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The Effect of One Lung Ventilation on Intrapulmonary Shunt During Different Anesthetic Techniques

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1. Introduction

To facilitate the work of the thoracic surgeon it has become accepted procedure in certain circumstances to collapse the diseased lung being operated upon. To accomplish this, the technique most frequently used by the anaesthetist calls for the insertion of a double lumen endobronchial tube. This makes it possible to isolate the intact dependent lung from the diseased upper one and thus to prevent contamination of the sound lung. On the other hand, collapse of the uppermost lung causes serious functional respiratory modifications which call for special compensatory measures to avoid hypoxaemia. The purpose of this study is to stress again that optimum maintenance of oxygenation is crucial for the prevention of sustained cellular hypoxia and to show how this may be achieved (1-3).

During one-lung ventilation (OLV) with patients in the lateral decubitus position, there is a potential risk of considerable intrapulmonary shunting of deoxygenated pulmonary arterial blood, which may result in hypoxemia. The consequences of an increase in pulmonary vascular resistance (PVR) in the nondependent (nonventilated) lung is to redistribute blood flow to the ventilated dependent lung, thereby preventing PaO₂ from excessive decrease. This increase in nondependent lung pulmonary vascular resistance is predominantly due to hypoxic pulmonary vasoconstriction (HPV) (4-8).

2. Physiological consequences of the lateral decubitus position

Sometimes, even in normal situations, and especially when there is a disease, a number of zones in the lungs are well ventilated, but the blood doesn't run through their vessels, while there are other areas with extraordinary blood flow, but with poor or no ventilation at all. It is clear that in each of the mentioned conditions the gas exchange through the respiratory membrane is seriously damaged, leading to severe respiratory difficulties, although the total ventilation and the total blood flow through the lungs are regular. A new concept is formulated on this basis, helping understand the respiratory gas exchange even when there is a disturbance of the relation between alveolar ventilation and alveolar blood flow. This term is so called ventilation/perfusion ratio, expressed in quantitative sense as V_a/Q_t .

In the awake subject, there is little or no additional ventilation/perfusion mismatch in the lateral position. The situation changes during anaesthesia. In the spontaneously breathing subject, there is a reduction in inspiratory muscle tone (particularly the diaphragm) and a

decrease in the volume of both lungs with a reduction in functional residual capacity. The compliance of the non-dependent upper lung increases and it receives more ventilation. Paralysis and intermittent positive pressure ventilation are used during thoracotomy and the compliance of the non-dependent lung is increased even further. In practice, it is usual to selectively ventilate the lower lung (OLV) at this point and allow the upper lung to collapse. This eliminates the preferential ventilation and facilitates surgical access, but creates the more serious problem of ventilation/perfusion mismatch (9).

3. Venous admixture

Pulmonary blood flow continues to the upper lung during one-lung anaesthesia, creating a true shunt in a lung where there is blood flow to the alveoli but no ventilation. This shunt is the major cause of hypoxaemia during OLV, although the alveoli with low ventilation/perfusion ratios in the dependent lung also contribute. In addition, the blood to the upper lung cannot take up oxygen and therefore retains its poorly oxygenated mixed venous composition. This mixes with oxygenated blood in the left atrium causing venous admixture and lowering arterial oxygen tension (PaO_2). Total venous admixture can be calculated from the shunt equation which estimates what proportion of the pulmonary blood flow would have bypassed ventilated alveoli to produce the arterial blood gas values for a particular patient. Venous admixture and shunt (Q_s/Q_t) are often used synonymously. Venous admixture increases from a value of approximately 10% - 15% during two-lung ventilation to 30% - 40% during OLV. The PaO_2 can be maintained in the range of 9-16 kPa with an inspired oxygen concentration between 50% and 100% in the majority of patients.

4. Hypoxic pulmonary vasoconstriction and one-lung ventilation

Hypoxic pulmonary vasoconstriction (HPV) is a mechanism whereby pulmonary blood flow is diverted away from hypoxic/collapsed areas of lung. This should improve oxygenation during OLV. Volatile anaesthetic agents depress HPV directly, but also enhance HPV by reducing cardiac output. There is therefore no change in the HPV response with volatile agents during thoracotomy and OLV.

Intravenous agents, such as propofol, do not inhibit HPV and should improve arterial oxygenation during OLV. There is some evidence to support this contention (10-17).

5. Cardiac output

Changes in cardiac output affect arterial oxygenation during thoracotomy. A decrease in cardiac output results in a reduced mixed venous oxygen content. Some of this desaturated blood is shunted during OLV and further exacerbates arterial hypoxaemia. Cardiac output can decrease for a number of reasons during thoracotomy. These include blood loss/fluid depletion, the use of high inflation pressures and the application of positive end-expiratory pressure (PEEP) to the dependent lung. Surgical manipulation and retraction around the mediastinum, causing a reduction in venous return, are probably the commonest causes of a sudden drop in cardiac output during lung resection (18-20).

6. Principles of ventilation

OLV should be established to adequately inflate the lung but also minimize intra-alveolar pressure and so prevent diversion of pulmonary blood flow to the upper lung. In practice,

this is not easy to achieve. It is reasonable to use an inspired oxygen concentration of 50% initially, which can be increased to 100%, if required. This cannot affect the true shunt in the upper lung but improves oxygenation through the alveoli with low V/Q ratios in the lower lung. Overinflating the single lung ('volutrauma') can be detrimental and lead to acute lung injury. Deflation and inflation of the operative lung with the potential for ischaemia/reperfusion injury has also been implicated in lung damage. The use of low tidal volumes improves outcome in ventilated patients with adult respiratory distress syndrome (ARDS) and this may also apply to OLV. Limiting ventilation can lead to carbon dioxide retention, but a degree of permissive hypercapnia is preferable to lung trauma (21-25).

7. Hypoxia during one-lung ventilation

It is difficult to predict which patients are likely to be hypoxic ($SpO_2 < 90\%$) during OLV. Patients with poor lung function are sometimes accepted for lung resection on the basis that their diseased lung is contributing little to gas exchange and this can be confirmed by V/Q scanning. Conversely, patients with normal lung function are more likely to be hypoxic during OLV because an essentially normal lung is collapsed to provide surgical access. The most significant predictors of a low arterial oxygen saturation during OLV are (1) a right-sided operation, (2) a low oxygen saturation during two-lung ventilation prior to OLV and (3) a high (or more normal) forced expiratory volume in 1 sec. preoperatively. Once hypoxia occurs, it is important to check the position of the endobronchial tube and readjust this if necessary. A high inflation pressure ($> 30-35$ cmH₂O) may indicate that the tube is displaced. It may be helpful to analyse a flow/volume loop or at least manually reinflate the lung to feel the compliance. If a tube is obstructing a lobar orifice, only one or two lobes are being ventilated at most and hypoxia is likely to occur. Suction and manual reinflation of the dependent lung may be useful. Other measures which can be used to improve oxygenation include increasing the inspired oxygen concentration, introducing PEEP to the dependent lung, or supplying oxygen to the upper lung via a continuous positive airway system, thereby reducing the shunt. In the face of persistent arterial hypoxaemia during OLV, it is pertinent to ask 'What is a low PaO₂ for this patient?'. An oxygen saturation below 90% is commonly tolerated. This arbitrary figure is affected by a variety of factors, including acidosis and temperature. Many patients will have a low PaO₂ when measured while breathing air preoperatively; hence, the usefulness of this preoperative measurement. Arterial hypoxaemia is obviously undesirable but it may be preferable to accept a PaO₂ slightly lower than the preoperative value, rather than undertake measures such as upper lung inflation which may hinder and prolong surgery (26-31).

8. Thoracic epidural anesthesia

Thoracic epidural anesthesia (TEA) with local anesthetics during OLV is increasingly being combined with general anesthesia (GA) in our clinical practice for thoracic surgery. A combination of TEA with GA might maximize the benefits of each form of anesthesia. Furthermore, epidural anesthesia and postoperative epidural analgesia with their effects that exceed pain release, may improve outcome in high-risk patients (32,33).

Thoracic epidural anesthesia reduces the incidence of respiratory complications as well as thoracic morbidity. Besides the excellent postoperative analgesia, it improves the strength and coordination of respiratory muscles; blocking the inhibitory phrenic reflex recovers the

function of the diaphragm and the lungs, decreasing the occurrence of atelectasis as well as lung infections. On account of all these effects, the thoracic epidural anesthesia permits early extubation along with decreased length of ICU treatment.

This type of anesthetic technique provides particular advantage in COPD patients as well as cardiac patients: controls tachyarrhythmia, lessens thrombotic complications, liberates from the angina pectoris, reduces myocardial straining, improves left-ventricular function, and makes the balance of myocardial oxygen supply better. By blocking sympathetic nervous system, the high thoracic epidural technique leads to vasodilatation and hypotension, reducing cardiac output. Furthermore, the consequence mentioned above enhances skin perfusion and improves the oxygen supply of peripheral tissues (34).

The blockade of the afferent nervous impulses made by the thoracic epidural anesthesia prevents and modifies neuro-endocrine, metabolic, immune, as well as autonomic response of the human body to surgical stress.

Potential disadvantages include the time required to establish epidural anesthesia, intravascular fluid administration needed to avoid hypotension, and the potential for technical complications, such as epidural hematoma.

The effect of intraoperative TEA with local anesthetics on HPV during thoracic surgery and OLV is unclear. Up till now, there isn't sufficient number of studies in the literature, capable to offer a definite answer to this dilemma. The pulmonary vasculature is innervated by the autonomic nervous system, and the sympathetic tone is dominant in the pulmonary circulation relative to parasympathetic activity. Theoretically, a TEA-induced sympathectomy might attenuate HPV (35). However, in one recent experimental study, TEA did not affect the primary pulmonary vascular tone, but it improved PaO₂ because of enhanced blood flow diversion from the hypoxic lobe (36-38).

