The influence of cardiopulmonary bypass on respiratory dysfunction in early postoperative period

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Key words: *lung injury, cardiopulmonary bypass, intrapulmonary shunt, atelectasis.*

Summary. *Background and objective. Pulmonary dysfunction is one of the most serious problems in an early postoperative period after cardiac surgery. This study was designed to reveal the impact of performed cardiopulmonary bypass on pulmonary function during early postoperative period by evaluating the intrapulmonary shunt.*

Material and methods. Twenty-one patients undergoing elective myocardial revascularization surgery were analyzed. The patients were divided into two groups. Group 1 included 11 patients who underwent cardiac surgery on cardiopulmonary bypass. Group 2 included 10 patients who underwent cardiac surgery without cardiopulmonary bypass. Preoperative data were similar in the both groups. Blood gas analysis for intrapulmonary shunt calculations was made at 20 minutes after the induction of anesthesia and at 4 hours after the surgery. Intrapulmonary shunt size (Qs/Qt) was also calculated and the records were studied for additional data.

Results. At 4 hours after surgery Qs/Qt increased, compared to the preoperative data in Group 1 (from 8.6±2.1 to 16.8±2.6%, $p<0.02$). Intrapulmonary shunt was great in Group 1 compared with Group 2 at four hours after the surgery (16.8±2.6 and 7.8±2.1%, $p<0.02$). In Group 1 80 % of alterations in a pulmonary function were caused by atelectasis, detected by chest X-ray. In Group 2 no increase in intrapulmonary shunt and no atelectasis were determined.

Conclusions. Arterial hypoxemia and increase in intrapulmonary shunt (due to atelectasis) have proven that alterations in pulmonary function are found more often and are more pronounced in patients after surgery on cardiopulmonary bypass.

Introduction

Pulmonary dysfunction is one of the most serious factors in an early postoperative period after cardiac surgery (1). Many studies have proven that postoperative pulmonary lesions occur in all hospitals worldwide. Pulmonary dysfunction prolongs mechanical ventilation, intensive care in ICU, total duration of hospitalization time and increases treatment costs (2, 3). During the last few decades, many pathogenetic factors and mechanisms with negative influence on pulmonary function (factors associated with anesthetic agents, myocardial protection, the extent of surgery, cardiopulmonary bypass and nonspecific inflammatory response syndrome) were found. The cause of postoperative pulmonary dysfunction remains unclear. In spite of new surgical approach, better extracorporeal oxygenation techniques and progress in anesthesiology, organ dysfunction due to cardiopulmonary bypass still remains an object of many clinical and experimental studies. Studies and developments of new methods for decreasing pulmonary complications are going on and prevention of such complications is becoming even more relevant.

The *aim* of the study was to evaluate the influence of cardiopulmonary bypass (CPB) on pulmonary function and intrapulmonary shunt.

Material and methods

Patients were selected according to the protocol, taking into account concomitant disorders, preoperative left ventricular ejection fraction (LVEF) and preoperative status according to ASA. The study consisted of two groups. Eleven patients in Group 1 underwent typical on-pump coronary artery bypass grafting (CABG) surgery, whereas 10 patients in Group 2 underwent off-pump CABG surgery. The patients' preoperative data are shown in Table 1. No statistically significant difference between groups was found.

Preoperative premedication and anesthesia were standard – analgesic anesthesia was used. Parameters

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of mechanical ventilation were constant ($paCO_2$ – 35–45 mm Hg before and after CPB). CABG was performed via a median sternotomy. In Group 1, a standard CABG procedure was performed using roller pump and cold crystalloid cardioplegia for myocardial protection. Mechanical ventilation during CPB was interrupted. In Group 2 CABG procedure was performed on a beating heart without CPB. After the surgery, all the patients were transferred to the ICU and were managed and monitored according to usual routine requirements.

