# Hypoxia during one lung ventilation in thoracic surgery

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## ABSTRACT

Background. The technique of one lung ventilation (OLV) is used with the purpose of achieving isolation of the diseased lung being operated upon, using a double-lumen endobronchial tube. Thoracic surgical procedures which are performed in the lateral decubitus position, nowadays could not be imagined without OLV. In spite of advantages regarding surgical exposure, OLV is associated with serious respiratory impairment. Hypoxemia is considered to be the most important challenge during OLV. The goal of this study was to establish the magnitude of intrapulmonary shunt, as well as the immensity of hypoxia during general anesthesia with OLV.

Materials and Methods. In this prospective interventional clinical study thirty patients were enrolled who underwent elective thoracic surgery with a prolonged period of OLV. The patients received balanced general anesthesia with fentanyl/propofol/rocuronium. A double-lumen endobronchial tube was inserted in all patients, and mechanical ventilation with 50% oxygen in air was used during the entire study. Arterial blood gases were recorded in a lateral decubitus position with two-lung ventilation, at the beginning of OLV (OLV 0) and at 10 and 30 min. (OLV 10, OLV 30, respectively) after initiating OLV in all patients. Standard monitoring procedures were used. Arterial oxygenation (PaO2), arterial oxygen saturation (SaO2) and venous admixture percentage - intrapulmonary shunt (Qs/Qt %) were measured, as well as mean arterial pressure and heart rate during the same time intervals. For the purpose of this study, the quantitative value of Qs/Qt% was mathematically calculated using the blood gas analyser AVL Compact 3. A p value <0.05 was taken to be statistically significant.

Results. When OLV was instituted, arterial oxygenation decreased, whereas Qs/Qt% increased, about 10 min. after commencement, with improvement of oxygenation approximately half an hour afterwards. A statistically relevant difference (p<0.05) occurred in $PaO_2$, $SaO_2$ and Qs/Qt at the different time points.

Conclusion. Hypoxia during OLV, with an increase in Qs/Qt, usually occurs after 10 min. of its initiation. After 30 min, the values of the Qs/Qt ratio regularly return to normal levels.

*Key words: one-lung ventilation, thoracic surgery, venous admixture, intrapulmonary shunt*

## INTRODUCTION

In order to achieve collapse of the affected lung during thoracic surgical procedures, a technique of ventilation of one lung (OLV) was introduced by inserting a double lumen endobronchial tube. This allows isolation of the dependent lung from the affected, independent lung, which is on top, thus preventing contamination of the healthy lung. On the other hand, the collapse of the affected lung causes serious functional respiratory disorders that require special compensatory measures to avoid hypoxemia. It should be emphasized that maintaining optimum oxygenation is crucial for preventing cellular hypoxia. (1-3)

During OLV with the patient in the lateral decubitus position, there is a potential risk of significant intrapulmonary shunting of deoxygenated pulmonary arterial blood, which may result in hypoxemia. A consequence of the increase in pulmonary vascular resistance (PVR) in the independent (unventilated) lung, predominantly as a result of activated hypoxic pulmonary vasoconstriction (HPV), is a redistribution of blood flow in the ventilated dependent lung. Thus, an excessive drop of partial pressure of oxygen in arterial blood (PaO2) is prevented. (4-8)

Intrapulmonary shunt is the main cause of hypoxemia in OLV, although alveoli with low ventilation/perfusion coupling (Va/Qt) in the dependent lung contribute to that. In addition, the blood that goes into the upper lung cannot take oxygen, so it keeps the mixed venous composition, which is poorly oxygenated. It is mixed with oxygenated blood in the left atrium of the heart, creating the so-called venous admixture and reducing PaO2. Venous admixture and intrapulmonary shunt (Qs/Qt) are often used as synonyms. Venous mixture increases from values of approximately 10-15% in ventilation of the two lungs (TLV) to 30-40% in OLV. In most patients, $PaO_2$ can have values in the range of 9-16 kPa using a fraction of inspired oxygen ($FiO_2$) 50-100%.

Hypoxic pulmonary vasoconstriction (HPV) is a compensatory mechanism by which the pulmonary blood flow is diverted away from hypoxic/collapsed areas of the lung. This should improve oxygenation during OLV. Volatile anesthetics directly depress HPV, but they also amplify it by decreasing cardiac output (CO). Therefore, there is usually no change in the response to HPV when using volatile anesthetics during thoracotomy and OLV. Intravenous anesthetics, such as propofol, do not inhibit HPV and should improve arterial oxygenation in OLV. There is some evidence in support of this. (9-16)

The purpose of the study was to determine the magnitude of the intrapulmonary

shunt and hypoxia during general anesthesia and OLV in thoracic surgery.