Our aim in this study was:

- To determine the quantity of intrapulmonary shunt during general anesthesia and OLV.
- To determine the quantity of intrapulmonary shunt during combination of thoracic epidural anesthesia and general anesthesia with OLV.
- To compare the values of intrapulmonary shunt in both mentioned techniques.

9. Material and methods

This prospective, longitudinal, randomized, interventional clinical study was performed at the Clinic of Anesthesiology, Reanimation and Intensive care and the Clinic of Thoracic-vascular surgery in Skopje, after getting an approvalal by our ethics committee, and signed, informed consent from each patient.

We studied 60 patients who underwent elective lung surgery (by thoracotomy / thoracoscopy), or other surgical procedure which required OLV in lateral decubitus position (LDP). Patients were randomized to one of two study groups by lottery: general iv anesthesia (GA group = Group A) or general iv anesthesia combined with TEA (TEA group = Group B).

Inclusion criteria:

- Patients undergoing lung resection (by thoracotomy: pneumonectomy, bilobectomy, lobectomy, segmentectomy) or thoracoscopic procedures;
- Procedures other than lung resection, requiring OLV in LDP;
- Age between 15 and 75 years;

- ASA 1, 2;
- Preoperative values of $\text{SaO}_2 \geq 90\%$.

Exclusion criteria:

- Renal insufficiency (creatinine $>114 \mu\text{mol/L}$);
- Liver dysfunction (aspartate amino transferase-AST $>40 \text{ U/L}$, alanine amino transferase-ALT $>40 \text{ U/L}$);
- Documented coronary or vascular disease ($\text{EF} < 50\%$);
- Previously existing chronic respiratory disease of non-operated lung;
- FVC , $\text{FEV}_1 < 50\%$,
- Patients who intraoperatively needed $\text{FiO}_2 > 0.5$.

Exclusion criteria from TEA group:

- Patients with serious haemostatic disorders and/or those under anticoagulant therapy (<12 hours since the last dose of LMWH);
- Patients with serious deformities of the vertebral column, neurological diseases, and/or
- Infection in the thoracic or lumbosacral region of the spine.

The methods used in this study included as follows:

Clinical evaluation: For all patients, preoperative assessment included: clinical examination, chest X-ray, echocardiography, measurements of forced vital capacity (FVC), forced expiratory volume in 1 sec. (FEV_1), these values as a percentage of predicted values ($\text{FVC}\%$, $\text{FEV}_1\%$), coagulation tests, standard biochemical analysis, and arterial blood gas analysis on the evening before surgery.

Anesthesia: In the GA group (group A), general anesthesia was induced using fentanyl iv ($3 \mu\text{g/kg}$), midazolam ($2\text{--}3 \text{ mg}$), and propofol (2 mg/kg); rocuronium (0.6 mg/kg) or succinyl cholin (1 mg/kg) was given to facilitate intubation of the trachea with a double-lumen endobronchial tube. Anesthesia was maintained with propofol at continuous perfusion ($6\text{--}7 \text{ mg/kg/h}$), with increments of fentanyl ($2 \mu\text{g/kg}$) to maintain the systolic blood pressure within 15 mm Hg of post induction values and rocuronium at continuous perfusion (0.3 mg/kg/h), or pancuronium (0.01 mg/kg).

In the TEA group – group B (combined anesthesia), an epidural catheter was placed at the Th5-6, Th6-7 or Th7-8 interspaces and advanced 3 cm in the epidural space before anaesthesia induction. TEA was then induced using an initial 6 to 8-ml dose of plain bupivacaine 0.5% ; if necessary, additional increment doses up to 14 ml were administered until a thoracic-sensitive blockade was induced. The level of anesthesia was determined by the loss of pinprick sensation. During the onset of epidural anesthesia, colloids were infused (7 ml/kg); crystalloids (8 ml/kg/h) were subsequently infused throughout the study (the same rate as in group A), and when systolic arterial blood pressure decreased to 100 mm Hg , ephedrine was planned to be injected in increments of 5 mg (yet, no patient received ephedrine). GA was induced using the same method as in group A. After tracheal intubation, with a double-lumen endobronchial tube, anesthesia was maintained by continuous epidural infusion ($6\text{--}8 \text{ ml/h}$) of bupivacaine 0.25% , plus propofol in continuous perfusion ($6\text{--}7 \text{ mg/kg/h}$) and rocuronium (0.3 mg/kg/h) in continuous perfusion, or pancuronium (0.01 mg/kg), as well as fentanyl.

In both groups, fluid replacement and transfusion management were based on hemodynamic monitoring and were under the direction of the attending anesthesiologist.

After the induction of anesthesia, an arterial catheter was placed in the radial artery, contra lateral from the operated side, with the intention of extraction of arterial blood samples and consequent blood gases and intrapulmonary shunt analysis.

After clinical confirmation of correct double-lumen tube placement (by inspection and auscultation) with the patient in both supine and lateral decubitus position, ventilation was controlled (volume-controlled mechanical ventilation – VC) by using 50% oxygen in air (for all patients) and tidal volume of 6-8 ml/kg at a respiratory rate to maintain PaCO₂ between 35 and 40 mm Hg (4, 5 – 6 kPa). Effective lung isolation was determined by the absence of leak from the nonventilated lumen of the endobronchial tube. When the pleura was opened, the isolation was confirmed by direct observation of the collapsed nonventilated lung and the absence of leak from this lung. During OLV, the same tidal volume, respiratory rate, and fraction of inspired oxygen were used; the bronchus of the lung not being ventilated upon was excluded and open to atmospheric pressure.

Monitoring during anesthesia:

- heart rate (HR)
- ECG
- mean arterial pressure (MAP)
- respiratory rate (RR)
- oxygen saturation from pulseoxymetry – SAT%
- inspired oxygen fraction – FiO₂
- partial pressure of carbon dioxide in arterial blood – PaCO₂

Measurements – in 4 stages (always in lateral position):

- T₀ - during TLV
- T₁ - immediately after beginning of OLV
- T₂ - 10 min. after beginning of OLV
- T₃ - 30 min after beginning of OLV

Blood samples were drawn simultaneously from the arterial catheter and analyzed within 10 min., using the blood gases analyzer AVL **Compact 3 BLOOD GAS** (which is used in our Intensive Care Unit).

Parameters evaluated in these 4 stages:

- partial pressure of oxygen in arterial blood (PaO₂)
- oxygen saturation of arterial blood (SaO₂)
- intrapulmonary shunt value (Q_s/Q_t).

The Q_s/Q_t% is usually calculated using the venous admixture equation:

$$Q_s / Q_t \% = (C_c'O_2 - C_aO_2) / (C_c'O_2 - C_vO_2) \times 100$$

$$C_c'O_2 = (Hb \times 1.39) \times SaO_2 + (PaO_2 \times 0.0031)$$

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

(PO₂ = PaO₂ or PvO₂)

But for the purpose of this study, the quantitative value of Q_s/Q_t % was mathematically calculated by the blood gases analyzer AVL **Compact 3 BLOOD GAS**.

Statistical analysis was performed using specific computer programs. Collected data were processed with standard descriptive and analytical bivariate and multivariate methods. Statistical significance of discrepancies between attribute series was tested using Student t – test and Mann-Whitney U test. The probability for association between distributions of frequencies of two attribute variables was evaluated with χ^2 – test.

Statistical relevance of dissimilarities inside groups was analysed with ANOVA test, which was additionally confirmed with post hoc test - Tukey honest significant difference (HSD) test.

For CI (confindence interval) was considered $p<0,05$.

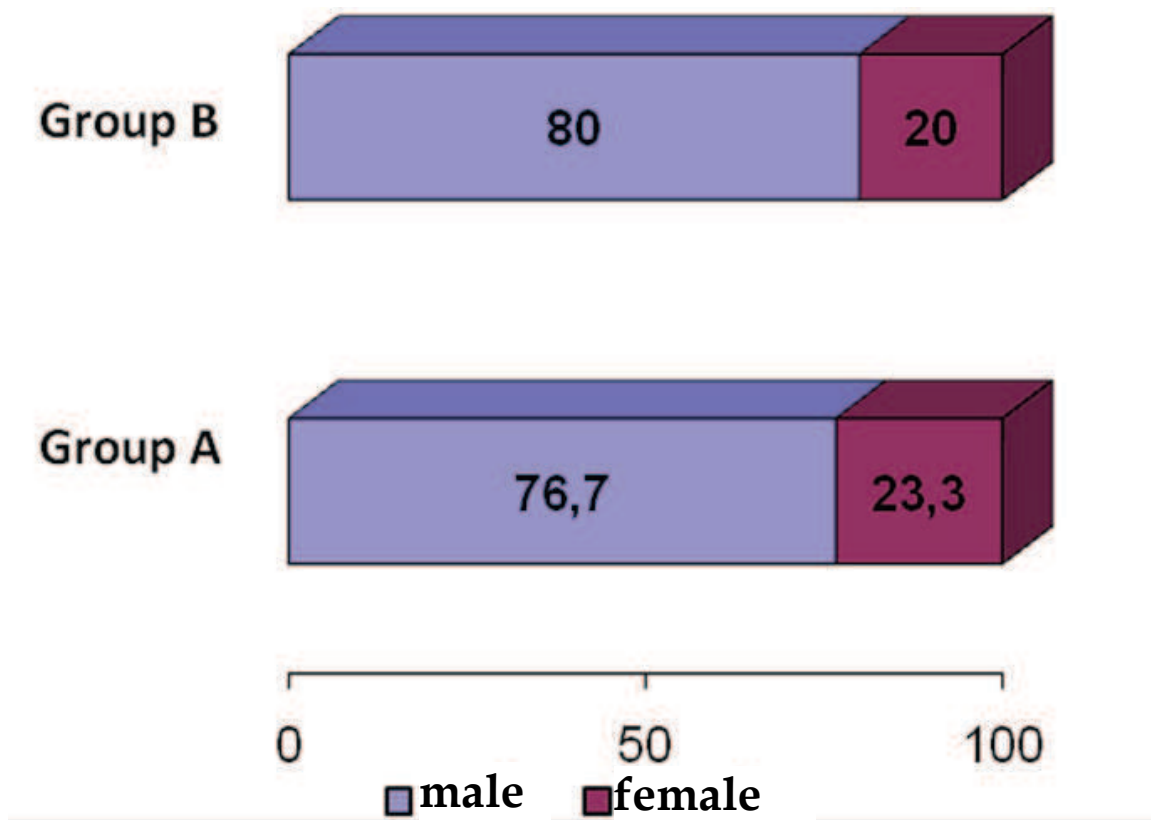
Results were displayed with table and graph illustrations.

