why certain patients experience desaturation [14,16]. Some studies indicate a paradoxical effect. The values obtained from spirometric tests, which are used to diagnose obstructive or restrictive ventilatory changes, show a negative correlation with oxygenation during OLV. In other words, the more pronounced the obstruction, the lower the likelihood of hypoxemia occurring during VATS.

Slinger et al. further confirmed that a lower forced expiratory volume in one second (FEV1) is associated with better oxygenation during OLV [9]. One possible explanation for this paradoxical relationship is that air trapping in the ventilated lung may generate auto-positive end-expiratory pressure (auto-PEEP) during OLV, thereby reducing the likelihood of atelectasis formation and improving oxygenation. Additionally, air trapped in the non-ventilated lung has a tendency to delay the onset of desaturation, and consequently, the onset of hypoxemia [17].

However, other studies have not found a relationship between the degree of auto-PEEP and oxygenation during one lung ventilation (OLV) [18]. Guenoun T. et al. also did not find a significant association in their study between the preoperative degree of bronchial obstruction, as assessed by functional tests (forced expiratory volume in 1 second, FEV1), and oxygenation during OLV [16].

Similar to the study by Slinger et al., our study found a significant moderate negative indirect correlation between the values of SAT% and FEV1% ($r = -0.235$, $p= 0.018$), as well as between SAT% and FVC% ($r = -0.288$, $p=0.005$), indicating an inverse correlation between FEV1 and SAT% [9].

Regarding the gas analyses, the low values of the partial pressure of oxygen in arterial blood (PaO2) can serve as reliable indicators of the abnormal pulmonary function and may predict the onset of hypoxemia during OLV. Slinger et al. demonstrated a strong positive correlation between the PaO2 level during spontaneous ventilation and particularly during ventilation of both lungs with PaO2 during OLV [9]. In our study, we analyzed the correlation between the preoperative PaO2 values and the subsequent drop in saturation below 90%. A non-significant moderate weak positive direct correlation was observed between SAT% and PaO2 ($r = 0.117$, $p =0.150$), suggesting a parallel decrease in both PaO2 and SAT% values.

In Hurford's study, neither preoperative arterial blood gas analyses, pulmonary function tests, nor lung volumes showed a correlation with oxygenation during VATS. However, it should be noted that only 30 patients were included in that study [19].

The implications of obesity on pulmonary physiology are well-established [20]. Obesity increases the elastic resistance of the chest wall and reduces the respiratory system compliance [21,22]. Most lung capacities are reduced, primarily functional residual capacity (FRC). According to the World Health Organization (WHO) classification, our participants were divided into two groups based on BMI: BMI ≥ 25 (overweight/obese) and BMI < 25 (normal weight) (23). We found a significant moderate negative indirect correlation between SAT% values and BMI ($r = -0.294$, $p = 0.004$). Further analysis of individual variables revealed that BMI is the only significant factor and represents a significant predictor for desaturation. Desaturation during OLV can lead to long-term consequences for patients and can contribute to numerous perioperative and postoperative complications. This underscores the importance of predicting, and therefore preventing, perioperative hypoxemia.

CONCLUSION

Patients undergoing right-sided thoracic surgery face a greater risk of hypoxemia, likely due to anatomical and physiological differences between the lungs. Preoperative lung function tests, particularly FEV_1 and FVC values at or above 70 percent, also correlate with increased hypoxemia risk during surgery, indicating that even patients with good baseline function may experience oxygenation challenges. Furthermore, a higher body mass index has been associated with poorer oxygen saturation during one-lung ventilation, highlighting the significance of comprehensive preoperative evaluations in efficiently managing possible oxygenation challenges.

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Резиме

ФАКТОРИ ШТО ВЛИЈААТ ВРЗ ПОЈАВАТА НА ДЕСАТУРАЦИЈА ЗА ВРЕМЕ НА ВЕНТИЛАЦИЈА НА ЕДНО БЕЛОДРОБНО КРИЛО

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Вовед: Хипоксемијата што се јавува при вентилација на едно белодробно крило (ВЕБК) во торакалната хирургија го зголемува ризикот од периоперативни и од постоперативни компликации, што влијае на морталитетот и на морбидитетот.

Цел: Целта на оваа студија е да се анализира појавата на периоперативна хипоксемија (SAT ≤ 90 %) и да се утврди дали резултатите од предоперативната спирометрија и гасните анализи од артериската крв влијаат врз неа.

Материјал и методи: Во оваа ретро-проспективна студија евалуиравме елективни 80 пациенти, кај кои со вентилација на едното белодробно крило се изведе ресекција на белиот дроб поради малигном (сегментектомија, лобектомија, билобектомија, пулмектомија). Пациентите имаа ASA I-III, EF > 50 %, FEV1>40%, PaO_2 > 60 mmHg. Анестезијата беше по стандарден протокол. Во студијата не се вклучија пациенти под 18 години, пациенти со патолошки аритмии, метастатски промени во контралатералното белодробно крило, со ендокрини заболувања, пациенти со нарушување на функцијата на бубрезите, на црниот дроб, на ендокриниот систем и на коагулацијата, и пациенти што претходно примиле радио- или хемотерапија. Кај сите пациенти ги евалуиравме демографските, клиничките и хируршките податоци, со посебна анализа на резултатите од предоперативната спирометрија и гасните анализи, и нивната корелација со појавата на десатурација (SAT ≤ 90 %), која ја одредувавме секои 10 минути последователно од почетокот на ВЕБК.

Резултати: Десатурацијата има најголема процентуална застапеност 20 минути по почетокот на ВЕБК (28,75 %). Почесто се јавува кај пациенти со деснострана операција, кај пациенти со вредности на FEV1 % ≥ 70 и FVC % ≥ 70 и кај надхранети пациенти (БМИ ≥ 25).

Заклучок: Фактори што влијаат врз појавата на хипоксемијата при ВЕБК во торакалната хирургија се: деснострананата операција и вредностите на FEV1 и FVC еднакви или поголеми од 70 %. Дополнително, зголемениот БМИ е предиктор за пад на сатурацијата при ВЕБК во торакалната хирургија. Овие фактори ја истакнуваат потребата од внимателна предоперативна процена за ефикасно управување со оксигенацијата.

Клучни зборови: гасни анализи, хипоксемија, ВЕБК, спирометрија