Intrapulmonary shunt (Qs/Qt) was calculated at 20 minutes after the induction of the anesthesia and at 4 hours after the surgery. Blood samples for Qs/Qt calculation were withdrawn from the pulmonary artery (mixed venous blood) and the radial artery (arterial blood) in no longer than 30 seconds interval. Intrapulmonary shunt size (Qs/Qt) was calculated accordance route clinical shunt equation and expressed in percentage:

$$Qs/Qt=CcO_2–CaO_2/CcO_2–CvO_2,$$
$$CaO_2=(Hb\times1.34\times SaO_2)+(0.0031\times PaO_2),$$
$$CvO_2=(Hb\times1.34\times SvO_2)+(0.0031\times PvO_2),$$
$$CcO_2=(Hb\times1.34\times ScO_2)+(0.0031\times PcO_2),$$

where: Hb is hemoglobin content in grams per 100 ml of blood;

SaO_2 and PaO_2 – hemoglobin saturation expressed in decimal form and partial pressure of oxygen in mmHg in arterial blood, respectively;

SvO_2 and PvO_2 – hemoglobin saturation expressed in decimal form and partial pressure of oxygen in mmHg in mixed venous blood, respectively;

ScO_2 and PcO_2 – hemoglobin saturation expressed in decimal form and partial pressure of oxygen in mmHg in end pulmonary capillary blood, respectively.

The changes in the chest X-ray on the first postoperative day, the duration of mechanical ventilation, the duration of stay in ICU, and the doses of medication used for anesthesia were compared between the studied two groups. The data are presented as mean ± standard deviations (M±SD). Statistical significance was checked by t test. The results were considered to be statistically significant when $p<0.05$.

Results

The doses of anesthetic agents differed in both groups. During anesthesia for off-pump CABG, the doses of upload analgesics (fentanyl) decreased statistically significantly (19.75±1.72 and 14±1.33 μg/kg, respectively; $p<0.05$); doses of benzodiazepines were significantly lower as well: doses of midazolam were 15.45±3.50 and 12.5±2.63 mg, respectively ($p<0.05$). The doses of thiopentone differed non-significantly (709.09±510.91 and 510.0±272.64 mg; $p>0.05$). The doses of muscle myorelaxants differed slightly (0.166±0.05 and 0.145±0.028 mg/kg; $p>0.05$). The need for inhalational agents was very similar. The total doses used during anesthesia are shown in Table 2.

The duration of artificial lung ventilation in both studied groups did not differ significantly (6.28±2.96 and 5.65±2.40 hours, respectively) (Fig. 1). Early extubation together with decreased time of stay in ICU was observed for both group patients. The difference between the groups was statistically non-significant: 1.18±0.40 and 1.70±1.06 days, respectively ($p>0.05$).

During on-pump surgery, the average positive fluid balance was 1754.54±1006.09 ml. During off-pump surgery the average positive fluid balance was much

Table 1. **Preoperative data**

Features	I (n–11)	II (n–10)	P
Sex m/f (%)	9/2 81.8/18.2 (%)	9/1 90/10 (%)	0.593
LVEF	44.9±7.07	45.7±9.15	0.83
Age (years)	61±7.96	57.7±7.56	0.25
ASA III class	11 (100%)	10 (100%)	
Concomitant disorders AH DM Arrhythmias GI diseases	 8 (72.7%) 0 1 (9.1%) 0	 6 (60%) 1 (10%) 0 1 (10%)	0.52

LVEF – left ventricular ejection fraction; AH – arterial hypertension; DM – diabetes mellitus; GI – gastrointestinal; M±SD – mean ± standard deviation.

Table 2. **Anesthetic agents and their total doses**

Medications	I (n-11)	II (n-10)	P
Fentanyl (μg/kg)	19.75±1.72	14±1.33	0.004
Midazolam (mg)	15.45±3.5	12.5±2.63	0.043
Thiopentone (mg)	709.09±280.9	510±272.4	0.12
Inhalational anesthetics (% of all patients)	9 (81.8%)	10 (100%)	0.155
Pipecuronium (mg/kg)	0.166±0.05	0.145±0.028	0.27

M±SD – mean±standard deviation.