## MATERIAL AND METHODS

This study was part of a larger prospective clinical trial designed to investigate the influence of thoracic epidural anesthesia on intrapulmonary shunt during OLV in thoracic surgery. It was conducted at the University clinic of anesthesia, reanimation and intensive therapy and the University clinic of thoracic-vascular surgery, University Clinical Centre in Skopje, with the collaboration from our colleagues from the Department of anesthesiology and perioperative intensive therapy from the University Medical Centre in Ljubljana. The study was performed in accordance with the Declaration of Helsinki and after receiving approval from the Ethics Committee of the Medical Faculty in Skopje. Each patient gave written informed consent before being included in the study.

The study included 30 patients undergoing elective lung surgery under general anesthesia with employment of OLV (thoracotomy with lung resection - pulmectomy, bi-lobectomy, lobectomy, segmentectomy) or video assisted thoracoscopy (VATS).

Inclusion criteria:
- Patients undergoing lung resection using thoracotomy (pulmectomy, bilobectomy, lobectomy, segmentectomy) or VATS
- Adult patients (18 years and more)
- ASA status 1 or 2
- Preoperative values of $SaO_2 > 90\%$

Exclusion criteria:
- Renal failure (creatinine > 114 umol / L)
- Hepatic dysfunction (AST > 40U/L, ALT > 40U/L)
- Documented coronary or vascular disease (EF < 50%)
- Pre-existing chronic respiratory disease in the non-operated lung
- FVC, FEV1 < 50%, or
- Patients requiring intraoperative $FiO_2$ > 0.5

Intravenous induction in general anesthesia was performed using midazolam (2-3 mg), fentanyl (3 µg/kg), propofol (2 mg/kg) and rocuronium bromide (0.6 mg/kg) to facilitate intubation with a double lumen endobronchial tube. Anesthesia was maintained with a continuous infusion of propofol (6-7 mg/kg/h), with the occasional additional boluses of fentanyl (2 µg/kg)

to maintain a systolic blood pressure in the range of 15 mmHg of post-induction value and rocuronium bromide (0.3 mg/kg/h), to achieve complete muscular relaxation. After clinical confirmation of the correct position of the double lumen tube in the patient placed in a supine, as well as in the lateral decubitus position, volume-controlled mechanical ventilation (VC) was implemented using an oxygen-air mixture = 50-50% ($FiO_2$= 0.5 for all patients) and tidal volume of 6 ml/kg, with respiratory rate determined so as to maintain the partial pressure of carbon dioxide in the arterial blood ($PaCO_2$) between 35 and 45 mmHg (4,5 - 6 kPa). Ventilated lung during OLV received PEEP of 5 cm $H_2O$. No CPAP was applied to non-ventilated lung for treatment of hypoxia during OLV. Also, no ligation of the pulmonary artery was done by the surgeon for the same reason.

After induction in general anesthesia, in all patients an arterial catheter was placed in the radial artery contra-lateral to the operated hemithorax, in order to extract arterial blood samples for acid base status (ABS), with arterial blood gas analysis and calculation of the value of intrapulmonary shunt.

During anesthesia we monitored heart rate (HR) via an ECG, invasive mean arterial pressure (MAP), respiratory rate (RR), oxygen saturation from pulse oxymetry - SAT%, fraction of inspired oxygen - $FiO_2$, ABS with arterial blood gas analysis.

Dynamics of measurements - In four phases, always with the patient in a lateral decubitus position: 1. T0 – during TLV; 2. T1 – after commencement of OLV; 3. T2 - 10 min. after commencement of OLV; 4. T3 - 30 min. after commencement of OLV. Blood samples for arterial blood gas analysis were drawn simultaneously from the arterial catheter and analyzed no later than 10 minutes afterwards, using the gas analyzer AVL Compact 3 Blood Gas Analyzer (AVL LIST GmbH Medizintechnik, Austria).

Parameters monitored in the four phases
1. Partial pressure of oxygen in arterial blood - $PaO_2$;
2. Oxygen saturation of arterial blood - $SaO_2$;
3. Value of the intrapulmonary shunt - Qs/Qt.

