AN IMPORTANT PARAMETER USED IN CARDIAC SURGERY: MIXED VENOUS OXYGEN SATURATION

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To investigate the changes in blood gas analysis results of peripheral arteries, pulmonary artery and right atrium in coronary artery bypass surgery patients during cardiopulmonary bypass (CPB) and the postoperative period.
45 patients who had coronary artery bypass surgery at Trakya University, Faculty of Medicine, Department of Cardiovascular Surgery were included in this study. Following the induction of anesthesia, a thermo dilution catheter was placed and PO_2, PCO_2, pH and O_2 saturation were measured in the blood samples taken from the right atrium, pulmonary artery and peripheral artery. Same measurements were repeated at the beginning of CPB, during hypothermia (28°C), at the end of CPB and 2, 6, 12 and 24 hours after CPB.
There were no statistically significant differences between the pulmonary artery and the right atrium in terms of PO_2 and O_2 saturation values before CPB (pulmonary artery PO_2=49.0± 12.4 and O_2 saturation= 79.1± 6.0, right atrium PO_2=44.0±11.3 and O_2 saturation= 75.3±10.8). Oxygenation was higher in the pulmonary artery (PO_2=78.2±40.2 and 191.1±94.5, O_2 saturation 87.1±7.8 and 86.1±11.9) compared to right atrium (PO_2= 47.8±10.4 and 48.8±7.8, O_2 saturation 78.0±9.3 and 68.4±11.2) at the beginning of CPB and during hypothermia. During CPB, when body temperature reached 37°C, PO_2 and O_2 saturation differences between right atrium and pulmonary artery disappeared (pulmonary artery, PO_2= 40.3±5.3 and O_2 saturation= 70.9±7.0, in right atrium PO_2=42.7±8.5 and O_2 saturation=71.3±8.8).
Significant differences may appear in PO_2 values from the right atrium, pulmonary artery and radial artery during CPB. For this reason, follow up of SvO_2 from pulmonary artery may give inaccurate results.

Key words: open heart surgery, mixed venous oxygen saturation, coronary artery bypass grafting

Several parameters, including mixed venous oxygen saturation (SvO_2) are utilized for the hemodynamic monitoring of patients in intensive care units [1-4]. SvO_2, defined as the percentage of hemoglobin binding to oxygen in the blood returning to the right side of the heart, gives an estimate of the perfusion in peripheral tissues. A healthy individual uses approximately 25% of arterial oxygen content under resting conditions, and the unused fraction remaining in venous blood is referred to as the mixed venous oxygen saturation. This value is between 60 and 80 percent in a healthy individual (average 75%) [5].

The factors that may alter the mixed venous oxygen saturation are depicted in the following formula [6-8]:

$$SvO_2 = \text{Arterial } O_2 \text{ satutarion} - \left(\frac{O_2 \text{ Consumption of the body}}{CO\,(L/min) \times Hb(g/L) \times 1.34} \right)$$

(SvO_2=mixed venous oxygen saturation, CO= cardiac output, Hb= Hemoglobin)

As shown in the formula above, SvO_2 is directly proportional to cardiac output (CO), hemoglobin (Hb), arterial O_2 saturation, and inversely related with the oxygen consumption of the body. An increase in the oxygen consumption or a decrease in the oxygen content of arteries can lead to a fall in SvO_2. Anemia, low cardiac output, desaturation of the arterial oxygen, and increased oxygen consumption are associated with a decreased SvO_2. On the other hand, increased supply of oxygen to the tissues, decreased utilization of oxygen, and decreased extraction of oxygen from tissues results in an increase in SvO_2 [6].

While the change in oxygen saturation in inferior vena cava, superior vena cava, jugular vein, hepatic vein or pulmonary artery has been frequently explored in critical patients during the postoperative periods or in intensive care units [1,3,9-14], studies investigating the alterations in SvO_2 during cardiopulmonary bypass are relatively scarce [6,15,16].

Blood samples are taken from venous cannulas for the evaluation of SvO_2 during CPB. However there are few studies concerning pulmonary artery blood gas changes during CPB.

This study was undertaken to examine the alterations in blood gases in peripheral arteries, right atrium and pulmonary arteries during CPB and postoperative first 24 hours.