10. Results

10.1 Demographic data

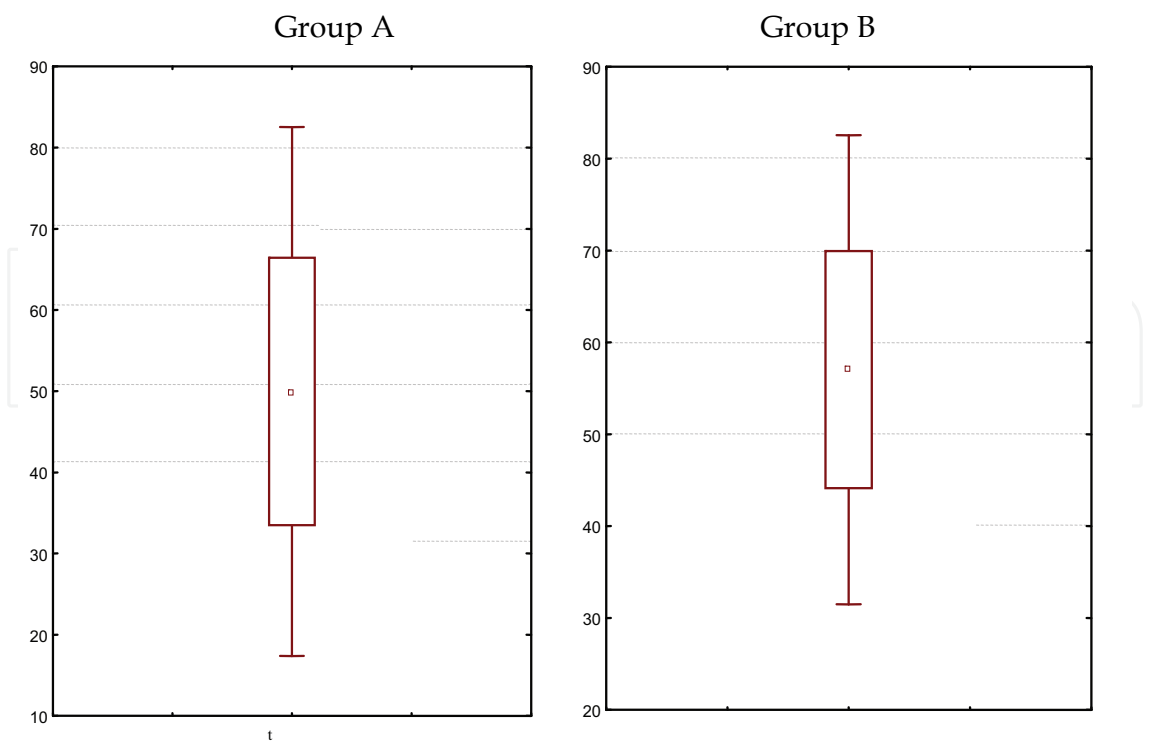
60 patients were enrolled in the study, 47 of which were men, and 13 were women ($p=0,020$). The examined patients were divided in two groups, each with 30 pts: group A, whose patients underwent thoracic surgery with OLV in general anesthesia, and Group B, subjected to the same operative procedure, performed in combined general and thoracic epidural anesthesia.

Graph 1 demonstrates patients' gender in groups, showing that no statistically significant difference exists between two examined groups of patients.



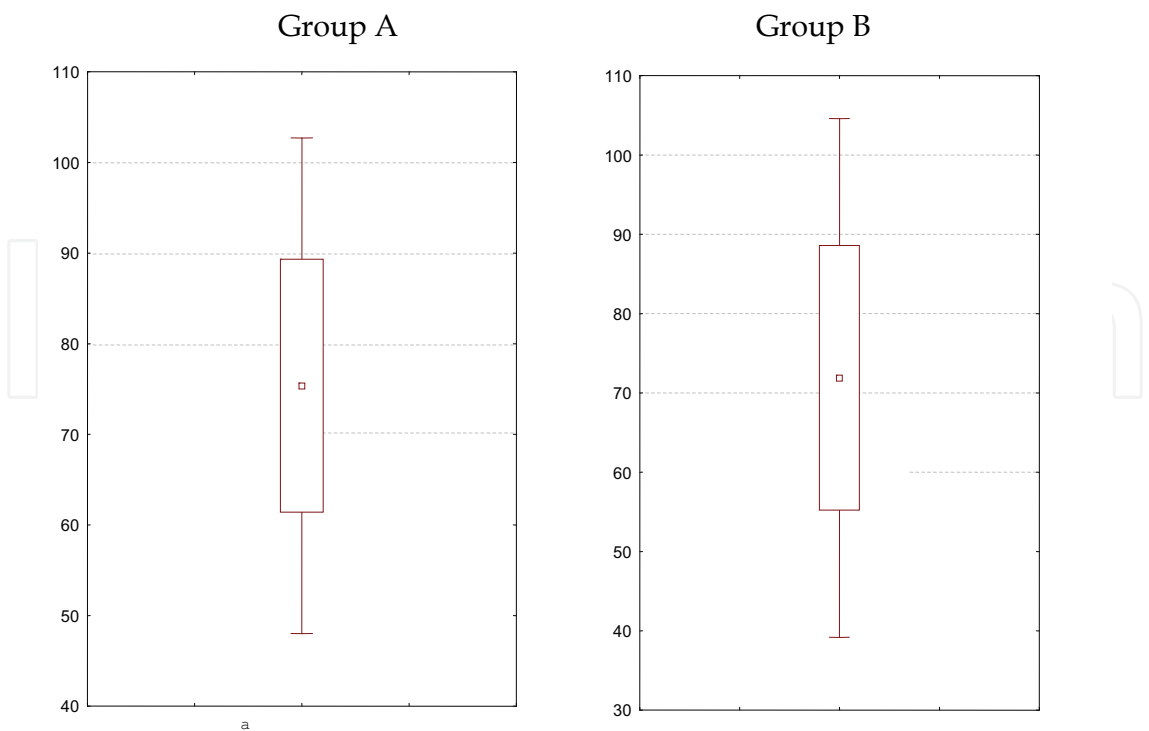
Graph 1. Gender distribution of patients

In group A are recorded 76,7% male pts and 23,3% females. Percentage variation registered among gender categories is statistically significant for $p=0,0001$. In group B 80,0% pts are male, and 20,0% female. This proportion dissimilarity is also statistically significant for $p=0,0000$. The diversity recorded among genders between two examined groups is statistically irrelevant for $p>0,05$, confirming similarity i.e. equal presence of genders among two studied groups of patients (Graph 1).



Graph 2. Average age of patients

The average age of patients in group A is $49,96 \pm 16,6$ years, minimum 17, maximum 74 years. The average age of patients in group B is $57,03 \pm 13,0$ years, minimum 26, maximum 78 years. The recorded difference in average age of patients among two studied groups is statistically insignificant for $p=0,0714$ (Graph 2).