Intrapulmonary shunt - Qs/Qt% can be calculated using Fick's formula for venous mixture:

$$Qs/Qt\% = (Cc'O_2 - CaO_2) / (Cc'O_2 - CvO_2) \times 100$$

$$Cc'O_2 = (Hb \times 1.39) \times SaO_2 (PaO_2 \times 0.0031)$$
$$C (a \text{ or } v) O_2 = (1.39 \times Hb \times SaO_2) (0.0031 \times PO_2),$$

($PO_2$ indicates either $PaO_2$ or $PvO_2$)

However, for the purpose of this study we have used the mathematically calculated value of Qs/Qt% directly from the readings of the printed blood gas analysis results, obtained using the gas analyzer AVL Compact 3 Blood gas.

This analyzer, based on measured values (pH, $pCO_2$, $PO_2$) and input values (patient temperature, total hemoglobin, hemoglobin type, P50 adult, P50fetal, respiratory quotient, $FiO_2$), performs mathematical calculations of several parameters (actual bicarbonate, base excess, base excess at actual oxygen saturation, total $CO_2$, standard bicarbonate, standard pH, hydrogen ion concentration, functional oxygen saturation, oxygen content, alveolar to arterial oxygen partial pressure difference, standardized ionized calcium, $PO_2$ at patient temperature, $PCO_2$ at patient temperature, pH at patient temperature, intrapulmonary shunt).

Relative Shunt volume - The value Qs/Qt is the fraction of venous blood that remains un-oxygenated after traveling from the right side of the heart to the left side of the heart. This fraction includes the effects of true shunts (i.e., anatomic shunts and true capillary shunts) along with the effects of a ventilation-perfusion mismatch.

$$Qs/Qt = (ctO_2c – ctO_2a) / (ctO_2c – ctO_2\tilde{v})$$

with

$$ctO_2a – ctO_2 \tilde{v} \approx 5.15 \text{ ml/dl}$$
$$ctO_2c \approx ctO_2A$$

**Calculation of $ctO_2A$:**

$$ctO_2A = 1.39ctHbSaO_2 + 0.00314PaO_2 \text{ ml/dl}$$

**Calculation of $ctO_2a$:**

$$SO_2 = cO_2Hb / (cO_2Hb + cHHb) \times 100$$
(Appendix 12-22, equation 13)

$$CtO_2 = O2ct + 0.00314 \times PO_2$$
(with co-oximetry data)

or

$$CtO_2 = 1.39 \times cHb \times SO_2 + 0.00314 \times PO_2$$
(no co-oximetry data)
(Appendix 12-23, equation 15)

**Calculation of $c_{tO2}\tilde{v}$:**

With co-oximetry data: $c_{tO2}a = (c_{tHb}a / c_{tHb}\tilde{v})$ $c_{tO2}\tilde{v} + 0.00314$ $P\tilde{v}O_2$ ml/dl

Without co-oximetry data and with measured mixed venous $PO_2$-values, the equations (13,15) are used for the calculation of $c_{tO2}$ $\tilde{v}$ -value.

Without co-oximetry data and without measured mixed venous $PO_2$-values, the equation (15) is used for the calculation of $c_{tO2}$ $\tilde{v}$ -value

The above described relations are only available for a body-temperature of 37 °C. If the patient's temperature is other than 37 °C, the numerical results are senseless and therefore are not printed. (17)

## Estimates of Qs/Qt

Approximation by the clinical shunt equation to Qs/Qt is provided by estimating the normal arterial to venous oxygen content difference.

Whichever method is used to estimate the intrapulmonary shunt, it should be noted that the value of estimating the shunt is in its ability to help identify changes in lung dysfunction. A change in intrapulmonary shunt can indicate an improvement in the patient's condition if the shunt is decreasing. If the shunt is, however, increasing, the clinical condition may be deteriorating. The use of intrapulmonary shunt estimates, allows the clinician to more routinely analyze changes in the patient's pulmonary status. Without estimating the intrapulmonary shunt, the clinician is limited in understanding how much of a discrepancy exists between how well the lungs are presently oxygenating the blood versus how well they should be oxygenating the blood. This understanding is important based on the levels of clinical support being given, that is increased $FiO_2$, PEEP and mechanical ventilation. In addition, use of shunt estimates helps the clinician avoid simply looking at the $PaO_2$ level. The shunt estimates encourage at least simultaneous analysis of $FiO_2$ and $PaO_2$. It is important to remember that measurement of intrapulmonary shunt does not identify which condition exists. It only reveals the extent of the pulmonary dysfunction induced by the clinical condition. As such, the intrapulmonary shunt is not a diagnostic tool but is used in the assessment of changes in lung function. (18)

## The 'rationale' behind Qs/Qt calculation

Clinical application of the shunt equation is limited by the requirement for a mixed venous blood sample. Two methods have been used to estimate $CvO_2$ without the need for a pulmonary artery catheter. A vena caval blood sample can be substituted with fair accuracy, but it still requires the use of a central line. Alternatively, an estimated shunt can be calculated using an assumed arterial-venous oxygen content difference (C, a v)$O_2$). Although it can vary widely with critical illness, this technique has been updated and used clinically.

