Routine SvO₂ measurement after CABG surgery with a surgically introduced pulmonary artery catheter

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Abstract

Objective: It has been argued that the poor correlation between cardiac output and mixed venous oxygen saturation (SvO₂) reduces the value of SvO₂. Routine use of Swan Ganz catheters is also controversial in cardiac surgery. Here our clinical experience with a simplified method for routine hemodynamic monitoring and the short-term prognostic value of SvO₂ after CABG surgery is presented.

Method: Peroperatively an epidural catheter is routinely introduced through the outflow tract of the right ventricle into the pulmonary artery for monitoring of pressure and blood sampling. Clinical data were retrospectively retrieved from the records and related to SvO₂ routinely obtained on admission to the ICU after 488 CABG procedures.

Results: Average SvO₂ on arrival to ICU was 67 ± 7%. The SvO₂ value of 55% represented a cut off point below which a high incidence of complications were found. Outcome after 456 procedures with SvO₂ ≥ 55% compared with 32 procedures with SvO₂ < 55%: mortality 0 vs. 9.4% (P = 0.0003), perioperative myocardial infarction 6.2 vs. 29% (P < 0.0001), ventilator treatment 8:9 ± 10:1 vs. 25:7 ± 54:9 h (P = 0.0074), ICU stay 1:4 ± 1:2 vs. 2:1 ± 1:7 days (P = 0.0010).

Conclusions: SvO₂ was of prognostic value and due to its specificity it seems particularly useful for telling which patients are unlikely to develop cardiorespiratory problems. Thus, this simple method for hemodynamic monitoring could contribute to cost containment as it seems that we can safely reserve Swan Ganz catheters for high-risk patients. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Mixed venous oxygen saturation; Cardiac output; Postoperative care; Cardiac surgery; Coronary surgery; Monitoring; Prognosis; Risk stratification

1. Introduction

There is a debate regarding the need for routine use of Swan Ganz catheters for hemodynamic monitoring in association with cardiac surgery. Other issues of controversy are the usefulness of mixed venous oxygen saturation (SvO₂) measurements for hemodynamic monitoring and the cost-effectiveness of fiberoptic catheters for continuous monitoring of SvO₂ [1–4]. At our institution we have routinely used an epidural catheter introduced peroperatively into the pulmonary artery (surgical PA catheter) for continuous monitoring of pressure and intermittent blood sampling for SvO₂. In the present study we report our clinical experience with this method after coronary artery bypass graft (CABG) surgery, with special reference to the short-term prognostic value of SvO₂ obtained on arrival to the intensive care unit (ICU), in a practice where SvO₂ served as the main guideline to determine the need for circulatory support.

2. Method

SvO₂ is monitored on the venous line of the cardiopulmonary bypass (CPB) circuit during and on weaning from CPB. Before weaning an epidural catheter cut 5 cm from its tip (Perifix-Katheter, B. Braun Melsungen AG, Germany) is routinely introduced by the surgeon through the outflow tract of the right ventricle 15 cm into the pulmonary artery for monitoring of pulmonary artery pressure and intermittent blood sampling. An epidural needle is used for puncture of the right ventricular wall and the abdominal wall. A 4-0 prolene purse string suture is gently tightened around the puncture site at the right ventricular outflow tract to minimize risk for bleeding at withdrawal, which is usually done the next morning before the withdrawal of the chest tubes.

In selected high risk patients, and if there are any doubts about the adequacy of hemodynamic state, sampling for SvO₂ from the pulmonary artery is performed early after weaning. On admission to the ICU a blood sample for SvO₂ is routinely obtained in all patients. Oxygen saturation is measured in an OSM3 Hemoximeter (Radiometer, Copenhagen). A sample for arterial blood gases is usually...
collected and analysed simultaneously (IL 1630, Instrumentation Laboratory SpA, Milan).