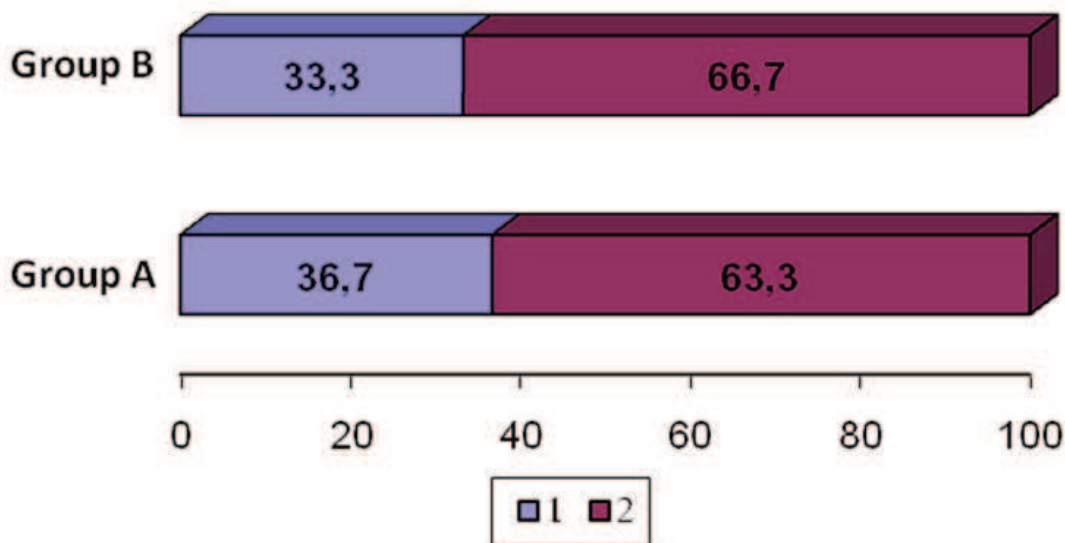


Graph 3. Average body weight of patients

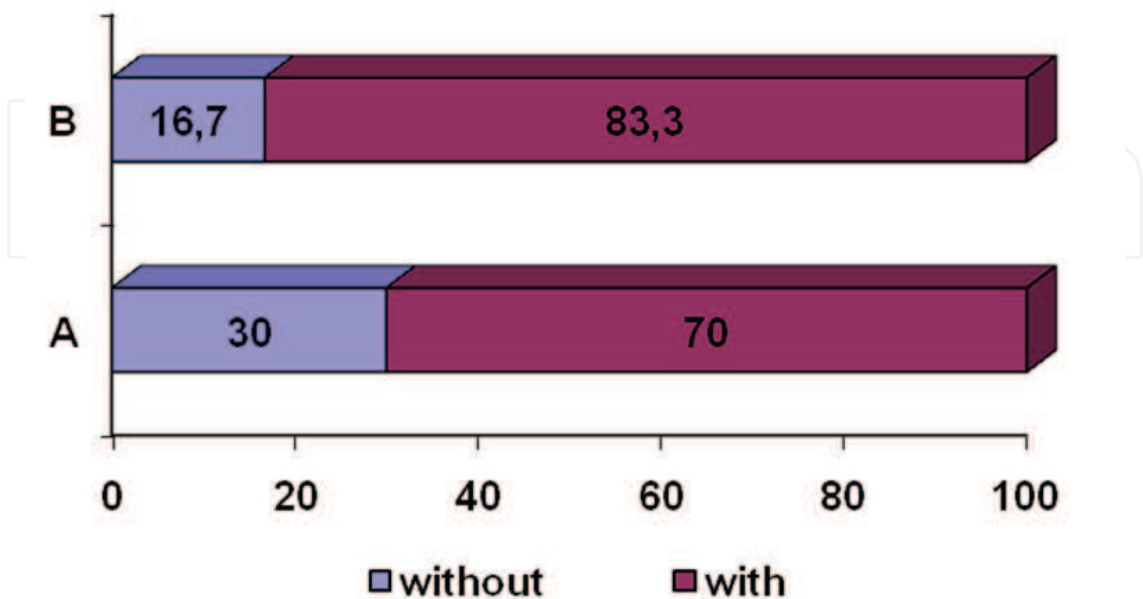
The average body weight of patients in group A is $75,4 \pm 14,0$ kg, minimum 53,7, maximum 105 kg. The average body weight of patients in group B is $72,0 \pm 16,7$ kg, minimum 40, maximum 120 kg. The difference in average body weight recorded between patients from two examined groups is not statistically important for $p=0,359335$ (Graph 3).

10.2 Clinical assessment

In group A, ASA 1 status is listed in 36,7% of patients, while in 63,3% pts ASA 2 status is recorded. In group B, 33,3% of patients had ASA 1 status, whereas 66,7% had status ASA 2. The percentage variety registered between the presence of ASA 1 and 2 inside both groups is statistically significant for $p<0,05$; on the other hand, percentage difference among both groups A and B is statistically insignificant for $p>0,05$ (Graph 4).



Graph 4. Distribution of patients according to ASA classification



Graph 5. Patients with / without positive medical history in both groups

30,0% of patients in group A don't have positive medical history for co-morbidities, and in group B - 16,7%; the difference is not statistically important for $p>0,05$. In both groups of patients, the most frequently recorded co-morbidities are smoking, hypertension, diabetes, duodenal ulcer etc. In some patients more than one disorder is listed (Graph 5).

Biochemistry	Rank Sum-A	Rank Sum-B	U	Z	p-level
Hb	916,5	913,5	448,5	0,022177	0,982307
Hct	941,0	889,0	424,0	0,384395	0,700686
Creatinin	872,5	957,5	407,5	-0,628338	0,529783
ALT	1027,5	802,5	337,5	1,663248	0,096264
AST	998,0	832,0	367,0	1,227107	0,219783

Table 1. Mann-Whitney U test for preoperative laboratory data

The average values of laboratory data (hemoglobin, hematocrit, creatinin, ALT, AST) in both studied groups are in the range of referent values. The recorded difference in average values of examined parameters among two groups of patients is statistically insignificant for $p>0,05$, according to Mann-Whitney U test (Table 1).

Screening haemostasis	Rank Sum-A	Rank Sum-B	U	Z	p-level
PT	963,5	866,5	401,5	0,71704	0,473347
aPTT	802,0	1028,0	337,0	-1,67064	0,094794
TT	854,5	975,5	389,5	-0,89446	0,371078
PLT	913,5	916,50	448,5	-0,02218	0,982307

Table 2. Mann-Whitney U test for screening haemostasis

The average values of PT, aPTT, TT and PLT from haemostasis in both studied groups are in the range of referent values. The recorded difference between these average values among two groups is statistically insignificant for $p>0,05$, according to Mann-Whitney U test (Table 2).

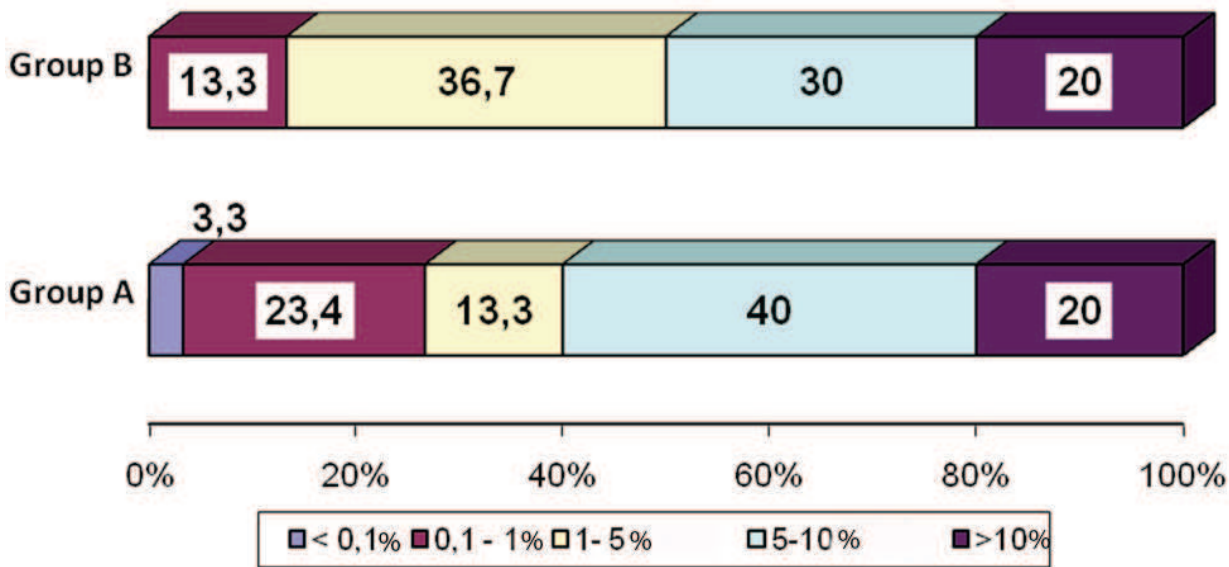
Gas status	Rank Sum-A	Rank Sum-B	U	Z	p-level
PaO2	934,0	896,0	431,0	0,280904	0,778784
PaCO2	979,0	851,0	386,0	0,946203	0,344046
SaO2	890,0	940,0	425,0	-0,369611	0,711673

Table 3. Mann-Whitney U test for preoperative gas status

The average values of PaO2, PaCO2 and SaO2 from preoperative gas status in both studied groups are in extend of referent values. The recorded differentiation between these values among two groups is not statistically significant for $p>0,05$, in accordance with Mann-Whitney U test (Table 3).

Graph 6 shows the dispersal of patients from both examined groups in relation to the value of preoperative intrapulmonary shunt - Qs/Qt.

The average values of FVC and FEV1 in patients from both studied groups are in range of referent values. The recorded variation between these average values among the two groups is statistically irrelevant for $p>0,05$, consistent with Mann-Whitney U test (Table 4).



Graph 6. Preoperative value of intrapulmonary shunt (Qs/Qt)

	Rank Sum-A	Rank Sum-B	U	Z	p-level
FVC	850,5	979,5	385,5	-0,95360	0,340289
FEV1	831,0	999,0	366,0	-1,24189	0,214277

Table 4. Mann-Whitney U test for FVC and FEV1

	Rank Sum-A	Rank Sum- B	U	Z	p-level
EF%	465,0	1365,0	0,00	-6,65299	0,000000*

Table 5. Mann-Whitney U test for EF%

The average values of EF% in patients from both examined groups are in extend of refferent values. The disclosed difference between these parameters among two groups is statistically significant for **p=0,00000***, according to Mann-Whitney U test (Table 5), but without clinical importance.

10.3 Intraoperative monitoring

Average values of HR/min. in both groups show rise during the operative monitoring from T0 to T3. The difference in HR/min. between groups A and B (Mann-Whitney U test) is statistically significant only for T0 and T3 (**p=0,02*** and **p=0,04***). On the other hand, the differences in these values inside groups A and B (ANOVA test) are statistically insignificant (Tables 6, 7).

Average values of MAP/mmHg in both groups illustrate increase during the operative monitoring from T0 to T2, and then decrease in T3. This difference between groups A and B is statistically irrelevant. Inside groups, the discrepancy of average values of MAP/mmHg is statistically significant only in group A (**p=0,019***).These statistically relevant differences for HR/min. and MAP/mmHg don't have clinical importance (Table 6,7).