Seear et al. calculated the intrapulmonary shunt using a non-invasive technique and compared it to an invasive "gold standard" in an animal model of acute lung injury. Although the correlation coefficient between the two measurements was 0.95, the scatter of results demonstrated by the Bland and Altman plot shows that the non-invasive prediction can only be viewed as an approximation of the true value. Their results are comparable with other non-invasive techniques for estimating Qs/Qt. Calculations based on substituting a vena caval blood sample generated a correlation coefficient of 0.974 which compares well with their coefficient of 0.95. There is a limit to the approximations that any mathematical equation will tolerate. The various attempts to estimate Qs/Qt without the need for a pulmonary arterial blood sample are no exception. Small improvements in accuracy are possible by substituting measured values for some of the assumed variables but the final result is still only a prediction. The assumptions underlying their mathematical model are based on extensive experience with critically ill children, but clearly cannot be expected to sum up every single patient. However, the small improvement in accuracy would hardly justify the extra work. The ongoing debate concerning the value of pulmonary artery catheters, reflects the trend towards non-invasive monitoring. A balance has to be found between the information derived from invasive catheters and the potential risk of side effects. At a time when non-invasive techniques are increasing in sophistication, it is probable that the necessity to derive Q~ - by whatever means – will decrease, making it unlikely that iso-shunt lines will have much clinical value. However, a detailed understanding of cardiopulmonary physiology will always be essential. This study has shown that their predictive equation provides a realistic model that gives a useful tool for teaching the physiology of oxygen transport. (19)

## Statistical Analysis

Databases were created using specific computer programs for this purpose. Their processing was performed using standard descriptive and analytical bivariant and multi-variant methods. Attribute statistical series were analysed by determining the ratio of relations, proportions, rates and determining the statistical significance among the detected differences. The numerical series were analysed with measures of central tendency and measures of dispersion of data. Statistical significance of differences between attributive series were tested using the Student t-test. The likelihood of association between the frequency distributions of the two attribute variables was assessed by x2-test. Statistical significance of differences was analyzed with ANOVA test, which was further confirmed by the post hoc HSD (honest significant difference) test. CI (confidence interval) was set to $p<0.05$. Results were displayed in tables and graphics.

## RESULTS

The study results are presented in tables (1-10) and figures (1-5).

Among patients in the study, 76.66% males and 23.3% females were registered. The difference between sexes is statistically significant for $p = 0.003$ (table 1). The average age of patients was 49.96 ± 16.6 years, a minimum of 17 and maximum of 74 years (table 2). The average weight of patients was 75.4 ± 1.0 kg, with minimum of 53.7 kg and maximum of 105 kg (table 2). According to the American Society of Anesthesiologists Classification, ASA, 36.7% of patients were ASA 1 and 63.7% ASA 2, with a statistically insignificant difference of $p = 0.144$ (table 3).

The average HR (bpm) values show a rise during intraoperative monitoring from T0 to T3 (from 85.5 to 88.5), (table 4, figure 4). The differences in average HR values for different measurements according to ANOVA test are statistically insignificant for $p>0.05$. The average values of MAP (mmHg) illustrate an increase during intraoperative monitoring from T0 to T2, and then decrease in T3 (from 86.4 - 94.4 – 95.2 to 91.5 mmHg). The discrepancy of average values of MAP in different measurements, consistent with ANOVA test is statistically significant for $p=0.019$. From

the additionally performed post-hoc test for MAP (table 6-10), it is obvious that the difference is statistically relevant between T0 and T1 (0.01), as well as T0 and T2 (0,008), (tables 4- 6, figure 5).

The average values of $PaO_2$ (kPa) show a fall during the intraoperative monitoring (from 23.29 to 15.66 kPa) (table 7, figure 1). The dissimilarities in these average values during different measurements, consistent with ANOVA test, are statistically significant for p=0,000002. From the additionally performed post-hoc test for $PaO_2$ (table 8) it is obvious that the difference is statistically relevant between T0 and T2 (p=0.0001); T0 and T3 (p=0.0003); T1 and T2 (p=0.02).

