Correlation between mixed venous blood saturation and cardiac output in patients undergoing cardiac surgery procedures

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Kardiochirurgia i Torakochirurgia Polska 2013; 10 (1): 79–83

Abstract

Background: The physiological reaction to a decrease of cardiac output (CO) is an increase of oxygen extraction. Patients with compromised circulation often are not capable of this reaction. The oxygen concentration in such cases will not change with respect to the CO; therefore the mixed venous blood saturation (SvO₂) will not be a reliable indicator of the blood flow.

Aim of the study: The aim of the study was to determine the reliability of the correlation between hemodynamic parameters and indices of tissue oxygenation in patients undergoing cardiac surgery procedures.

Material and methods: We performed a retrospective analysis in 19 patients who required Swan-Ganz catheter (SGC) insertion. Measurements were taken at three time points. Values of cardiac index (CI), mixed venous oxygen saturation (SvO₂), oxygen uptake (VO₂), oxygen extraction ratio (O₂ER), and base excess (BE) were analyzed and compared with oxygen partial pressure (PaO₂), carbon dioxide partial pressure (PaCO₂) and arterial blood saturation (SaO₂).

Results: Our study revealed an increase of CI, VO₂ and O₂ER and a decrease of SvO₂ after the operation in comparison with the preoperative period. There was a positive correlation between the trends of SvO₂ and CI before and after the surgery.

Conclusions: Correct values of SaO₂, PaO₂ and PaCO₂ do not mean that the level of subcellular processes associated with the extraction of oxygen proceed in a physiological way. Only SvO₂ and CI results obtained with the SGC make it possible to assess the delivery of oxygen and its consumption at the tissue level.

Key words: Swan-Ganz catheter, cardiac surgery procedure, thermodilution.

Streszczenie

Wstęp: Fizjologiczną reakcją organizmu na obniżenie rzutu serca (*cardiac output* – CO) jest wzrost ekstrakcji tlenu. Pacjenci, u których występuje zaburzenie krążenia, często nie są zdolni do takiej reakcji. W takich przypadkach stężenie tlenu we krwi nie ulegnie zmianie w stosunku do CO i tym samym saturacja krwi żyłnej mieszanej (*mixed venous oxygen saturation* – SvO₂) nie będzie wiarygodnym wskaźnikiem przepływu krwi.

Cel pracy: Ocena miarodajności korelacji między parametrami hemodynamicznymi a wskaźnikami utlenowania tkankowego u pacjentów poddawanych zabiegom kardiochirurgicznym.

Materiał i metody: Badanie miało charakter retrospektywny. Ocenie poddano 19 pacjentów, którzy wymagali zastosowania cewnika Swana-Ganza (S-G). Pomiarów wykonano w trzech punktach czasowych. Analizie poddano wartości wskaźnika sercowego (*cardiac index* – CI), SvO₂, zużycia tlenu (*oxygen uptake* – VO₂), współczynnika ekstrakcji tlenu (*oxygen extraction ratio* – O₂ER) i niedoboru zasad (*base excess* – BE). Uzyskane wartości porównywano z ciśnieniem parcjalnym tlenu we krwi tętniczej (*partial pressure of arterial oxygen* – PaO₂), ciśnieniem parcjalnym dwutlenku węgla we krwi (*partial pressure of carbon dioxide* – PCO₂), saturacją krwi tętniczej tlenem (*arterial oxygen saturation* – SaO₂).

Wyniki: Badanie wykazało wzrost CI, VO₂, O₂ER oraz spadek SvO₂ po zabiegu chirurgicznym w porównaniu z wartościami występującymi przed zabiegiem. Stwierdzono istnienie dodatniej korelacji między wartościami SvO₂ i CI przed zabiegiem i po operacji.

Wnioski: Prawidłowe wartości SaO₂, PaO₂, PaCO₂ nie oznaczają, że ekstrakcja tlenu na poziomie subkomórkowym przebiega w sposób fizjologiczny. Jedynie wartości SvO₂ i CI uzyskane za pomocą cewnika S-G dają możliwość oceny dostarczania tlenu oraz jego zużycia przez tkanki.

Słowa kluczowe: cewnik Swana-Ganza, operacja kardiochirurgiczna, termodylucja.

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Introduction

Cardiac surgery with cardiopulmonary bypass (CPB) is a source of stress reaction and burdens the organism. Also the surgical wounds lead to permanent adrenergic stimulation and pain which requires the use of strong analgesics. The blood supply of the organs begins to be dependent on the CPB and short episodes of blood pressure drops affect the incidence of periods of temporary ischemia in organs. Removing the blood from the operation field by suction leads to erythrocyte damage. Cardiopulmonary bypass is also associated with the risk of organ micro- and macroembolization.