PATIENTS AND METHODS

A total of 45 patients undergoing coronary artery bypass grafting (CABG) under CPB in our unit participated in this study. The patients that had valvular surgery, congenital cardiac defects, perioperative MI and patients undergoing beating heart surgery were not included in this study. The mediastinum was opened via median sternotomy in all subjects. A membrane oxygenator (Dideco Mirandola, Italy) and a roller pump (Stöckert, Germany) were used. The perfusion rate was kept at and above 2.4 $L/m^2/min$ during CPB. All operations were performed under CPB, which was established via the cannulation of the ascending aorta and right atrium (two stage cannula). Myocardial protection was provided by antegrade cold hyperkalemic crystalloid cardioplegic solution (Plegisol, Abbot Laboratories, Chicago, IL, USA) (10 ml/kg) and it is repeated at every 20 minutes. Neutralization of heparin was done by protamine HCl (Protamine 1000, Roche) with a ratio of 1:1. Immediately after induction of the anesthesia, a thermodilution catheter was placed into the right internal jugular vein (7.5 F Opticatch, Abbot, North Chigaco, IL, ABD). Blood samples were collected from the lumens of thermodilution catheters opening into the right atrium and pulmonary artery, and from the peripheral artery cannula. Then blood gas analysis (partial O_2 pressure=PO_2, partial CO_2 pressure=PCO_2, pH, O_2 saturation and hematocrit) was performed. The same measurements were repeated at the commencement of CPB, during hypothermia (28°C), at the termination of CPB, and 2, 6, 12 and 24 hours after the termination of CPB.

Statistical analysis

The results are expressed as mean ± SD. All statistical tests were performed with SPSS 10.0 software. Pearson correlation analysis was used for the changes in peripheral arterial saturation and SvO_2, and Wilcoxon test was used for the comparison of right atrial and pulmonary artery data. A p value lower than 0.05 was considered as significant.

RESULTS

Demographic and operative variables of the participants are shown in Table 1. The mean age was 58.0 ± 10.0 and the mean number of used grafts was 2.6 ± 0.7. The mean cardiopulmonary bypass time (CPBT) was 103.0 ± 26.0 min, and the mean cross-clamp time (CCT) was 58.0 ± 21.0 min.

Blood gas measurements of simultaneously collected blood samples from radial artery, right atrium and pulmonary artery are shown in Table 2.

The comparison between pulmonary artery and right atrium in terms of SvO_2 and PO_2 values by Wilcoxon test revealed significant (p=0.000) differences during the commencement of CPB and during hypothermia.

There were statistically significant differences in PO_2 values between the right atrium and pulmonary artery for the first measurement (p=0.002), 6th measurement (p=0.001), and for the 2nd, 3rd, 4th, 5th and the 7th measurements (p=0.000); no difference was observed for the 8th measurement (p=0.920).

Statistically significant pH changes were found in all measurements [in 2nd, 3rd, 4th, 7th measurements (p=0.000), in the 1st and the 5th measurements (p=0.001), in the 6th measurement (p=0.003), and in the 8th measurement (p=0.005)].

Changes in PO_2 are shown in Figure 1. While PO_2 values were similar for right atrium and pulmonary artery in the first measurement, PO_2 in the pulmonary artery was significantly higher throughout CPB.

Table 1. The demographic and operative characteristics of participants.

Age (yr)	58.0±10.0
Gender (M/F)	27/18
BMI	27.2±4.1
Graft	2.6±0.7
CPBT (min)	103.0±26.0
CCT (min)	58.0±21.0
EF (%)	52.4±9.3

BMI = Body-mass index
CPBT = Cardiopulmonary bypass time
CCT = Cross-clamp time
EF = Left ventricular ejection fraction

As can be seen from the pH changes in Figure 2, pH value was lower in the right atrium compared to those in the radial artery and pulmonary artery. Except for the 2nd measurement of the pulmonary artery, pH of the pulmonary artery was lower than the pH of radial artery.

Figure 3 shows the changes in oxygen saturation.