The average values of $SaO_2$ (%) illustrate a decrease during intraoperative monitoring (from 99.1 to 95.3%) (table 7, figure 2). The dissimilarities in these average values during different measurements, consistent with ANOVA test, are statistically relevant for p=0.000008. From the additionally performed post-hoc test for $SaO_2$ (table 9), it is evident that the difference is statistically significant between T0 and T2 (p=0.0001); T0 and T3 (p=0.004); T1 and T2 (p=0.003). The acquired statistically significant differences for $PaO_2$ and $SaO_2$ during different intraoperative measurements show that sometime after initiation of OLV (after 10 min.) hypoxia develops, with a decrease in the values of $PaO_2$ and $SaO_2$.

The average values of Qs/Qt illustrate a dynamic trend during intraoperative monitoring. It begins with the value 1% in T0, increases to 8.03% in T2, and then it decreases in T3 to 3.9% (table 7, figure 3). The variations in these average values for different measurements, in accordance with ANOVA test, are statistically relevant for p=0.0007. With the additionally performed post-hoc test for Qs/Qt (table 10), it is evident that the difference is statistically significant between T0 and T2 (p=0.0005); as well as T1 and T2 (p=0.01). The obtained statistically significant differences for Qs/Qt during the four measurements demonstrate that some time after beginning of OLV (after 10 min.) hypoxia develops, with an increase in the value of the intrapulmonary shunt.

*Table 1. Distribution of patients by sex*

| Sex | number | % |
| --- | --- | --- |
| Male | 23 | 76,66 |
| Female | 7 | 23,33 |
| | | p value=0,003 |

*Table 2. Distribution of patients by age and weight*

| Age | average | ± Stan.Dev. |
| --- | --- | --- |
| | 49,96 | 16,62 |
| **Weight** | **average** | **± Stan.Dev.** |
| | 75,36 | 13,95 |

*Table 3. Distribution by ASA status*

| ASA | number | % |
| --- | --- | --- |
| ASA 1 | 11 | 36,66 |
| ASA 2 | 19 | 63,33 |
| | | p value = 0,144 |

*Table 4. Average values of MAP and HR during the four measurements*

| Parameters | average | ± St. Dev. |
| --- | --- | --- |
| HR T0, bpm | 85,56 | 12,53 |
| HR T1, bpm | 85,43 | 10,98 |
| HR T2, bpm | 88,03 | 12,86 |
| HR T3, bpm | 88,53 | 12,19 |
| MAP T0,mmHg | 86,43 | 11,41 |
| MAP T1,mmHg | 94,40 | 11,82 |
| MAP T2,mmHg | 95,23 | 13,56 |
| MAP T3,mmHg | 91,50 | 10,06 |

*Table 5. t-Test for MAP: Two-Sample Assuming Equal Variances*

| | MAP T0 vs. MAP T1 | | MAP T0 vs. MAP T2 | | MAP T0 vs. MAP T3 | | MAP T1 vs. MAP T2 | | MAP T1 vs. MAP T3 | | MAP T2 vs. MAP T3 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 86,43 | 94,4 | 86,43 | 95,23 | 86,43 | 91,5 | 94,4 | 95,23 | 94,4 | 91,5 | 95,23 | 91,5 |
| Variance | 130,25 | 139,90 | 130,25 | 184,11 | 130,25 | 101,36 | 139,90 | 184,11 | 139,90 | 101,36 | 184,11 | 101,36 |
| Observations | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Pooled Variance | 135,07 | | 157,18 | | 115,80 | | 162,009 | | 120,63 | | 142,73 | |
| Hypothesized Mean Difference | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| Df | 58 | | 58 | | 58 | | 58 | | 58 | | 58 | |
| t Stat | -2,65 | | -2,71 | | -1,82 | | -0,25 | | 1,02 | | 1,21 | |
| P(T<=t) one-tail | 0,005 | | 0,004 | | 0,036 | | 0,40 | | 0,15 | | 0,11 | |
| t Critical one-tail | 1,67 | | 1,67 | | 1,67 | | 1,67 | | 1,67 | | 1,67 | |
| P(T<=t) two-tail | 0,01* | | 0,008* | | 0,07 | | 0,80 | | 0,31 | | 0,23 | |
| t Critical two-tail | 2,001 | | 2,001 | | 2,001 | | 2,001 | | 2,001 | | 2,00 | |

*Table 6. Post hoc test for MAP, p value from two sample t-test*

| | MAP T0 | MAP T1 | MAP T2 | MAP T3 |
|---|---|---|---|---|
| MAP T0 | | 0,01* | 0,008* | 0,07 |
| MAP T1 | | | 0,80 | 0,31 |
| MAP T2 | | | | 0,23 |
| MAP T3 | | | | |