2.1. Patients

Four hundred and ninety nine consecutive patients undergoing 500 CABG procedures performed by two surgeons were included in the study. One patient died in the operating room and hence data were not accessible for analysis. In eleven patients SvO2 measurement was not performed or recorded. Of the drop outs, nine patients had an uneventful postoperative course, one patient had transient elevation of s-creatinine and one patient, who was resuscitated preoperatively, had a transient hemiparesis and elevation of cardiac enzymes compatible with myocardial infarction. Clinical data including SvO2 on arrival to ICU were recovered from a data base in the remaining 488 procedures. SvO2 measurements performed in the operating room were not available for analysis. Demographic and peroperative data are presented in Table 1. Hemodynamic data obtained with Swan Ganz catheters were recovered from 64 patients. In 29 patients (5.8%) the Swan Ganz catheter had been used because of clinical indication such as perioperative heart failure or anticipated problems in high risk patients. In 35 patients a Swan Ganz catheter had been used for scientific purposes, mainly in elective low risk patients with uneventful outcome (n = 33) but also in two patients with unstable angina and uneventful outcome. A cardiac index corresponding to a simultaneously obtained SvO2 value on admission to the ICU was available in all patients having a Swan Ganz catheter due to scientific purposes, but only in 12 patients having a Swan Ganz catheter due to clinical indication.

2.2. Clinical management

After an overnight’s fast, and administration of the individual doses of betablockers and calcium-antagonists, the patients were premedicated with 7.5–10 mg morphine hydrochloride and 0.4 mg scopolamine i.m. Anesthesia was induced with thiopentone 1–2 mg/kg body weight and fentanyl 10 μg/kg body weight. Pancuronium bromide was used for neuromuscular blockade, which was usually repeated prior to closure of the sternum. Anesthesia was maintained with fentanyl and isoflurane. CPB was conducted with a membrane oxygenator and a roller pump generating non-pulsatile flow. A crystalloid fluid containing no glucose or lactate (Ringer’s acetate) and mannitol was used for priming the extracorporeal circuit. Moderate hemo-dilution (hematocrit 20–25%) and moderate hypothermia (32–35°C) were employed. Antegrade or combined anterograde and retrograde delivery of St. Thomas’ cold crystalloid cardioplegic solution was used for myocardial protection. Weaning off CPB was started at a rectal temperature of 35–36°C. Heparin was neutralized with protamine chloride. Ringer’s acetate was used for volume substitution postoperatively. Shed mediastinal blood was routinely retransfused in the ICU. Postoperative rewarming was facilitated by radiant heat provided by a thermal ceiling. Perioperatively the patients were managed according to a metabolic strategy with the objective of reducing the consequences of myocardial ischemia and surgical trauma. The basic concepts have been reported previously and include general measures in all patients to reduce myocardial metabolic demands. [5,6] The general measures imply reduction of adrenergic stress on the heart and measures to reduce systemic oxygen demand. Inotropic drugs are, therefore, avoided if possible. Muscle relaxants are liberally administered prior to closure of the sternum, and patients with severe cardiac failure are kept sedated (usually with midazolam during the study period) until hemodynamic recovery is considered satisfactory. SvO2 and diuresis serve as the main guidelines for assessment of the adequacy of hemodynamic state, rather than cardiac output measurements. Volume work by the heart rather than pressure work is promoted by after-load reduction when feasible. Systolic arterial blood pressures between 90–130 mmHg are usually

| Table 1 | Pre-and peroperative data (mean ± SD) in the study population of 488 CABG procedures and the subgroups with SvO2 ≥ 55% and SvO2 < 55% on arrival to ICU. The right column indicates statistically significant differences between these subgroups. ns, not significant |
|---|---|---|---|---|
| | Overall (n = 488) | SvO2 ≥ 55% (n = 456) | SvO2 < 55% (n = 32) | P-values |
| Age (years) | 64 ± 9 | 64 ± 8 | 68 ± 9 | 0.0017 |
| Female (%) | 19 | 18 | 38 | 0.0068 |
| Diabetes (%) | 12 | 11 | 25 | 0.0208 |
| Hypertension (%) | 29 | 29 | 28 | ns |
| Peripheral vascular disease (%) | 14 | 14 | 16 | ns |
| Preoperative lung disease (%) | 5.4 | 5.5 | 3.2 | ns |
| NYHA class | 3.1 ± 0.7 | 3.1 ± 0.7 | 3.3 ± 0.7 | ns |
| Left ventricular ejection fraction | 0.52 ± 0.1 | 0.52 ± 0.11 | 0.51 ± 0.12 | ns |
| Redo procedure (%) | 0.8 | 0.2 | 9.4 | 0.0010 |
| Unstable angina (%) | 28 | 27 | 38 | ns |
| Left main stenosis ≥ 70% (%) | 11 | 9.5 | 25 | 0.0054 |
| Number of bypassed vessels | 3.4 ± 1.2 | 3.3 ± 1.2 | 3.7 ± 1.3 | ns |
| Aortic cross clamp time (min) | 39 ± 18 | 38 ± 17 | 54 ± 23 | 0.0003 |
| Cardiopulmonary bypass time (min) | 81 ± 34 | 78 ± 29 | 126 ± 57 | < 0.0001 |
accepted in routine patients. In patients with severe heart failure systolic blood pressures in the region of 85–100 mmHg are considered acceptable, and even desirable, unless the patient has any critical arterial stenosis. Pulmonary artery diastolic pressure is used to assess the degree of left ventricular filling. A pressure of 10–15 mmHg is usually accepted in routine patients. In patients with heart failure slightly higher filling pressures are accepted and determined by guidance of transoesophageal echocardiography. However, use of the Starling curve to maximize cardiac output is avoided as post-ischemic hearts in our experience poorly tolerate over distention of the ventricles. Urinary output is monitored hourly in all patients and a continuous urinary drip of approximately 1 ml/kg body weight 1 h or more is considered desirable. Metabolic support with intravenous glutamate infusion and glucose-insulin-potassium is used in selected cases with the aim to improve myocardial tolerance to ischemia and to enhance recovery of the post-ischemic heart (Table 2) [5,7,8].