Parameters	Rank Sum-A	Rank Sum-B	U	Z	p-level
HR/minT0	1076,500	753,500	288,5000	2,38768	0,016955*
HR/min T1	969,000	861,000	396,0000	0,79836	0,424663
HR/min T2	1020,000	810,000	345,0000	1,55236	0,120576
HR/min T3	1049,000	781,000	316,0000	1,98111	0,047579*
MAP/mmHg T0	787,000	1043,000	322,0000	-1,89241	0,058438
MAP/mmHg T1	916,000	914,000	449,0000	0,01478	0,988204
MAP/mmHg T2	922,000	908,000	443,0000	0,10349	0,917573
MAP/mmHg T3	857,000	973,000	392,0000	-0,85750	0,391171
RR/min T0	915,000	915,000	450,0000	0,00000	1,000000
RR/min T1	986,500	843,500	378,5000	1,05709	0,290473
RR/min T2	973,000	857,000	392,0000	0,85750	0,391171
RR/min T3	942,000	888,000	423,0000	0,39918	0,689761
SAT% T0	1021,000	809,000	344,0000	1,56715	0,117081
SAT% T1	1009,500	820,500	355,5000	1,39713	0,162376
SAT% T2	961,000	869,000	404,0000	0,68008	0,496452
SAT% T3	915,000	915,000	450,0000	0,00000	1,000000
PCO ₂ /mmHg T0	914,500	915,500	449,5000	-0,00739	0,994102
PCO ₂ /mmHg T1	953,500	876,500	411,5000	0,56920	0,569221
PCO ₂ /mmHg T2	912,500	917,500	447,5000	-0,03696	0,970516
PCO ₂ /mmHg T3	919,000	911,000	446,0000	0,05914	0,952842

Table 6. Mann-Whitney U test for parametres of intraoperative monitoring

Group	Monitoring	SS	df	MS	SS	Df	MS	F	P
A	HR/min	236,425	3	78,8083	17165,177	116	147,97566	0,5326	0,660834
	MAP/mmHg	1422,1588	3	474,0528	16113,43	116	138,9089	3,4127	0,019858*8
	RR/min	369,000	3	123,0000	36,87	116	0,3178	387,0163	0,000000*
	SAT%	429,425	3	143,1417	1745,17	116	15,0445	9,5145	0,000011*
	PCO ₂ /mmHg	20,852	3	6,9508	106,57	116	0,9187	7,5659	0,000115*
B	HR/min	741,6667	3	247,2222	20349,13	116	175,4236	1,4093	0,243640
	MAP/mmHg	119,4917	3	39,8306	25576,10	116	220,4836	0,1807	0,909345
	RR/min	333,0250	3	111,0083	62,10	116	0,5353	207,3586	0,000000*
	SAT%	408,4250	3	136,1417	1267,57	116	10,9273	12,4589	0,000000*
	PCO ₂ /mmHg	22,8277	3	7,6092	112,34	116	0,9685	7,8570	0,000081*

Table 7. Analysis of Variance –ANOVA test

The average values of RR/ min. in both groups show rise during operative monitoring. The differences in these values are insignificant between groups A and B, and statistically significant inside groups (**p=0,00000***) (Tables 6,7). This difference doesn't have clinical importance for the aims of the study (since respiratory rate during OLV is deliberately increased in all patients, in order to decrease the value of PaCO₂).

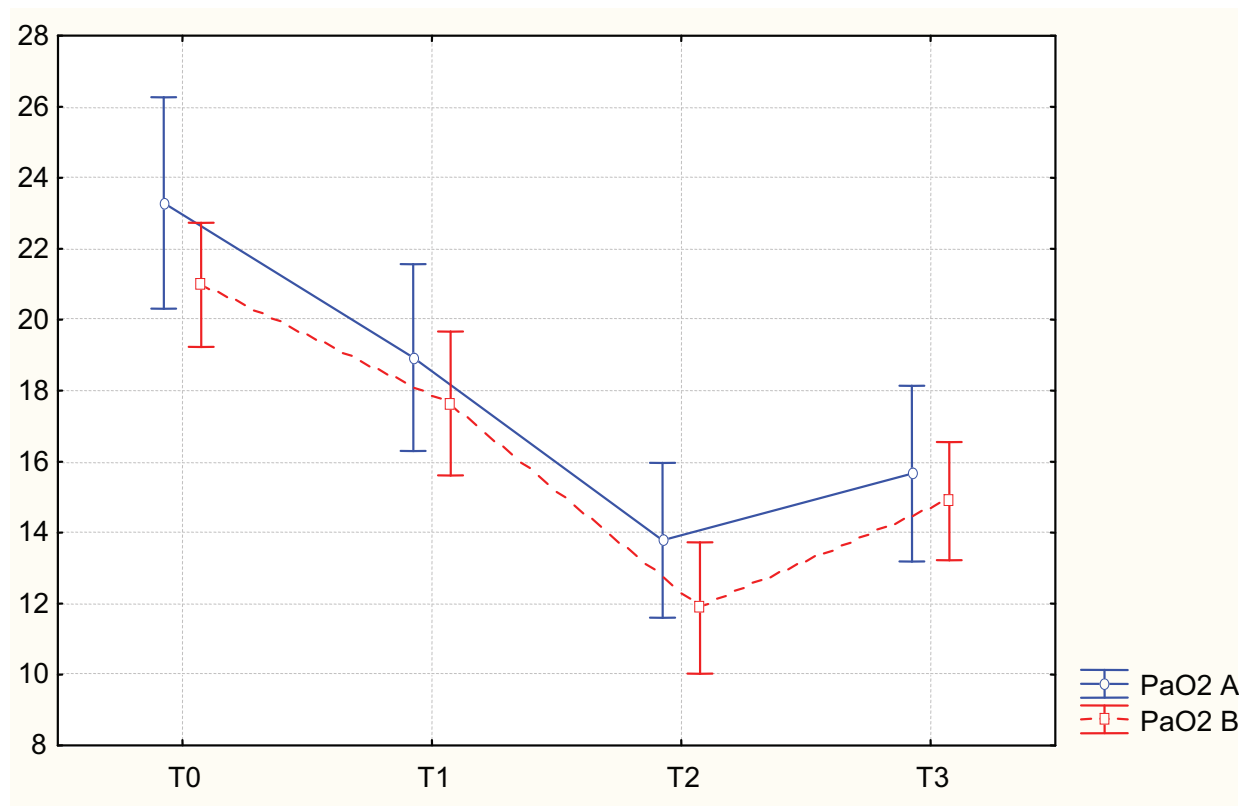
The average values of SAT% in both studied groups demonstrate fall during the operative monitoring. The difference in these values is statistically irrelevant between groups A and B; however, the dissimilarities inside groups A and B is statistically significant for **p=0,000011*** and **p=0,00000*** (Tables 6, 7), showing decrease in arterial oxygen saturation during OLV in patients from both groups.

The average values of PCO₂/mmHg in both groups demonstrate increase during operative monitoring. The differences in these values are statistically insignificant between groups A and B; on the other hand, inside groups A and B, the discrepancy is statistically significant for **p=0,000115*** and **p=0,000081*** (Tables 6, 7). This inequality illustrates the phenomenon of so called *permissive hypercapnia* during OLV (which is expected, inspite of therapeutic increase of RR/min., with intention of maintaining PaCO₂ in normal range of values).

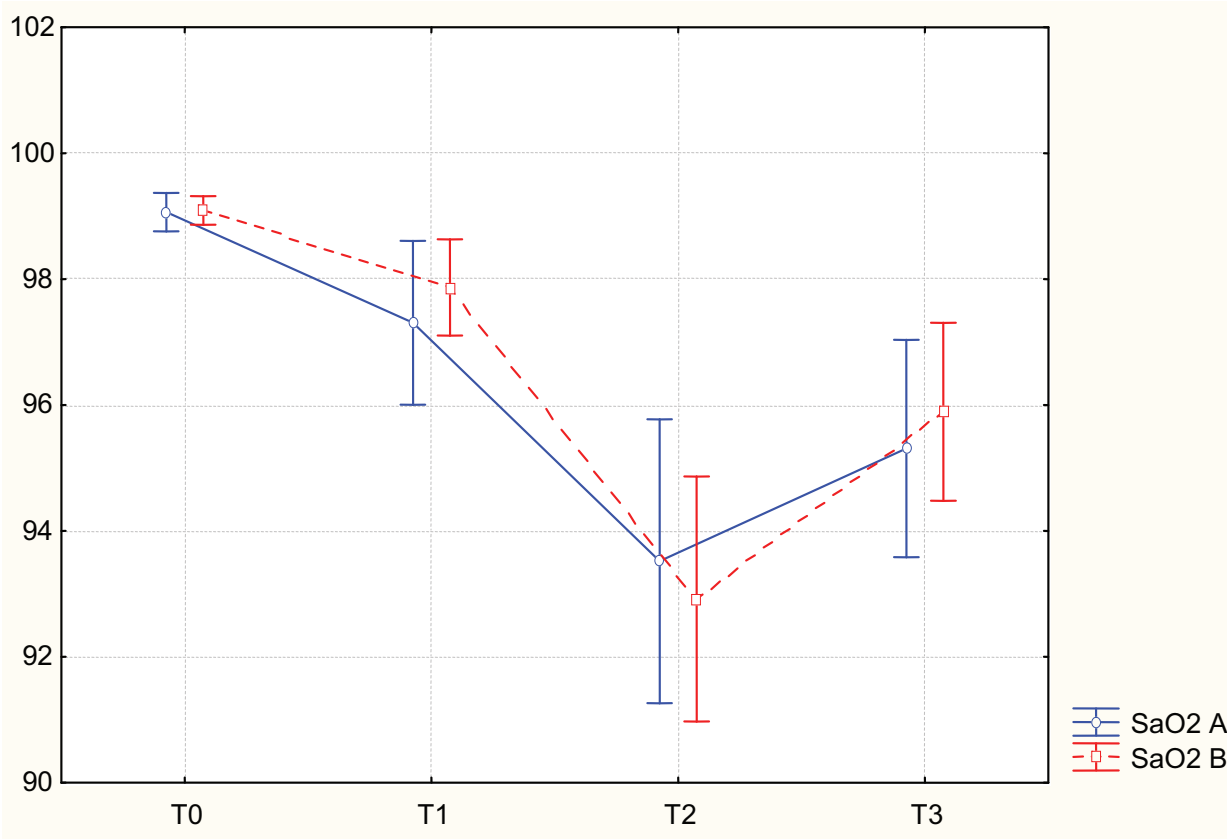
10.4 Intraoperative gas analysis and intrapulmonary shunt

The average values of PaO₂ in both studied groups show fall during the operative monitoring. The differences in these values between groups A and B are statistically insignificant. Inside groups A and B the dissimilarities are statistically significant for **p=0,0000021*** and **p=0,000000***. The additionally performed post-hoc test for PaO₂ in group A and B shows which differences (i.e. measuring times) are statistically relevant (**Tables 8, 9, 10, 12**).