*Table 7. Average values of the parameters of intraoperative arterial blood gas status*

| Parameters | average | Stan.Dev. |
|---|---|---|
| PaO2 T0 | 23,29 | 7,97 |
| PaO2 T1 | 18,93 | 7,05 |
| PaO2 T2 | 13,78 | 5,84 |
| PaO2 T3 | 15,66 | 6,62 |
| SaO2 T0 | 99,06 | 0,81 |
| SaO2 T1 | 97,30 | 3,48 |
| SaO2 T2 | 93,52 | 6,03 |
| SaO2 T3 | 95,31 | 4,62 |
| Qs/Qt T0 | 1 | 0 |
| Qs/Qt T1 | 2,79 | 5,11 |
| Qs/Qt T2 | 8,03 | 10,59 |
| Qs/Qt T3 | 3,94 | 6,21 |

*Table 8. Post- hoc - Tukey honest significant difference (HSD) test for PaO2*

| PaO2 | T0 | T1 | T2 | T3 |
|---|---|---|---|---|
| T0 | | 0,07 | 0,0001 | 0,0003 |
| T1 | 0,07 | | 0,02 | 0,26 |
| T2 | 0,0001 | 0,02 | | 0,71 |
| T3 | 0,0003 | 0,26 | 0,71 | |

Table 9. Post- hoc - Tukey honest significant difference (HSD) test for SaO2

| SaO2 | T0 | T1 | T2 | T3 |
|------|------|------|--------|-------|
| T0 | | 0,37 | 0,0001 | 0,004 |
| T1 | 0,37 | | 0,003 | 0,25 |
| T2 | 0,0001 | 0,003 | | 0,35 |
| T3 | 0,004 | 0,25 | 0,35 | |

Table 10. Post- hoc - Tukey honest significant difference (HSD) test Qs/Qt

| Qs/Qt | T0 | T1 | T2 | T3 |
|-------|--------|------|--------|------|
| T0 | | 0,72 | 0,0005 | 0,32 |
| T1 | 0,72 | | 0,01 | 0,90 |
| T2 | 0,0005 | 0,01 | | 0,08 |
| T3 | 0,32 | 0,90 | 0,08 | |

## DISCUSSION

OLV creates an obligatory transpulmonary shunt through the collapsed lung. Passive (gravity and surgical manipulation) and active (HPV) mechanisms minimize the diversion of blood flow to the collapsed lung and prevent the excessive fall of $PaO_2$; however, the most significant diversion of blood flow to the dependent lung is caused by HPV. (20)

Hurford et al. in a study (21) tested the hypothesis that intraoperative hypoxemia during LV is likely to happened when there is a greater preoperative pulmonary blood flow in the operated lung. Their study examined 30 patients who underwent thoracic surgical procedures in the lateral decubitus position using OLV in whom a preoperative ventilation-perfusion scan was performed. The percentage of blood flow in the operated lung seen on preoperative perfusion scan correlated inversely with $PaO_2$ after 10 min. of the start of OLV (r =-.72). When the percentage of blood flow in the operated lung on the preoperative scan was greater than 45%, likelihood of hypoxemia ($PaO_2 < 75$ mm Hg) was greater. Because in these patients preoperative regional ventilation was equivalent to regional perfusion, the percentage of preoperative ventilation also correlated inversely with $PaO_2$ after 10 min. of the commencement of OLV (r =-.73). Preoperative arterial blood gas analysis, pulmonary function tests, nor lung volumes did not correlate with oxygenation during OLV. This contradicts the results of Slinger and colleagues. (22) In their study they found that an equation with three variables [$PaO_2$ during intraoperative two lung ventilation (TLV) in lateral decubitus position, side of operation and preoperative value of relationship forced expiratory volume in 1st second/vital capacity (FEV1/VC), can be used to predict (p =.73) PaO2 during OLV using application of continuous positive airway pressure (CPAP) to the unventilated lung. However, Katz and colleagues (23) agree with the findings of Hurford and associates (21) that routine preoperative gas analysis of arterial blood and pulmonary function tests do not accurately predict which patients are at risk of hypoxemia during OLV.

The results from our study confirm that preoperative blood gas analysis obtained from arterial blood, as well as FVC (forced vital capacity) and FEV1 cannot be taken as conclusive evidence that a particular patient will develop a greater or lesser degree of hypoxia during OLV.