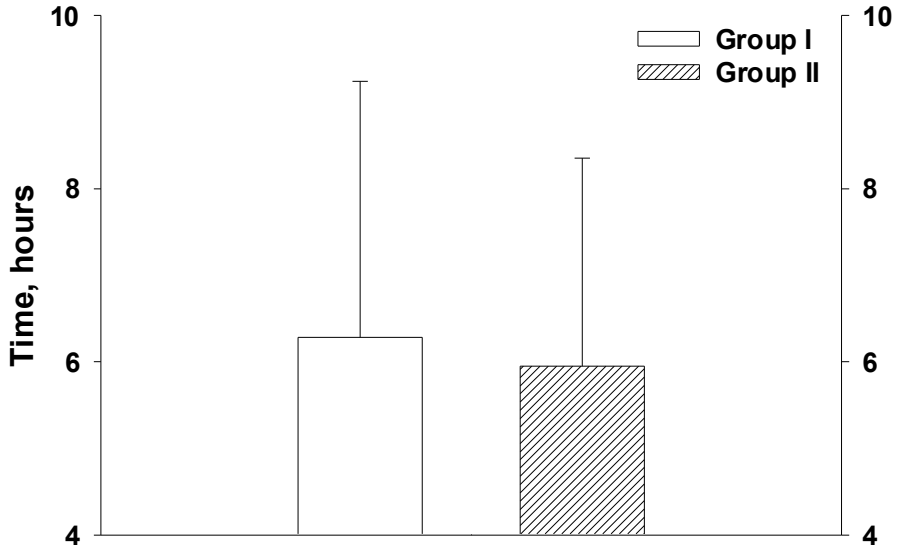

Figure 1. **The duration of postoperative mechanical lung ventilation**

lower 195±170 ml ($p<0.001$). Similar results were found when evaluating the fluid balance during the first postoperative day in both groups. The difference between the groups was statistically significant 954.54±567.37 and 88.89±116.67 ml, respectively ($p<0.001$) (Fig. 2).

Patients in Group 1 had more lesions identified by chest X-ray than in Group 2 (11 (100%) and 6 (60%) cases); respectively lesion in the left pleural cavity was found in 3 (27.3%) patients of Group 1, atelectasis was revealed in 11 (52.4%) patients: in Group 1 – 9 (81.8%) and in Group 2 – 2 (20%), respectively ($p<0.05$) (Fig. 3).

Pulmonary dysfunction with arterial hypoxemia was dominating complication in both groups: in Group 1 it was observed for 3 (27.3%) patients and in Group 2 – for 2 (20%) patients, respectively ($p<0.05$).

Intrapulmonary shunt size evaluation showed that at 4 hours after the surgery intrapulmonary shunt size statistically significantly increased in Group 1 patients from 8.64±7.22 to 16.85±8.62%, $p<0.05$ (Fig. 4). The difference between the groups was significant at 4 hours after the surgery (16.8±2.6 and 7.8±2.1%, $p<0.05$). Meanwhile, patients in Group 2 had insignificant increase in Qs/Qt.

Increase of intrapulmonary shunt is found in patients undergoing on-pump CABG surgery with atelectasis diagnosed by chest X-ray. The correlation between the intrapulmonary shunt size and intrathoracic lesions revealed by X-ray is shown in Fig. 5.

Discussion

In order to analyze the influence of CPB on pulmonary functions the data on 11 patients undergoing on-pump CABG surgery and 10 patients, undergoing off-pump CABG surgery were analyzed. This study demonstrated that patients who have had off-pump surgery needed less fentanyl and midazolam for anesthesia, but the duration of mechanical lung ventilation did not differ significantly. All patients in both the groups experienced early extubation.