Graphs 7. Parametres from intraoperative gas status.



Graph 7a - PaO₂ in both groups



Graph 7b – SaO2 in both groups

Parameters	Rank Sum-A	Rank Sum-B	U	Z	p-level
PaO2 T0	973,000	857,0000	392,0000	0,857497	0,391171
PaO2 T1	961,000	869,0000	404,0000	0,680084	0,496452
PaO2 T2	1019,500	810,5000	345,5000	1,544972	0,122354
PaO2 T3	914,000	916,0000	449,0000	-0,014784	0,988204
SaO2 T0	947,000	883,0000	418,0000	0,473102	0,636141
SaO2 T1	935,000	895,0000	430,0000	0,295689	0,767468
SaO2 T2	978,500	851,5000	386,5000	0,938811	0,347829
SaO2 T3	899,000	931,0000	434,0000	-0,236551	0,813005

Table 8. Mann-Whitney U test

Group	Parameters	SS	df	MS	SS	df	MS	F	p
A	PaO2	1561,721	3	520,5735	5550,851	116	47,85217	10,87879	0,0000021
	SaO2	520,737	3	173,5789	2047,983	116	17,65503	9,83170	0,000008
B	PaO2	1358,527	3	452,8423	2778,338	116	23,95119	18,90688	0,000000
	SaO2	652,413	3	217,4710	1334,600	116	11,50518	18,90201	0,000000

Table 9. Analysis of Variance –ANOVA test

PaO2	T0	T1	T2	T3
T0		0,075231	0,000139*	0,000352*
T1	0,075231		0,024138*	0,265002
T2	0,000139*	0,024138*		0,719175
T3	0,000352*	0,265002	0,719175	

Table 10. Post- hoc - Tukey honest significant difference (HSD) test for Group A - PaO2

SaO2	T0	T1	T2	T3
T0		0,371996	0,000142*	0,004258*
T1	0,371996		0,003861*	0,259930
T2	0,000142*	0,003861*		0,355108
T3	0,004258*	0,259930	0,355108	

Table 11. Post-hoc - Tukey honest significant difference (HSD) test for Group A - SaO2

PaO2	T0	T1	T2	T3
T0		0,045269*	0,000137*	0,000158*
T1	0,045269*		0,000202*	0,135773
T2	0,000137*	0,000202*		0,086017
T3	0,000158*	0,135773	0,086017	

Table 12. Post-hoc - Tukey honest significant difference (HSD) test for Group B - PaO2

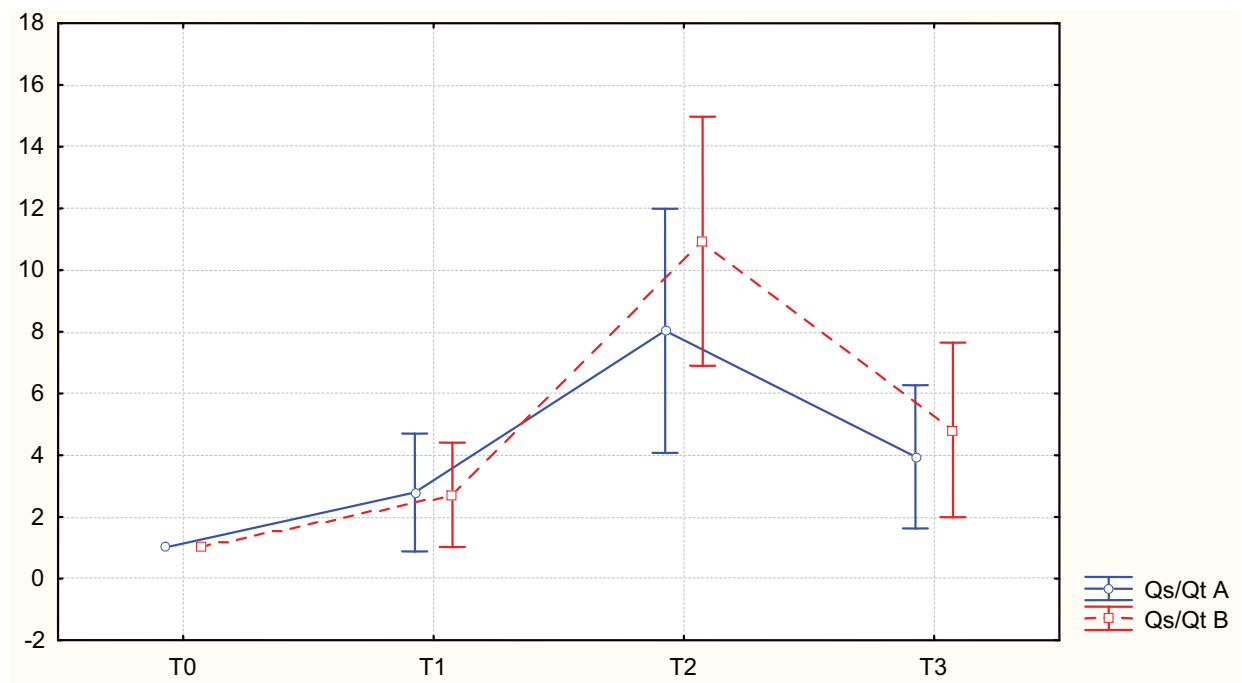
SaO2	T0	T1	T2	T3
T0		0,503957	0,000137*	0,002297*
T1	0,503957		0,000137*	0,115369
T2	0,000137*	0,000137*		0,005223*
T3	0,002297*	0,115369	0,005223*	

Table 13. Post-hoc - Tukey honest significant difference (HSD) test for Group B - SaO2

The average values of SaO2 in both groups illustrate decrease during the operative monitoring. The difference between these values among groups A and B is statistically insignificant. Inside groups A and B, the discrepancies are statistically relevant for **p=0,000008*** and **p=0,000000***. The additionally performed post-hoc test for SaO2 in groups A and B demonstrates which differences (i.e. measuring times) are statistically relevant (**Tables 8, 9, 11, 13**).

The acquired statistically significant differences for PaO2 and SaO2 inside the groups A and B show that after some time of OLV initiation (after 10 min.) hypoxia develops, with decrease of the values of PaO2 and SaO2.

The absence of statistically relevant variation for PaO2 and SaO2 among the groups A and B demonstrates that TEA doesn't provoke augmentation of hypoxia during OLV.



Graph 8. Average intraoperative values of intrapulmonary shunt – Qs/Qt in both groups

Parameters	Rank Sum-A	Rank Sum-B	U	Z	p-level
Qs/Qt T0	915,0000	915,0000	450,0000	0,000000	1,000000
Qs/Qt T1	925,0000	905,0000	440,0000	0,147844	0,882466
Qs/Qt T2	853,5000	976,5000	388,5000	-0,909242	0,363223
Qs/Qt T3	939,0000	891,0000	426,0000	0,354826	0,722720

Table 14. Mann-Whitney U test

Group	Parameters	SS	df	MS	SS	df	MS	F	p
A	Qs/Qt	801,6449	3	267,2150	5133,088	116	44,25076	6,038653	0,000739
B	Qs/Qt	1692,620	3	564,2068	5648,059	116	48,69017	11,58769	0,000001

Table 15. Analysis of Variance –ANOVA test

Qs/Qt	T0	T1	T2	T3
T0		0,725131	0,000563*	0,320393
T1	0,725131		0,014827*	0,907021
T2	0,000563*	0,014827*		0,086875
T3	0,320393	0,907021	0,086875	

Table 16. Post-hoc - Tukey honest significant difference (HSD) test for Group A - Qs/Qt

Qs/Qt	T0	T1	T2	T3
T0		0,776395	0,000137*	0,152861
T1	0,776395		0,000202*	0,648599
T2	0,000137*	0,000202*		0,005223*
T3	0,152861	0,648599	0,005223*	

Table 17. Post-hoc - Tukey honest significant difference (HSD) test for Group B - Qs/Qt

The average values of Qs/Qt in both inspected groups illustrate dynamic trend during the operative monitoring. In group A it begins with the value < 1 in T0, increases in T2, and then decreases in T3. In group B it also starts with a value < 1 in T0, grows up in T2, and then the value drops. The difference between the average values of Qs/Qt recorded among groups A and B is statistically insignificant. On the other hand, the variations in these values inside groups A and B are statistically relevant for $p=0,000739^*$ and $p=0,000001^*$. With the additionally performed post-hoc test for Qs/Qt in group A it is evident that the difference is statistically significant **between T0 and T2 and T1 and T2**. The completed post-hoc test for Qs/Qt in group B shows that the dissimilarity is statistically relevant **between T0 and T2, T1 and T2, as well as T2 and T3 (Tables 14-17)**.

The obtained statistically significant differences for Qs/Qt inside groups A and B demonstrate that some time after beginning of OLV (after 10 min.) hypoxia develops, with an increase of the value of intrapulmonary shunt.

The nonexistence of statistically relevant dissimilarity for Qs/Qt among the groups A and B, confirms that TEA neither leads to intensification of hypoxia, nor to an increase of the shunt during OLV.

11. Discussion

OLV creates an obligatory transpulmonary shunt through the atelectatic lung. Passive (gravitation and surgical manipulation) and active (HPV) mechanisms minimize the redirection of blood flow towards the atelectatic lung, thus preventing the fall of PaO2; yet, the most important turn of the blood flow towards the dependent lung is caused by HPV (39).