The activation of coagulation (the intrinsic and the extrinsic coagulation pathway), and the fibrinolysis process are the causes of consumptive coagulopathy. Coagulation failure is intensified by heparin. The manifestation of all of the physiological aberrations in the function of the organism is the occurrence of systemic inflammatory response syndrome (SIRS) in every patient after cardiac surgery with the use of CPB [1].

Evaluation of blood oxygen status in patients during cardiac surgery procedures is routinely carried out by oxygen partial pressure (PaO_2), carbon dioxide partial pressure (PaCO_2) and arterial blood saturation (SaO_2). These parameters allow an intermediate assessment of the oxygen delivery. If there were indications for Swan-Ganz catheter (SGC) insertion, it was used during the cardiac surgery operation to monitor the hemodynamic and the gas exchange parameters [2-4]. Initially, we get ten parameters which describe the cardiovascular system efficiency and four parameters of the systemic oxygen transport: mixed venous oxygen saturation (SvO_2), dissolved oxygen (DO_2), oxygen uptake (VO_2) and oxygen extraction ratio (O_2ER).

Some of the hemodynamic parameters should be shown as an index value, that means calculated per 1 m^2 of the body surface area (BSA). In the case of cardiac output (CO) it is the cardiac index (CI) [5]. By the use of the SGC it is also possible to take samples of the venous blood from the right atrium and samples of the mixed venous blood from the pulmonary artery. Some types of SGC give the ability of continuous monitoring of SvO_2 . The value of SvO_2 shows both the oxygen delivery and the oxygen consumption. This value is dependent on the hemoglobin concentration (C_{Hb}), arterial blood saturation and CO [5]. A proper compensation reaction of the decrease of CO is the increase of oxygen extraction (O_2ER) from the capillary vessels, which is necessary to keep a constant value of the oxygen uptake (VO_2). Oxygen extraction adjustment, depending on the requirement, is especially intensified in life-threatening states; thus decrease of SvO_2 may indicate a decrease of CO. Not every patient reacts with an increase of O_2ER to a decrease of blood flow. Often severely ill patients are not capable of such an adaptive reaction [6, 7]. In these patients oxygen concentration will not change due to the changes in CO; thus the value of SvO_2 will not be a reliable indicator of the blood flow [6].

Aim of the study

The aim of the study was to determine the reliability of the correlation between hemodynamic parameters and in-

dices of tissue oxygenation in patients undergoing cardiac surgery procedures and to assess the correlation between SvO_2 and CI in the study group.

Material and methods

A retrospective analysis was performed for 19 patients undergoing cardiac surgery procedures at the 2nd Department of Cardiac Surgery, Medical University of Silesia in Katowice between February 2010 and April 2010. The study inclusion criterion was the requirement for hemodynamic and systemic oxygen transport monitoring by the use of the SGC. The study group is shown in Table I.

In all patients surgical anesthesia was performed by the same method of analgesic anesthesia by using etomidate, fentanyl and pancuronium. Anesthesia was maintained by using isoflurane and during CPB by continuous infusion of propofol and fentanyl.

Dopamine, adrenaline and noradrenaline were used for inotropic support as a monotherapy or in different combinations depending on the circulatory system condition. Values of CI, SvO_2 , SaO_2 and BE_{ecf} (base excess in extracellular fluid) were analyzed.

Measurements by the SGC were taken in every patient at three time points: T_0 – after the intubation and after the insertion of the SGC; T_1 – 15 minutes after discontinuing CPB; and T_2 – 30 minutes after admitting the patient to the postoperative unit.

Obtained values were compared with the parameters used for the assessment of intermediate oxygen delivery: PaO_2 , PaCO_2 , SaO_2 and C_{Hb} . DO_2 , VO_2 and O_2ER were also analyzed.

Results

Statistical analysis was performed using Statistica PL v.5.0. Data from time points T_0 and T_2 were analyzed. The analysis did not contain data from time point T_1 because of the large range of obtained values.