2.3. Definitions

Mortality was defined as 30-day-mortality. Complications presented refer to in-hospital events occurring at our institution with the exception of infectious complications which also include patients being referred back to our institution after discharge. Cardiorespiratory morbidity or mortality was defined as occurrence of mortality, myocardial infarct, postoperative heart failure, postoperative renal failure or prolonged ventilator treatment (>24 h). Atrial fibrillation, which was common independent of SvO₂, was not included in this analysis. Perioperative myocardial infarction (PMI) was diagnosed according to screening routines at our institution. Aspartate aminotransferase (ASAT) is analyzed in all patients and in cases with ASAT ≥3.0 µkat/l further analysis of Troponin-T and CKMB is undertaken. However, due to incomplete Troponin-T and CKMB data, patients with a postoperative ASAT level ≥3.0 µkat/l and an alanine aminotransferase level less than half of the ASAT were considered to have a PMI. As ASAT is less specific than Troponin-T and CKMB, the rate of PMI is probably overestimated to some extent. ECG findings were not considered due to recently reported uncertainty regarding ECG diagnosis of PMI [9,10]. Postoperative renal failure was defined as a postoperative increase of s-creatinine by more than 50% compared with preoperative values as suggested by Andersson et al. [11] In contrast to criteria involving a fixed value for s-creatinine this definition detects changes in renal function occurring after surgery, and also moderate impairments of renal function in patients with a preoperatively normal renal function are caught.

Postoperative heart failure was defined as a hemodynamic state (such as difficulty to wean from CPB or dete-
riorating hemodynamics after weaning from CPB) that required specific active measures directed at improving myocardial function such as prolonged CPB, metabolic or pharmacological treatment.

2.4. Statistical analyses

Mann–Whitney U-test was used for unpaired comparison of continuous data. Chi-square analysis, or Fisher’s exact test when expected frequencies fell below 5, were used for analysis of categorical data. Non-parametric statistical methods, thus, have been employed with the exception for analysis of correlation between cardiac index and SvO₂ where the issue of linearity was considered to have prime interest. Statistical significance was defined as P < 0.05. Data are presented as mean ± SD. Proportions presented as percentages are given without decimals with the exception of percentages <10% or >90%. The number of observations is denoted by n. Predictive value, sensitivity and specificity were calculated according to standard formulae. Statistical analyses were performed using a computerized statistical package (Statistica 5.5, StatSoft, Inc., Tulsa).

2.5. Ethical aspects

The study was approved by the Ethical Committee for Medical Research at the University Hospital in Linköping.

3. Results

3.1. Hemodynamic results

Average SvO₂ on arrival to ICU was 67.1 ± 7.3%. The distribution of SvO₂ values on admission to the ICU is demonstrated in Fig. 1. The average SvO₂ in preoperative risk groups was 64.3 ± 7.8% in females, 65.1 ± 7.6% in diabetics, 66.6 ± 7.9% in unstable angina, 64.5 ± 9.3% in patients with left main stenosis ≥70%, 55.9 ± 8.4% after redo procedures and 65.3 ± 8.3% in patients with a preoperative Higgins score ≥5. In patients with signs of cardiac failure on weaning from CPB SvO₂ was 62.0 ± 10.2% on arrival to ICU.