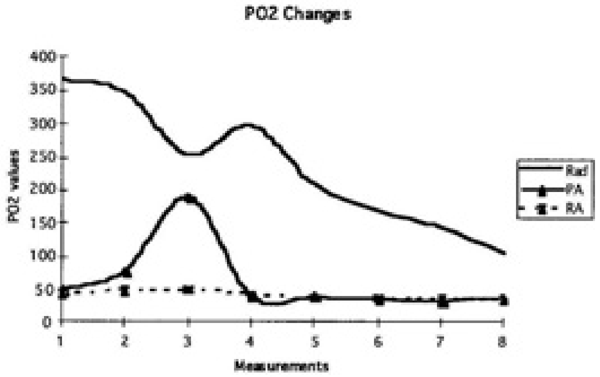
Arterial oxygen saturation was above 99%, except for the last two measurements. Saturation in the pulmonary artery was high during CPB, and later returned to the levels similar to those in the right atrium.

Decrease in the oxygen of air inhaled by the patient (FiO_2), and extubation are important factors for the progressive decline in PaO_2 and arterial oxygen saturation.

Table 2: The blood gas analyses

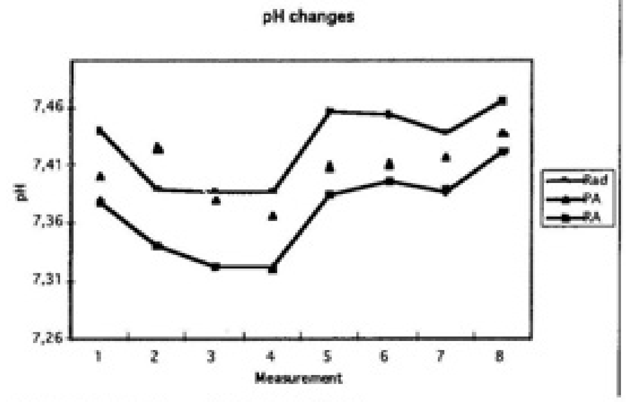
Mea.	Radial Artery				Pulmonary Artery				Right Atrium			
	PO_2	PCO_2	pH	Sat	PO_2	PCO_2	pH	Sat	PO_2	PCO_2	pH	Sat
A	366.9±104.2	34.9±5.3	7.44±0.06	99.9±0.4	46.0±12.4	41.3±4.9	7.40±0.05	78.1±6.0	44.7±11.3	43.6±4.2	7.38±0.05	76.3±10.8
B	347.3±78.4	39.3±6.3	7.39±0.06	99.8±0.2	78.2±40.6	39.0±8.6	7.43±0.13	87.1±7.8	47.8±10.1	45.9±7.4	7.34±0.06	78.0±9.3
C	253.6±51.9	39.2±7.2	7.39±0.06	99.6±0.8	191.1±94.5	38.0±5.8	7.38±0.08	86.1±11.9	48.8±7.8	46.8±8.7	7.32±0.05	71.3±11.2
D	298.8±106.9	38.9±6.0	7.39±0.06	99.7±0.5	40.3±5.3	43.1±3.3	7.37±0.04	70.9±7.0	42.7±8.5	47.5±6.7	7.32±0.07	68.4±8.8
E	208.4±82.3	34.7±5.6	7.46±0.06	99.4±0.6	38.1±5.2	40.9±5.5	7.41±0.05	73.1±5.7	36.7±7.0	43.8±9.7	7.38±0.08	70.4±8.4
F	169.9±43.8	34.1±4.9	7.45±0.06	99.3±0.6	36.1±4.2	40.0±4.0	7.41±0.05	66.2±8.4	36.1±7.2	42.8±8.3	7.40±0.06	68.8±10.1
G	144.0±50.2	38.0±4.3	7.44±0.06	98.8±1.7	37.2±3.8	40.0±4.2	7.42±0.04	67.9±6.6	38.0±6.0	42.8±5.7	7.39±0.06	69.6±9.2
H	105.9±36.9	36.8±5.2	7.47±0.05	95.9±9.8	36.0±6.1	42.8±3.7	7.44±0.04	67.8±8.3	35.0±7.1	43.3±5.6	7.42±0.05	65.4±9.1

A = Induction of anesthesia
B = At the beginning of CPB
C = Hypothermia (28°C)
D = Termination of CPB
E = 2 hours post-CPB
F = 6 hours post-CPB
G = 12 hours post-CPB
H = 24 hours post-CPB
Mea: measurement