Tab. I. Demographic data and types of cardiac surgery procedure characteristics

Data	Values
Number of patients (n)	19
Age	62 ± 12
Sex (M/F)	12/7
BMI (m^2/kg)	28.02 ± 2.8
BSA (m^2)	1.9 ± 0.2
CPB time (min)	74 ± 30
Cross-clamp time (min)	46 ± 28
Types of cardiac surgery procedures (n)	
CABG	10
AVR + MVR	4
MVR + CABG	2
AVR + CABG	1
AVR	1
aortic wrapping	1

BMI – body mass index; BSA – body surface area; CPB – cardio-pulmonary bypass; CABG – coronary artery bypass graft; AVR – aortic valve replacement; MVR – mitral valve replacement

Increase of the average value of CI after the operation (Fig. 1) in comparison with the value before the operation ($p < 0.05$) was observed.

In the study group there was a decrease of SvO_2 after the operation (Fig. 2) in comparison with the preoperative period ($p < 0.05$).

In two patients at time point T_0 high values of SvO_2 were noted: 95% and 96%.

There was a positive correlation between the trends of SvO_2 and CI in patients before and after the surgery. The correlation coefficient (r) before the operation (Fig. 3) was 0.38 ($p > 0.05$) and after the operation (Fig. 4) it was 0.52 ($p < 0.05$).

The CI increased in 63% of patients, it decreased in 16%, while in 21% of patients it did not change. Correct values of CI in the study group before the operation were noted in 31% of patients and in 69% of patients this value was below the lower reference limit (reference limits: 2.4-4.0 l/min/m²). After the operation CI within the correct reference limits was noted in 42% of patients.

The VO_2 after the operation increased in 84% of patients, a decrease was noted in 11%, and in 5% of patients this value did not change ($p < 0.05$). In 15% of patients before the operation values of VO_2 were noted within the reference limits (reference limits: 110-160 ml/min $\times$ m²). In 85% of patients the value of VO_2 was below the lower reference limit while after the cardiac surgery procedure values within the reference limits were noted in 31% of patients. Values below the lower reference limit were noted in 69% of patients.

An increase of DO_2 took place in 58% of patients, a decrease in 37%, and in 5% of patients this value did not change. Before the operation in 90% of patients values below the lower reference limit (reference limits: 520-570 ml/min $\times$ m²) were noted. None of the patients had a DO_2 within the reference limits after the operation.

The O_2ER was within the reference limits (reference limits: 20-30%) in 53% of patients. An increase of O_2ER was noted in 84% of patients. After the cardiac surgery procedure an increase of O_2ER above the upper reference limit was noted in 58% of patients. In 5% of patients the value of O_2ER was below the lower reference limit. Values within the reference limits were noted in 27% of patients.

The BE_{ecf} before the operation was below the lower reference limit in 10% of patients and above the upper reference limit in 5% of patients. After the operation BE_{ecf} was below the lower reference limit in 53% of patients and above the upper reference limit in 5% of patients.

In 50% of patients the postoperative course was complicated with atrial fibrillation ($n = 4$), increased postoperative drainage ($n = 2$), thrombocytopenia ($n = 2$), infection of the upper respiratory tract ($n = 2$) and urinary infection ($n = 1$). There was one death in the study group.

Discussion

The mean value of cardiac index (CI) after cardiac surgery using cardiopulmonary bypass was increased compared with the value before the operation, which leads to a posi-

Fig. 1. Mean values of CI before and after the operation ($p < 0.02$)

Fig. 2. Mean values of mixed venous blood saturation before and after the operation ($p < 0.01$)

Fig. 3. Correlation between CI and SvO_2 before and after the operation ($r = 0.38$, $p > 0.10$)

Fig. 4. Correlation between CI and SvO_2 30 minutes after admitting the patient to the postoperative unit ($r = 0.52$, $p = 0.02$)

tive result of the surgery. A gradual reduction of the dose of anesthetic drugs, restoration of homeostasis, reverse of the anticoagulant effect of heparin, the transfusion of fluids and effective analgesic therapy ultimately allow stabilization of the cardiovascular system. In some patients post-operatively the cardiac index has decreased or its value did not change. Perhaps that group of patients needed a longer period of time to achieve homeostasis, when the positive outcome of the operation showed its effect.

Many of the patients had a BMI indicating obesity (Table I). We did not analyze in the study group the liver and kidney function, adipose tissue content, serum protein concentration after cardiac operation, fluid balance type or the volume of transfusion fluids. We did not observe in every patient a return to normal values of the cardiac index after the operation. However, it was not surprising. Achieving the correct value of CI in cardiac surgery patients, who have a long-term coronary heart disease or organic changes of the heart, because of, for example, coexisting valvular defects, is a process that occurs gradually and takes time [8]. The correct physiological reaction that we expected in patients after cardiac surgery was an increase of oxygen consumption by tissues. Because hemodilution used during cardiac surgery procedures impacts on the oxygen supply to the tissues, it is highly important to carry out an evaluation of the oxygen transport in patient who undergo these procedures. In patients after the operation there is an increase of the VO_2 value. It can be explained by the phenomenon of the body's reflex hyperemia after ischemia, a phenomenon that is referred to in the literature as the "overshoot effect". The periodic increase of VO_2 is required to compensate the oxygen debt acquired during the operation [6]. Increase of VO_2 is related to the growth of the value of O_2ER that we observed in our study.