Hurford et al. in their study (40) tested the hypothesis that during OLV is more likely to come to intraoperative hypoxia if there is bigger pulmonary blood flow in the operated lung before surgery. In their study they examined 30 patients with previously performed ventilation-perfusion scan preoperatively, who underwent a thoracic procedure in lateral decubitus position with OLV. The percentage of blood flow in the operated lung seen on the preoperative perfusion scan reversely correlated with PaO2, 10 minutes after initiating of OLV ($p=-.72$). If the percentage of blood flow in the operated lung on the preoperative scan was greater than 45%, the probability for hypoxemia ($PaO_2 < 75$ mm Hg) was bigger. Since the preoperative regional ventilation in these patients was equivalent with the perfusion, also the percentage of preoperative ventilation correlated reversely with PaO2 after 10 min. of OLV initiation ($p=-.73$). *The arterial gas analyses, pulmonary functional tests and pulmonary volumes, were not associated with the oxygenation during OLV.*

This is opposite of the results of Slinger et al. (41). In their study they discovered that one equation with three variables [PaO2 during intraoperative two lung ventilation in lateral decubitus position, side of surgery and preoperative relation of forced expiratory volume in 1st second (FEV1) and vital capacity (VC)], could be used to predict ($p =.73$) PaO2 during OLV, using CPAP (continuous positive airway pressure) in non-ventilated lung. However,

Katz et al. (51) agreed with the findings of Hurford et al. (40) that routine preoperative arterial gas analysis and pulmonary functional tests do not anticipate precisely which patients are under risk of developing hypoxia during OLV.

Our results from this study verify that preoperative arterial gas analysis, as well as FVC and FEV1, can't be perceived as confident evidence that the exact patient will develop hypoxia of bigger or smaller extent during OLV.

Previous clinical research studies showed controversial results regarding oxygenation, shunt fraction and hemodynamic parameters during OLV (42, 43, 44, 45).

Spies et al. (42) compared TIVA with propofol (10 mg/kg/h) versus 1 MAC enflurane in patients during thoracotomy. Cardiac output and shunt significantly increased when TLV was converted to OLV, and PaO₂ decreased.

Van Keer et al. (43) studied 10 patients who underwent thoracotomy. Their anesthesia was maintained with continuous iv infusion of propofol (10 mg/kg/h). No changes were noticed concerning cardiac output, shunt and PaO₂, during TLV (two lung ventilation) and OLV. This fact could be due to methodological differences because all the measurements for the duration of OLV were initiated before opening of the thoracic cavity.

Steegeers et al. (44) examined 14 patients who were about to undertake lobectomy, in intravenous general anesthesia with continuous infusion of propofol (6-9 mg/kg/h). The shunt fraction and PaO₂ didn't differ during OLV compared with TLV. Their study doesn't include any basic data, like cardiac output. Changes in these hemodynamic parameters would cause secondary alterations in pulmonary circulation.

Kellow et al. (45) studied patients who underwent thoracotomy and noticed significant increase of cardiac index and shunt fraction when TLV was switched to OLV. Nevertheless, interpretation of the shunt fraction is limited as the patients were ventilated with 50% nitrous oxide in oxygen and no PaO₂ was measured.

Several studies, including the one of Slinger et al. (46), demonstrated that the beginning of hypoxia is, approximately, about 5-10 min. after initiating of OLV and reaches maximum after 15 min. This matches the time needed for complete absorption of the gases (oxygen and nitrous oxide) from closed cavities, when blood flow is maintained. PaO₂ and Qs/Qt usually begin to return towards values existing during TLV about 30 min. after commencing OLV. That is the period required for development of the compensatory mechanism called HPV (hypoxic pulmonary vasoconstriction) and redirection of blood flow away from the atelectatic lung. As a result, the shunt fraction will also decrease.

Our results confirmed the conclusions from the last mentioned studies - that during conversion from TLV to OLV in patient placed in lateral decubitus position throughout thoracotomy / thoracoscopy, it comes to decrease in arterial oxygenation, as well as increase in shunt fraction. Namely, the average values of PaO₂ in two examined groups of patients fall down throughout the operative monitoring (group A from 23,29+/-7,97 kPa in TLV, to 13,78+/-5,84 kPa after 10 min. of OLV, and returns to 15,66+/-6,62 kPa, 30 min. after OLV; and group B - from 20,98+/-4,68 kPa during TLV, to 11,87+/-4,95 kPa, 10 min. after OLV, and returns to 14,88+/-4,45 kPa 30 min. after OLV); the average values of SaO₂ in the two groups show decrease during operative monitoring (group A - from 99,06+/-0,81% during TLV, to 93,52+/-6,03%, 10 min. after OLV, and returns to 95,31+/-4,62%, 30 min. after OLV; and group B - from 99,09+/-0,6% during TLV, to 92,92+/-5,2%, 10 min. after OLV, and returns to 95,89+/-3,78%, 30 min. after OLV); also, the average values of Qs/Qt in two examined groups demonstrate dynamic changes during operative monitoring - in the group A begins with quantity < 1% in T0, increases to 8,03+/-10,59% in T2, and in T3

decreases to $3,94 \pm 6,21\%$; in the group B, it begins with value $<1\%$ in T0, increases to $10,93 \pm 10,8\%$ in T2, and in T3 decreases to $4,82 \pm 7,58\%$. The statistically significant differences for PaO₂, SaO₂ and Qs/Qt, inside the groups A and B, show that after a certain time from initiating of OLV (after 10 min.), hypoxia develops with drop of values of PaO₂ and SaO₂, as well as increase of the quantity of intrapulmonary shunt. The subsequent decrease of Qs/Qt in the fourth measurement (T3), illustrates the development of HPV in this period of time, over and above the decrease of the shunt fraction 30 min. after the beginning of OLV in lateral decubitus position during thoracotomy / thoracoscopy.

Other factors that could reduce PaO₂ are cardio-vascular and hemodynamic effects of thoracic epidural anesthesia (TEA): the decline of HR, SAP, stroke volume and cardiac output (CO), as a result of the blockade of sympathetic nervous system. Even more, the systemic consequences from the absorption of local anesthetics could lead to circulatory changes, like reduction of CO (47,48).

The results in our study demonstrated that the average values of HR/min. in both groups showed increase during operative monitoring from T0 to T3 (group A $85,56 \pm 12,53$ to $88,53 \pm 12,19$ and group B $76,16 \pm 13,15$ to $81,6 \pm 13,49$). The difference in average values for HR/min. recorded between groups A and B is statistically significant in T0 and T3 ($p < 0,05$), whilst in T1 and T2 it isn't statistically significant ($p > 0,05$). Inside the groups A and B, the variation in average values of HR/min. is statistically non-significant ($p > 0,05$). But, as it is demonstrated by the comparison of the data from intraoperative arterial gas analysis between the groups A and B, obviously this dissimilarity for HR/min. which is a result of the depth of anesthesia, as well as administration of TEA in group B, doesn't lead to an important difference in arterial oxygenation and shunt fraction between two groups. The other hemodynamic parameter which is intraoperatively monitored in our patients, SAP/mmHg, doesn't differ considerably among two groups, which advocates even more the previous statement – that the mentioned hemodynamic diversity in our patients doesn't have any significance in the process of delivering the conclusions in this study.

The degree of difficulty of the disease in non-dependent lung is also a critical determinant of the quantity of blood flow in non-dependent lung. If this lung is seriously 'diseased', there could be a preoperative fixed reduction of its blood flow, thus its 'collapse' may not cause considerable increase in shunt fraction.

In fact, Hurford et al. (40) in their prospective study provided evidence that the patients who had in affected lung less than 45% of their pulmonary blood flow, had notably smaller risk for development of hypoxia during OLV.

As literature shows, the administration of sodium nitroprussid or nitroglycerin – which is supposed to diminish hypoxic pulmonary vasoconstriction (HPV) in patients with COPD (chronic obstructive pulmonary disease), who have fixed reduction of their pulmonary vascular bed, doesn't initiate enhancement of the shunt. This observation supports the fact that the affected (diseased) pulmonary vasculature is incapable to develop HPV (49, 50). On the other hand, these medicaments augment the shunt fraction in patients with acute regional lung disease, who otherwise have normal pulmonary vascular bed. *Due to this fact, it is more likely that greater degree of shunt through non-dependent lung during OLV will develop in patients who should be subjected to thoracotomy because of non-pulmonary disease.*

This statement was confirmed with our patients also. In three patients with diagnosis Ca esophagi who underwent thoracotomy with intraoperative utilization of OLV (one in group A and two in group B), are recorded values of Qs/Qt during OLV that are very close to the maximal registered ones in two groups of patients. However, this clinical feature could be only understood as higher probability, but not as a rule.

OLV has much less effect on PaCO₂ than on PaO₂ (52). During clinical use of OLV, the respiratory rate is adjusted in order to maintain a 'safe' level of elimination of CO₂, guided by the measurements of capnography (End-tidal CO₂) and/or arterial gas analysis. Sometimes the minute ventilation achieved by employing these ventilatory parameters could be minor than the ideal one. The minute ventilation could be limited due to air trapping, not only in patients with COPD, but also in patients with normal preoperative lung function. Controlled hypoventilation is called permissive hypercapnia; furthermore, it is demonstrated as a harmless technique in patients with ARDS (acute respiratory distress syndrome), even with values of pH of 7.15 and of PaCO₂ up to 80 mm Hg (10,66 kPa) (53). Maintaining adequate oxygenation (PaO₂ > 60 mm Hg, i.e. 8 kPa) is crucial during this period. The secure level of acute hypercapnia for patients under general anesthesia is not known, but the values in this range could be adequate.

In our study, the average (middling) values of PaCO₂/kPa in both examined groups show increase during the operative monitoring (group A and B - from 5,4 to 6,4 kPa). The difference in average values of PaCO₂/kPa between two groups (A and B) is not statistically significant ($p > 0,05$), whereas this variation inside the groups A and B is statistically significant ($p < 0,05$). Precisely this difference illustrates the appearance of already mentioned permissive hypercapnia during OLV (which is expected, although RR/min. was increased to facilitate preservation of PaCO₂ in normal ranges).