1st measurement = During anesthesia
2nd measurement = Initiation of CPB
3rd measurement = Hypothermia during CPB
4th measurement = Termination of CPB
5th measurement = 2 hours post-CPB
6th measurement = 6 hours post-CPB
7th measurement = 12 hours post-CPB
8th measurement = 24 hours post-CPB

Rad = Radial artery
PA = Pulmonary artery
RA = Right atrium



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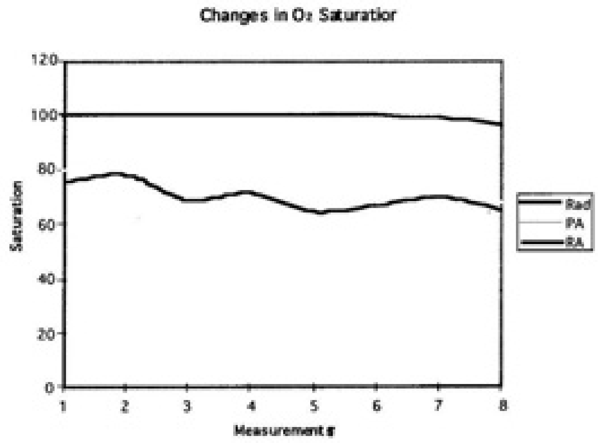
DISCUSSION

Because alterations in SvO_2 reflect the general status of the patient and the metabolism in peripheral tissues, this parameter is frequently used to monitor the tissue oxygen balance in patients undergoing cardiac surgery. While continuous monitoring of SvO_2 allows for the collection of instant information, measurement of blood gases to determine alterations in SvO_2 may be time consuming. Also, the site of blood sampling is important in the latter approach. Jugular bulbous venous oxygen saturation is commonly used to assess the cerebral perfusion [11,17].

Partial oxygen pressure and oxygen saturation from the inferior vena cava are higher compared to those in the superior vena cava and in the coronary sinus, thus blood samples obtained from this site can be misleading due to the overestimation of SvO_2. Since blood in the coronary sinus is the most desaturated blood in the body, saturation of the blood in right atrium should be decreased when it is mixed with the blood coming from the coronary sinus. This demonstrates that brain and heart use the blood they receive more efficiently compared to the kidneys, liver and skin [1-3,6,18]. Plötz et al. [9] suggest that a catheter placed into the VCI via the umbilical vein can be more effective in evaluating the VCI saturation in newborns, due to possible difference in oxygen saturation of the right atrial and pulmonary artery samples that arises from the cardiac left to right shunts. Although sampling from the pulmonary artery is preferred for an accurate mixed venous blood gas analysis and because of the difference in saturation rates from the central veins, it is important to note a possible impact of congenital cardiac defects on blood oxygen content.

In our study, significant differences with regard to the oxygen pressure and oxygen saturation in the right atrium and pulmonary artery were observed during the entire course of CPB. Compared to the values in the right



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atrium, PO_2 in the pulmonary artery increased abruptly following the initiation of CPB, reached a peak when the body temperature is the lowest, and then returned to the levels similar to those in the right atrium by the end of CPB. Subsequent measurements did not reveal any significant differences. Although the factors responsible from these differences are not clear, some suggestions can be made. The patient is systemically cooled after the commencement of CPB, then the heart is arrested by cardioplegia and its metabolism is minimized, leading to an increase in oxygen saturation of blood in the coronary sinus; as well, it is likely that antegrade cold cardioplegia with high oxygen content may have a role. The cannula placed into the VCI through right atrium quickly vents the blood from right atrium and VCI. Concurrently, the blood in the coronary sinus may increase the oxygen content of blood that goes from the atrium to the right ventricle and then to the pulmonary artery, thus resulting in a higher oxygen content in pulmonary arteries.

Another possible influence is due to the vacuum effect of venous cannula placed into the right atrium during the CPB that can be frequently observed externally. This vacuum effect can influence the blood in the right atrium, in the coronary sinus, in the right ventricle, and even in the pulmonary artery. In the case of right atrial, right ventricular or pulmonary arterial injuries, excess accumulation of air in the venous line may cause difficulties, demonstrating that vacuum effect of cannula has an effect on a wide area. A possible explanation is the increase in the oxygen content of pulmonary arteries due to the entry of highly oxygenated blood from the left system into the pulmonary artery, facilitated by the absence of valves in pulmonary venous system.