When the metabolism is increased, even normal values of oxygen consumption are not sufficient to maintain the body's needs and the metabolism enters an anaerobic phase [9]. In most patients after the operation there was a decrease of mixed venous oxygen saturation, which was probably related to inadequate tissue perfusion and anaerobic metabolism of cells. This situation occurs after using cardiopulmonary bypass. After the operation the correct body compensatory response should be based on the increase of CI and VO_2 [9, 10].

An increase of VO_2 is related to a decrease of SvO_2 , because the oxygen uptake from blood by the tissues is associated with a decrease of SvO_2 [9]. The ability to adapt to the oxygen extraction of the body's needs is one of the identifying features of a life-threatening condition; thus a reduction of SvO_2 may signal a decrease of cardiac output [11]. Not every organism reacts with an increase of O_2ER to a decrease in blood flow. In some patients the oxygen concentration will stay in the range of initial values despite the changes in cardiac output, so the final value of SvO_2 is not a reliable indicator of blood flow. Some of the patients in the study group responded to a decrease of SvO_2 with an increase of cardiac output after the operation [12]. Per-

haps the compensatory physiological response after cardiac surgery is the reason for this phenomenon. In these patients an increase of CI and a decrease of SvO_2 indicate an accelerated metabolism and higher oxygen demand [2, 7, 13-15]. Positive correlations between SvO_2 and cardiac index before and after the operations were, respectively: $r = 0.38$ (average correlation) and $r = 0.52$ (high correlation). We found similar studies in the available literature where the statistical results differ from the material. Krauss et al. presented a very high correlation ($r = 0.78$) between the values of mixed venous oxygen saturation and cardiac index in patients undergoing heart or lung surgery [16]. Waller et al. when examining patients undergoing coronary artery bypass surgery, with continuous monitoring of SvO_2 by SGC, found a strong correlation between changes in SvO_2 and CI values: $r = 0.69$ [17]. The high values of SvO_2 at T_0 may indicate a leak caused by the change of direction of arterial blood flow (shunting) in peripheral tissues. This phenomenon occurs in states such as sepsis, and cirrhosis of the liver [18]. After excluding the possibility of existence of such diseases in patients, a probable cause of such high values of SvO_2 was the admixture of oxygenated blood coming from the alveolar capillaries. To further characterize the patients after determining BMI ($28.02 \pm 2.8 \text{ kg/m}^2$) we calculated the rate of BSA. We analyzed the BSA value, which, although it is not very specific, is however a better indicator of metabolic body weight, because it is less influenced by the excess amount of body adipose tissue. In three patients the BSA was greater than 2.0 m^2 , and these patients had a decrease of SvO_2 and a decrease of CI values after surgery.

The values of BE_{ecf} were below the lower reference limit, and there was a decrease of DO_2 . Perhaps the adipose tissue has the main impact on the value of these parameters. That phenomenon is connected with greater cardiovascular burden and the need to use higher doses of medication during the procedure and a longer return to normal body temperature [19-22].

Parameters such as SaO_2 , PaO_2 and PaCO_2 do not give the ability of assessing the transport of oxygen through the circulatory system.

Furthermore, the correct values of these parameters do not mean that at the subcellular level the processes involved in the extraction of oxygen proceed physiologically. Only the values of SvO_2 and CI obtained with the SGC allow the assessment of the supply of oxygen and its consumption by the tissue.

Results enriched with information such as DO_2 , VO_2 and O_2ER can be very useful in treatment of patients with severe conditions, in whom the body is unable to restore homeostasis after surgery [13, 23-25].

Conclusions

1. An increase of CI after the operation in comparison with CI before the operation was observed.
2. In the study group there was a decrease of SvO_2 after the operation in comparison with the values of SvO_2 before the operation.

3. There was a positive correlation between the trends of SvO₂ and CI before and after the cardiac surgery.
4. In the study group there was an increase of VO₂ after the operation in comparison with the VO₂ before the operation.
5. In the study group there was an increase of O₂ER after the operation in comparison with O₂ER before the operation.

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