Cardiac index on arrival to ICU in patients having a Swan Ganz catheter on clinical grounds was 1.87 ± 0.48 l/min per m² BSA and the corresponding SvO₂ was 63.5 ± 9.5%. Cardiac index on arrival to ICU in patients having a Swan Ganz catheter due to scientific purposes was 2.07 ± 0.36 l/min per m² BSA and the corresponding SvO₂ was 70.0 ± 7.2%. The correlation between cardiac index and SvO₂ on arrival to ICU was 0.50 (P = 0.098) in patients having a Swan Ganz catheter on clinical indication, and 0.64 (P < 0.0001) in the group having it due to scientific purposes.

3.2. Clinical outcome

Overall results are presented in Table 2. The overall mortality in patients accessible for analysis was 0.6%. If all 500 CABG procedures primarily considered for analysis were included the mortality was 0.8%. There were no complications recorded that could be attributed to the use of the surgical PA catheter.

The SvO₂ value of 55% represented a cut off point below which a high incidence of mortality and prolonged ICU stay due to cardiorespiratory morbidity was found (Fig. 3). Four hundred and fifty six procedures had SvO₂ ≥55% and 32 procedures had SvO₂ <55% on admission to the ICU. Clinical outcome in the SvO₂ ≥55% group versus the SvO₂ <55% group is presented in Table 2. Cardiorespiratory morbidity or mortality was encountered in 63% of the patients with SvO₂ <55% compared with 13% in the SvO₂ ≥55% group (P < 0.0001).

The specificity and sensitivity of SvO₂ <55% on arrival to ICU with respect to cardiorespiratory morbidity or mortality was 97.1 and 25%, respectively. The most important cause for the low sensitivity was that heart failure already had been diagnosed in the operating room and treated successfully in 41% of the patients with cardiorespiratory morbidity and SvO₂ ≥55% on arrival to ICU. In a further 33% of these patients enzymatic evidence of periparative myocardial infarct was found with no evident impact on hemodynamic state or postoperative course.

Cardiorespiratory morbidity that was unknown on arrival to ICU and required prolonged ICU stay (>2days) developed in 1.1% (n = 5) of patients with SvO₂ ≥55%. In two cases this was due to bleeding and tamponade requiring circulatory support and reoperation. Two patients with obstructive lung disease required prolonged ICU stay because of respiratory problems. One patient had no signs of circulatory failure but fulfilled criteria for PMI and stayed in the ICU for observation due to temporarily reduced capacity in the ward.

In the 12 patients without cardiorespiratory morbidity who had SvO₂ below 55% on arrival to ICU the predominant cause was considered hypovolemia in half the cases and shivering in the remaining cases, although a mixture of

![Fig. 1. The distribution of SvO₂ values (given in number of patients) on arrival to the ICU.](image-url)
these conditions associated with vasoconstrictive hypertension was common. Therefore, multiple measures directed mainly against hypovolemia, shivering and hypertension were undertaken. Thus, all twelve patients were treated with volume and sedatives, 10 patients were given nitroprusside, five patients received muscle-relaxants and in three patients inotropic drugs were also employed. All the patients responded to these measures with \( \text{SvO}_2 \) increasing from an average 51.1 ± 3.9 to 62.9 ± 5.6%.

There was no difference in base excess (BE) between the \( \text{SvO}_2 \geq 55\% \) group and the \( \text{SvO}_2 < 55\% \) group. Clinically significant acidosis (BE < -5.0 mmol/l) was encountered in only two patients (0.4%) on arrival to ICU.

4. Discussion

This a report of clinical experience that addresses two issues, namely the safety of a simplified approach to routine postoperative monitoring with a surgical PA catheter and the prognostic value of \( \text{SvO}_2 \) and hence its value for assessment of hemodynamic state. The overall results with a low rate of complications related to heart failure suggests that intermittent \( \text{SvO}_2 \) measurements can be used for routine hemodynamic monitoring without compromising safety of perioperative care. Furthermore, \( \text{SvO}_2 \) on admission to the ICU was of prognostic value. The \( \text{SvO}_2 \) value of 55% represented a cut off point below which a high incidence of complications were found. Postoperative myocardial infarct and heart failure were significantly more frequent in the \( \text{SvO}_2 < 55\% \) group. As a consequence mortality, renal impairment, prolonged ventilator treatment and prolonged ICU stay were more common in the \( \text{SvO}_2 < 55\% \) group, as was the need for metabolic, pharmacological and mechanical circulatory support (Table 2).