In experimental studies using thoracic epidural anesthesia, TEA didn't inhibit HPV (36, 54). Ishibe et al. (36) demonstrated enhanced response of HPV and improved arterial oxygenation during OLV and TEA in dogs, which was a result of decreased PvO₂ and CO owing to the blockade of sympathetic nerve activity. The sensitivity of these variables depends on the extent of lung tissue exposed to hypoxia. In this study the authors used left lower lobe-LLL, which represents approximately one sixth of total lung volume. The hypoxic ventilation reduced the blood flow of LLL and PaO₂. The extent of these changes is "realistic", if the pulmonary artery of LLL is supposed to contract maximally. It is obvious that TEA inhibited sympathetic efferent nerve activity in dogs from this study. Because of that, it is probable that TEA-induced changes in systemic hemodynamics resulted in enhancement of HPV, since it is well known that decrease of CO, PAP and PvO₂ augment HPV response. However, in this study, the effects of TEA-induced enhancement of HPV on pulmonary hemodynamics and systemic oxygenation were minimal, most probably because the relative extent of hypoxic lung tissue was minor and the intensity of basic HPV response was already near the maximal level before commencement of TEA.

Brimioulle et al. (54) noticed enhancement of HPV during epidural blockade, but without an effect of the previous α - or β -blockade, meaning that all its consequences on pulmonary circulation are connected with sympathetic blockade.

On the contrary, Garutti et al. (55) observed higher shunt fractions (39,5%) and lower values of PaO₂ (120 mmHg) during OLV in TEA group, compared with TIVA group in patients who underwent thoracotomy. They concluded that TEA could not be recommended for use in thoracic surgery when OLV is needed (55). Nonetheless, their study has great limitations. CO and PvO₂, which are important factors for assessment of the impact of HPV, were not measured. The venous blood for gas analysis used to determine shunt fraction, was taken using central venous catheter (55). TEA was combined with propofol. Kasaba et al. (56) reported that hypotensive effects of propofol are additive to those of epidural anesthesia. Garuti et al. (55) used iv ephedrine only in TEA group when systolic arterial pressure dropped below 100 mmHg. Ephedrine is partial α and β agonist (57). This explains the

similarity of compared values of HR and SAP in both groups, but does not make clear the worst oxygenation, because it seems that ephedrine provides an increase of PaO₂ without alteration of intrapulmonary shunt during OLV in thoracic surgery. For the reason that copies of β -adrenergic subtype are found in porcine tissue of the lungs and left ventricle (β_1 : 67/72; β_2 : 33/28; β_3 : 2/25) (58), it can't be excluded that augmentation of cardiac output through β -receptor activity could be responsible for increasing the shunt fraction and poorer oxygenation in the study of Garutti et al. (55).

Hackenberg et al. (59), by using multiple elimination of inert gas for analysis of inequality of ventilation/perfusion matching, demonstrated that TEA didn't influenced the development of shunt, before and after induction in general anesthesia.

The reason for the eventual fall of PaO₂ while using TEA could be as follows: pulmonary vasculature is innervated by autonomous nervous system. Stimulation of the sympathetic nerves in the lungs causes enhancement of PVR (pulmonary vascular resistance), as a result of the activation of α -receptors in pulmonary vascular bed. The mediator released on the sympathetic nerve endings is norepinephrine (47, 48, 54). The blockade of the sympathetic nervous system with α -adrenergic antagonists or β -adrenergic agonists diminishes HPV, while β -adrenergic antagonists enhance this response. So, maybe the actual factor is the block of the activity of thoracic sympathetic system over pulmonary vascular response.

However, previously mentioned studies, like the one of Ishibe et al. (36), demonstrate that TEA didn't affect the primary pulmonary vascular tone during OLV, but slightly augmented the redistribution of blood flow away from hypoxic lobe and towards other well oxygenated lung areas.

The explanation lies in the fact that most of these studies were not completed under same conditions (for example, anesthetized patients, lateral decubitus position, atelectatic lung tissue).

Our results show that no statistically significant difference exists ($p > 0,05$) for Q_s/Q_t % between the groups A and B in all stages of measurements. This points to the fact that when two anesthetic techniques are compared, the use of combined anesthesia (GA plus TEA with local anesthetics) for thoracic surgery doesn't lead to bigger reduction of PaO₂ and greater increase of intrapulmonary shunt during OLV, than intravenous GA.

12. Summary

Based on the experiences of other authors from literature, as well as on our own research, we would provide following recommendations for safe anesthesia during OLV, regarding **the principles of ventilation:**

- OLV should be established in a way that the lungs would inflate adequately, but minimizing the intra-alveolar pressure at the same time, in order to prevent redistribution of pulmonary blood flow towards upper (non-dependent, non-ventilated) lung. It is not easy to accomplish this in practice.
- It seems reasonable to use initial FiO₂ of 50%, which could be increased up to 100%, as needed. This can't influence the real shunt in upper lung, but it improves oxygenation throughout alveoli with low V_a/Q_t relations in lower lung.
- „Over inflation“ of one lung (volutrauma) is harmful and leads to acute lung injury. Deflation and inflation of the operated lung, with a possibility of ischemic/reperfusion injury, is also included in lung trauma. Application of very low tidal volumes improves the outcome of mechanically ventilated patients (50, 51, 56).

- Arterial hypoxemia is obviously undesirable, but in spite of everything, it might be better to accept PaO₂ a little lower than preoperative value, than to undertake measures like inflation of the upper lung, which could present an obstacle for surgical intervention and could prolong it (21, 22, 42, 59, 66, 67).

At the end, it could be concluded that:

- In patients subjected to OLV in general anesthesia (GA), hypoxia develops, with decrease in PaO₂ and increase of the value of intrapulmonary shunt, a period of time after initiation of OLV (after 10 min.), with subsequent return of Q_s/Q_t towards lower values (after 30 min. of OLV), because of the development of compensatory mechanisms (HPV).
- In patients subjected to OLV managed with thoracic epidural anesthesia (TEA) combined with general anesthesia (GA), hypoxia occurs, also, with fall of PaO₂ and increase of the value of intrapulmonary shunt, 10 min. after commencement of OLV, and returning of Q_s/Q_t towards normal values (approximately), about 30 min. after initiated OLV.
- Thoracic epidural anesthesia (TEA) doesn't lead to augmentation of hypoxia and enhancement of the shunt fraction during OLV.

13. Glossary of terms

1. **LDP** = lateral decubitus position
2. **OLV** = one lung ventilation
3. **TLV** = two lung ventilation
4. **(i)PEEP** = (intrinsic) positive end expiratory pressure
5. **CPAP** = continuous positive airway pressure
6. **V_a/Q_t** = ventilation/perfusion ratio
7. **Q_s/Q_t⁰%** = intrapulmonary shunt
8. **PA** = alveolar pressure
9. **P_{pa}** = pulmonary artery pressure
10. **P_{pv}** = pulmonary venous pressure
11. **P_{isf}** = pulmonary interstitial pressure
12. **P_{pl}** = pleural pressure
13. **PO₂** = partial pressure of oxygen (a = in arterial blood, v = in venous blood, A = in the alveoli)
14. **PCO₂** = partial pressure of carbon dioxide (a = in arterial blood, v = in venous blood, A = in the alveoli)
15. **FRC** = functional residual capacity
16. **FiO₂** = inspired oxygen fraction
17. **PVR** = pulmonary vascular resistance
18. **HPV** = hypoxic pulmonary vasoconstriction
19. **TIVA** = total intravenous anesthesia
20. **MAC** = minimal alveolar concentration
21. **TEA** = thoracic epidural anesthesia
22. **GA** = general anesthesia
23. **FOB** = fiber-optic bronchoscope
24. **ARDS** = acute respiratory distress syndrome
25. **PPPE** = post pneumonectomy pulmonary edema

26. **COPD** = chronic obstructive pulmonary disease
27. **I : E** = inspiration : expiration
28. **ASA** = „American Society of Anesthesiologists“ (classification)
29. **SaO₂** = oxygen saturation of arterial blood
30. **AST** = aspartate amino transferase
31. **ALT** = alanine amino transferase
32. **EF** = ejection fraction of the heart
33. **CO** = cardiac output
34. **FEV₁** = forced expiratory volume in 1st sec.
35. **FVC** = forced vital capacity
36. **VC** = volume controlled mechanical ventilation
37. **PC** = pressure controlled mechanical ventilation
38. **HR** = heart rate
39. **ECG** = electrocardiography
40. **MAP** = mean arterial pressure
41. **RR** = respiratory rate
42. **SAT%** = oxygen saturation from pulseoximetry
43. **Cc'O₂** = oxygen content of pulmonary capillary blood
44. **CaO₂** = oxygen content - ml O₂/100 ml arterial blood
45. **CvO₂** = oxygen content - ml O₂/100 ml venous blood
46. **LLL** = lower left lobe
47. **Hb** = hemoglobin
48. **1.39** = Hifner coefficient (1g Hb binds 1.39 ml O₂ when totally saturated)
49. **0.0031** = coefficient of oxygen dissolution in plasma
50. **FFP** = fresh frozen plasma
51. **SAGM** = packed erythrocytes
52. **LMWH**=low molecular weight heparin

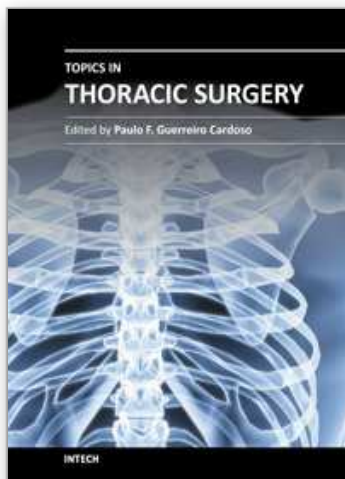
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