In the early postoperative period pulmonary lesions were more significant in on-pump group, as it was proved in our earlier studies (4–6). X-ray revealed that

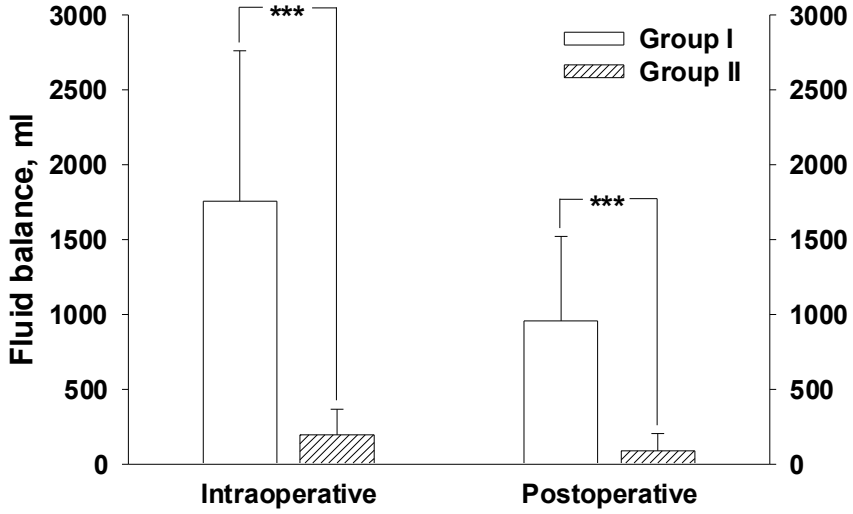

Figure 2. **The fluid balance**

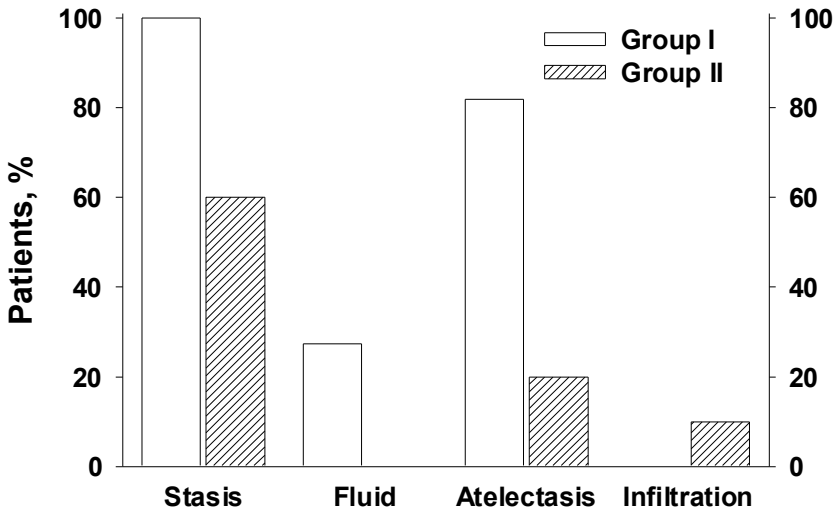

Figure 3. **Thoracic alterations revealed by X-ray**

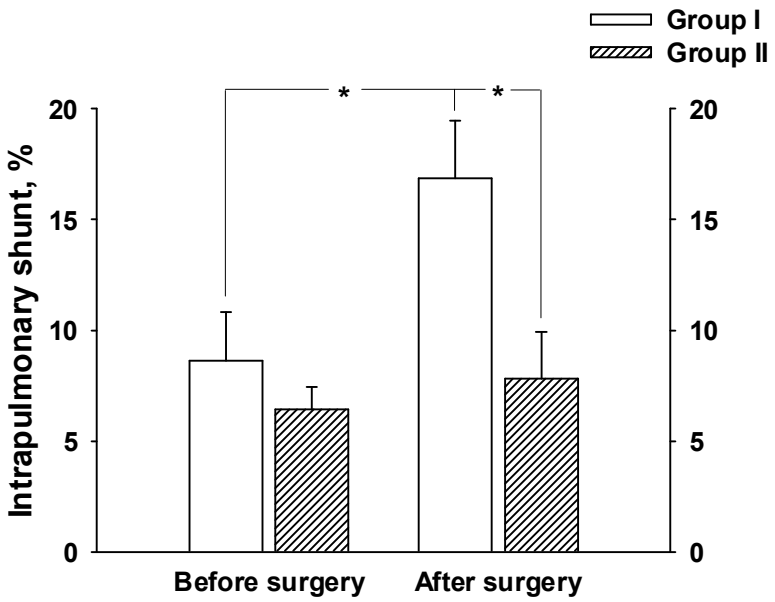

Figure 4. **Intrapulmonary shunt size changes**

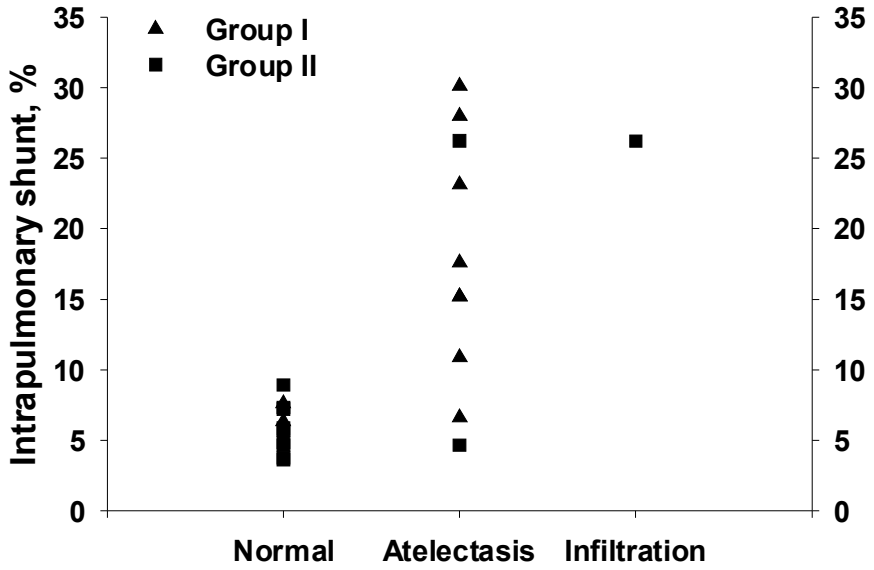

Figure 5. **Qs/Qt size in correlation with thoracic alterations revealed by X-ray ($p<0.05$)**

pulmonary lesions were mainly determined by atelectasis (found in 81.8% of the patients). Other findings were caused by pleural lesion (effusion or air in the pleural cavity). D. Johnson and coworkers (7) noticed that all patients after on-pump CABG surgery experience atelectasis.

Early increase in intrapulmonary shunt fraction (from 8.6±2.1 to 16.8±2.6%, $p<0.05$) was found in Group 1. In patients undergoing off-pump surgery intrapulmonary shunt size did not increase significantly, and the isolated cases were related to the increased oxygen tension in mixed venous blood (PvO_2). This may happen in cases of the intracardiac blood shunting from left to right side of the heart. In Group 2, atelectasis was found significantly more rarely. It has been proven that CPB causes pulmonary lesions by inducing atelectasis. Poorly oxygenated blood from the atelectatic areas lowers the partial oxygen tension in the arterial blood (8). We suppose that atelectasis in the post-bypass period is the main cause of intrapulmonary shunt and poor arterial oxygenation. The data of our study brings up to date the proposition by Y. Weiss, published in 2000, that increase in intrapulmonary shunt size is a sign of an acute disorder, i. e. atelectasis (9).

The pulmonary alterations must be diagnosed as quickly as possible and treated timely in a proper way. Usual blood gas sample provides not enough information about essential mechanisms of lung lesions (10, 11). According to the data of our study, the intrapulmonary shunt size is essential in determining the alterations of oxygenation. Evaluation of the intrapulmonary shunt Qs/Qt size and arterial-venous oxygen concentration difference changes are the main parameters for selecting the method of treatment and estimating its effectiveness.