Previous clinical studies have shown controversial results regarding oxygenation, shunt fraction and hemodynamic parameters during OLV. (24-27)

Van Keer et al. (24) studied 10 patients who underwent thoracotomy. Anesthesia was maintained with continuous intravenous infusion of propofol (10 mg/kg/h). During TLV and OLV no changes were observed in the CO, the shunt fraction and $PaO_2$. This could be due to methodological differences, since the measurements during OLV were started before the opening of the chest. Kellow et al. (25) studied patients undergoing thoracotomy and noticed a significant increase in cardiac index and shunt fraction during the change from TLV to OLV. However, the interpretation of the shunt fraction is limited because patients were ventilated with 50% nitrous oxide in oxygen and PaO2 was not assessed for. Steegers and co-workers (26) studied 14 patients who underwent a lobectomy in general anesthesia with continuous iv infusion of propofol (6-9 mg/kg/hr). The fraction of the shunt and $PaO_2$ did not differ in comparison of TLV/OLV. Their study did not include any basic data such as CO. Changes in these hemodynamic parameters would cause secondary changes in the pulmonary circulation. (25) Spies et al. (27) compared TIVA with propofol (10 mg/kg/hour) versus 1 MAC enflurane in patients who underwent thoracotomy. CO and intrapulmonary shunt significantly increased when changing from TLV to OLV, while $PaO_2$ decreased by definition.

Several studies, including that of Slinger and colleagues (28) showed that early hypoxemia occurred approximately 5-10 minutes after commencement of OLV and reached a maximum level after 15 minutes. This corresponds to the time it takes for absorbent gases (oxygen and nitrous oxide) to be completely absorbed by the closed cavities where blood flow is maintained. $PaO_2$ and Qs/Qt usually begin to return to the values that existed in TLV after about 30 minutes of commencement of OLV. This period is necessary to develop a compensatory mechanism of HPV that will divert blood flow away from the collapsed lung tissue. As a result, the shunt fraction will decrease.

Our results confirmed the findings of the recently mentioned studies, in that when changing from TLV to OLV in a patient placed in the lateral decubitus position during thoracotomy/thoracoscopy, there is a decline in arterial oxygenation and an increase in the fraction of intrapulmonal shunt. Namely, the average values of $PaO_2$ showed a decline during intraoperative monitoring (from 23.29 +/- 7.97 kPa at TLV, to 13.78 +/- 5.84 kPa after 10 min. of OLV, and a return to 15. 66 +/- 6.62 kPa after 30 min. of OLV); average values of $SaO_2$

showed a decrease during intraoperative monitoring (from 99.06 +/- 0.81% in TLV to 93.52 +/- 6.03% after 10 min. of OLV, with a return to 95.31 +/- 4.62% after 30 min. of OLV); and average values of Qs/Qt showed dynamic movement throughout intraoperative monitoring (starting with value <1% in T0, rising to 8.03 +/- 10.59% in T2, with a drop in this value to 3.94 +/- 6.21% in T3).

The hemodynamic measurements show that MAP, similar to the intrapulmonary shunt, significantly increased when changing from TLV to OLV (T0 to T1 and T2, and then decrease in T3, ie. average values - from 86.4 mmHg at TLV to 94.4 mmHg at beginning of OLV and 95.2 mmHg after 10 min of OLV, dropping again to 91.5 mmHg 30 min after commencement of OLV). These changes of invasive mean arterial pressure are similar to the alterations of the shunt during the four measurements in the study.

Statistically significant differences obtained for $PaO_2$, $SaO_2$ and Qs/Qt, showed that after a certain time from the commencement of OLV (10 min.), hypoxia develops with a decline in the values of $PaO_2$ and $SaO_2$, as well as an increase in the value of the intrapulmonary shunt, which is on the other hand followed also by a rise of mean arterial pressure. Repeated reduction in Qs/Qt in the fourth measurement (T3), suggests the development of HPV in this period and reduction of the shunt fraction 30 min. from the initiation of OLV in the lateral decubitus position during thoracic surgery.

Nonetheless, our study has some limitations. Namely, CO and $PvO_2$ (partial pressure of oxygen in mixed venous blood) which are important factors for assessment of the impact of HPV on oxygenation, were not measured. Instead, we have tried to make some analogy between hemodynamic changes in our patients with the alterations of oxygenation status by using the values of MAP obtained by invasive arterial pressure measurement.

## CONCLUSION

In patients undergoing OLV during general anesthesia, the development of hypoxia occurs with a decline in $PaO_2$ and increase in the value of intrapulmonary shunt after a certain period of time following commencement of OLV (10 min.). This is followed by a return of $PaO_2$ and Qs/Qt to values close to normal (30 min. of OLV) due to the development of compensatory mechanisms (HPV).