It should also be noted that the amount of blood returning to the left side of the heart can be increased by bronchial-pulmonary anastomoses, if a high pump flow is maintained during CPB to obtain sufficient tissue perfusion.

Increased difference in the level of oxygen saturation between arterial and mixed venous blood is a sign of increased use of oxygen by the tissues. Extraction of oxygen from the tissues during hypothermia in CPB is impaired, producing an increase in SvO_2 by the formation of arterio-venous shunts. With re-warming, more oxygen is used and amount of shunting is decreased in peripheral tissues, and consequently SvO_2 is decreased. Inadequate perfusion of splanchnic area during the CPB may lead to a decrease in SvO_2 in vena cava inferior, and this has been shown to be possibly associated with increased morbidity and mortality [2,6]. In the study by Cavaliere et al. [6], it has been reported that VO_2 is increased parallel to the increase in body temperature, thus resulting in an alteration in SvO_2. On the other hand, Lindholm et al. [16] reported that systemic temperature has no effect on SvO_2 and regional oxygen saturation. Also, the same investigators found that the saturation in hepatic vein was lower than SvO_2 before surgery, at hypothermia and in all measurements performed 30 minutes after the termination CPB. Lindholm et al. reported that PO_2 and mixed venous oxygen saturation was significantly higher in the group of cardiac surgery patients who were given glucose, insulin and potassium infusions beginning from hypothermia [19]. During stable hypothermia at a flow rate of $2.4 L/m^2$, SvO_2 is $> 70\%$, and SvO_2 tends to decline during warming [2].

In our study, the level of saturation in right atrial blood was 78% at the initiation of CPB, 71.3% during hypothermia, and 68.4% at the termination of CPB. Oxygen saturation in the right atrium was greater than 70% during extracorporeal circulation and lower than 70% by the end of CPB when normothermia was attained. This suggests that changes in the temperature may be associated with changes in SvO_2.

Changes in PCO_2 and pH can be continuously monitored by a catheter placed into a central vein or pulmonary artery. Arterial and venous pH is linearly correlated with PCO_2 when the perfusion is normal and the cardiac output is adequate. Durkin et al. [20] found an arterio-venous PCO_2 difference of 4.88 ± 0.4 mmHg, and a pH difference of 0.027 ± 0.004 U in patients with normal cardiac index. The reported figures by Tobias et al. [21] are 2.4 mmHg for PCO_2, and 0.02 U for pH.

In our study, with the exception of 7th measurement, arterio-venous PCO_2 difference was higher than 4.8 mm Hg. While the difference between arterial PCO_2 and pulmonary artery PCO_2 decreased during hypothermia, the difference between central vein and pulmonary artery increased with this respect. Subsequent measurements followed a reverse pattern. The arterio-venous pH difference was between 0.05 and 0.08 U, and there were no significant alterations in pH differences during hypothermia and normothermia.

It is known that SvO_2 is a marker of the balance between distribution and the use of oxygen in tissues; thus the decrease in the difference with the arterial system is a sign of decreased peripheral use [22]. In the present study, saturation difference between the arterial system and the mixed venous oxygen was 21.8% for the first measurement, and this difference rapidly declined to 12.7% during hypothermia. Then, the difference increased again after CPB.

In previous studies performed during hypothermia, samples were collected from central veins or right atrium, leading to differences in measurements of SvO_2. Svedjeholm et al. [2] and Cavaliere et al. [6] assessed the mixed venous oxygen saturation from the venous cannulas.

Our study demonstrated a saturation difference in samples obtained from the right atrium and pulmonary artery during hypothermia and cardiac arrest. This observed difference arises a question regarding the site that should be used to evaluate the mixed venous PO_2 and oxygen saturation during hypothermia and cardiac arrest. Pulmonary artery is used for routine assessments, so can we thus take samples from pulmonary artery during CPB as well?

In conclusion, SvO_2 is still an important parameter that is used to evaluate the oxygen balance in tissues. Routine measurements of SvO_2 are performed in samples taken from the pulmonary artery, and implementation of the same approach can lead to faulty measurements during CPB; therefore, measurements in blood samples obtained from venous cannula seem more appropriate.

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