In summary, we can state that the complex use of up-to-date means and methods (low fentanyl doses, optimal myocardial protection, normothermic CPB, minimally positive fluid balance, and short mechanical lung ventilation) reduce early postoperative organ dysfunction cases, and shorten the stay in ICU. The proper evaluation of alterations in respiratory function and analysis of pulmonary state by estimating intrapulmonary shunt size in early postoperative period allows to judge alterations in perspective, justify them clinically, and improve the quality of treatment.

Conclusions

1. Pulmonary alterations are more common after on-pump CABG surgery: patients who underwent on-pump surgery had more alterations revealed by chest X-ray; in early postoperative period 80% of patients undergoing on-pump surgery, experience atelectasis; atelectasis causes arterial hypoxemia ($p<0.05$) and increase in intrapulmonary shunt fraction ($p<0.05$).

2. Estimation of intrapulmonary shunt size predicts atelectasis formation.

Recommendations

It is recommended to estimate the intrapulmonary shunt size besides the other investigations of pulmonary function for patients in ICU. Calculation of intrapulmonary shunt size is simple and unsophisticated procedure.

Dirbtinės kraujo apytakos įtaka kvėpavimo sutrikimams ankstyvuoju pooperaciniu laikotarpiu

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Raktažodžiai: plaučių pažeidimas, dirbtinė kraujo apytaka, intrapulmoninis šuntas, atelektazė.

Santrauka. *Darbo tikslas.* Įvertinti plaučių funkcijos pokyčius ankstyvuoju pooperaciniu laikotarpiu po širdies operacijų matuojant intrapulmoninio šunto frakcijos dydį.

Tirtųjų kontingentas ir tyrimo metodai. Ištirtas 21 pacientas po planinių miokardo revaskulizacijos operacijų. Tiriamieji suskirstyti į grupes pagal operacijos apimtį: pirmą grupę sudarė 11 ligonių, operuotų su dirbtine kraujo apytaka, antrą grupę – 10 ligonių, operuotų be dirbtinės kraujo apytakos. Abiejų grupių ligonių prieš-operaciniai ir operaciniai statistiniai duomenys tarpusavyje nesiskyrė. Kraujo dujų tyrimai šuntui apskaičiuoti atlikti praėjus 20 minučių nuo įvadinės anestezijos ir praėjus 4 val. po operacijos. Šuntinio kraujo kiekis (Qs/Qt) apskaičiuotas procentais (apskaičiuota pagal klinikinio šunto formules).

Rezultatai. Ligoniams, operuotiems su dirbtine kraujo apytaka, nuo operacijos praėjus 4 val., nustatytas reikšmingas Qs/Qt padidėjimas (nuo 8,6±2,1 iki 16,8±2,6 proc., kai $p<0,02$). Šių parametrų skirtumai tarp ligonių grupių statistiškai patikimi (16,8±2,6 ir 7,8±2,1 proc., kai $p<0,02$). Operuotųjų su dirbtine kraujo apytaka grupėje plaučių funkcijos sutrikimą 80 proc. sąlygojo atelektazės, nustatytos rentgenologinio tyrimo metu. Operuotų be dirbtinės kraujo apytakos grupėje reikšmingo plautinio šunto padidėjimo neužfiksuota, nenustatyta ir atelektazių.

Išvados. Plaučių funkcijos sutrikimai patikimai dažnesni po operacijų su dirbtine kraujo apytaka, nes ankstyvuoju pooperaciniu laikotarpiu ligoniams, operuotiems dirbtinės kraujo apytakos sąlygomis, nustatyta arterinė hipoksemija, padidėjo intrapulmoninio šunto frakcija, kurios priežastis – atelektazės atsiradimas.

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Received 3 September 2003, accepted 7 November 2003
Straipsnis gautas 2003 09 03, priimtas 2003 11 07