## ABBREVIATIONS:

1. LDP = lateral decubitus position
2. OLV = one lung ventilation
3. TLV = two lung ventilation
4. PEEP = positive end expiratory pressure
5. CPAP = continuous positive airway pressure
6. Va/Qt = ventilation/perfusion ratio
7. Qs/Qt% = intrapulmonary shunt
8. $PO_2$ = partial pressure of oxygen (a=in arterial blood, v=in mixed venous blood, A=in the alveoli)
9. $PCO_2$ = partial pressure of carbon dioxide (a=in arterial blood, v=in venous blood, A=in the alveoli)
10. FRC = functional residual capacity
11. $FiO_2$ = inspired oxygen fraction
12. PVR = pulmonary vascular resistance
13. HPV = hypoxic pulmonary vasoconstriction
14. TIVA = total intravenous anesthesia
15. MAC = minimal alveolar concentration
16. COPD = chronic obstructive pulmonary disease
17. ASA = „American Society of Anesthesiologists" (classification)
18. $SaO_2$ = oxygen saturation of arterial blood
19. AST = aspartate amino transferase
20. ALT = alanine amino transferase
21. EF = ejection fraction
22. CO = cardiac output
23. FEV1 = forced expiratory volume in 1st sec.
24. FVC = forced vital capacity
25. VC = volume controlled mechanical ventilation
26. PC = pressure controlled mechanical ventilation
27. HR = heart rate
28. ECG = electrocardiography
29. MAP = mean arterial pressure
30. RR = respiratory rate
31. SAT% = oxygen saturation from pulse oximetry
32. $Cc'O_2$ = oxygen content of pulmonary capillary blood
33. $CaO_2$ = oxygen content – ml O2/100 ml arterial blood
34. $CvO_2$ = oxygen content – ml O2/100 ml venous blood
35. Hb = hemoglobin
36. 1.39 = Hifner coefficient (1g Hb binds 1.39 ml O2 when totally saturated)
37. 0.0031 = coefficient of oxygen dissolution in plasma
38. VATS = video assisted thoracoscopic surgery
39. $ct_{O2}c$ = oxygen content at patient temperature in pulmonary capillary blood
40. $ct_{O2}a$ = oxygen content at patient temperature in arterial blood
41. $ct_{O2}\bar{v}$ = oxygen content at patient temperature in mixed venous blood
42. $ct_{O2}A$ = oxygen content at patient temperature in alveoli
43. pH = hydrogen ion activity
44. $PCO_2$ = partial pressure of carbon dioxide
45. $PO_2$ = partial pressure of oxygen
46. BP = actual barometric pressure
47. ctHb = hemoglobin oxygen capacity at $PCO_2$ = 40 mmHg
48. BE = base excess
49. BEecf = base excess of extra cellular fluid
50. BEact = base excess at actual oxygen saturation
51. BB = buffer base
52. $HCO_3$ = actual bicarbonate
53. $cHCO_3$ = standard bicarbonate at a $PCO_2$ = 40 mmHg
54. ctCO2 = PCO2 of 40 mmHg
55. pHst = standard pH value at a PCO2 of 40 mmHg
56. AaDO2 arterial-alveolar oxygen partial pressure difference
57. cH+ = hydrogen ion concentration
58. $SO_2$ = oxygen saturation
59. $ctO_2$ = oxygen content
60. relative shunt volume = measurement for the direct mixture venous blood in the oxygenated circulatory system
61. P50 value = the oxygen partial pressure at which the hemoglobin is half-saturated with oxygen (half-saturation tension)
62. tHb = total hemoglobin
63. $FiO_2$ = fraction of inspired oxygen
64. RQ = respiratory quotient
65. $ctCO_2$ = total CO2 in plasma
66. $ctO_2$ = oxygen content
67. $cO_2Hb$ = concentration of oxyhemoglobin in arterial blood
68. cHHb = concentration of deoxyhemoglobin in arterial blood
69. $cO_2Hb$ + cHHb = concentration of total hemoglobin capable of binding oxygen
70. cH+=hydrogen ion concentration
71. $ctCO_2$ = total CO2 in plasma
72. cHCO3st = standard Bicarbonate
73. pHt = pH at patient temperature
74. $PCO_2t$ = $PCO_2$ at patient temperature
75. $PO_2t$ = $PO_2$ at patient temperature
76. AaDO2t = alveolar-arterial oxygen tension difference
77. bpm = beats per minute
78. mmHg = millimeters of mercury
79. kPa = kilopascals

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