Evidently the cut off value of 55% is arbitrary and liable to criticism. However, as this to our knowledge represents the largest collection of \( \text{SvO}_2 \) data in this setting, an attempt to identify such a level may be justified. Cardiorespiratory morbidity represented a wide spectrum of conditions from elevation of cardiac enzymes without further clinical significance to conditions associated with prolonged ICU stay and mortality (Figs. 2 and 3). If the latter conditions were considered, either alone or even more strikingly together, the most prominent increase in incidence was observed at the 55% level (Fig. 3). The low risk of developing cardiorespiratory morbidity that required prolonged ICU care found in patients with \( \text{SvO}_2 \geq 55\% \) suggest that this level may be of relevance to identify patients who are least likely derive advantage from more extensive investigations. Furthermore, as is done in our clinical practice, sampling can easily be repeated in patients who arrive to the ICU with an borderline \( \text{SvO}_2 \) between 55 and 60% to exclude a negative trend.

Thus, it is essential to emphasize that \( \text{SvO}_2 \) was not used only once on admission to the ICU. The patients were monitored on weaning from CPB regarding \( \text{SvO}_2 \) and sampling for \( \text{SvO}_2 \) was repeated whenever there was doubt about hemodynamic adequacy. Results of serial measurements of \( \text{SvO}_2 \) have been presented previously in patients with severe heart failure [5]. However, a complete set of \( \text{SvO}_2 \) data was only available on arrival to ICU. Furthermore, \( \text{SvO}_2 \) was not used as a single parameter to assess the hemodynamic state. Pressure monitoring was routinely performed with the PA catheter and clinical judgement incorporating data provided by arterial lines, central venous lines, PA pressure, ECG and urinary output have influenced the outcome. In selected patients Swan Ganz catheters and transoesophageal echocardiography were employed. However, the patients were routinely managed so that basic hemodynamic variables were kept within certain limits (given in Section 2) whereas \( \text{SvO}_2 \) and urinary output (as opposed to cardiac output) were used to determine the need for metabolic or additional pharmacological circulatory support. Thus, given that \( \text{SvO}_2 \) served as a corner stone in a strategy aimed at reducing myocardial metabolic demands, including restrictive use of inotropic drugs and acceptance of low cardiac outputs, we suggest that the safety of using \( \text{SvO}_2 \) for assessment of hemodynamic state...
was thoroughly tested. The use of the surgical PA catheter and SvO2 in particular, therefore, will be discussed from a distinctive point of view to explain its role in such a strategy.

SvO2 is theoretically an ideal parameter for assessment of the hemodynamic state as it provides information about the adequacy of the oxygen delivery system [12]. However, the usefulness of SvO2 measurements has been under debate. SvO2 is dependent on cardiac output, arterial oxygen saturation, the oxygen carrying capacity (hemoglobin) of blood and systemic oxygen demand. Therefore, SvO2 can be expected to correlate with cardiac output only when these variables are kept constant [6]. Another aspect to be considered is capacity of the heart to compensate for changes of these variables by increasing cardiac output. A drop in SvO2 is expected to correlate with cardiac output only when these conditions are maintained in spite of a low cardiac output. This can be accounted for the weak correlation with cardiac output provide rather than of the adequacy of SvO2 to detect circulatory problems. If weaning from CPB was uneventful and SvO2 exceeded 55% on arrival to ICU the risk of developing cardiorespiratory problems that required prolonged ICU care (>2 days) was just over 1%. Thus, we suggest that SvO2 is a variable that deserves to be evaluated in risk stratification protocols to predict prolonged ICU care. Furthermore, in clinical practice we find that the main attention can be directed towards the small proportion of patients with SvO2 values below 55%, the cut off point below which a high incidence of postoperative morbidity was found.

Benign causes for a low SvO2 such as shivering and hypovolemia are usually easy to detect and correct. Patients arriving to the ICU shivering may present with a low SvO2 in spite of a high cardiac output [17]. To reduce this problem and to avoid strain on the heart during early post-ischemic recovery in high risk patients, muscle relaxants can be administered prior to closure of sternum. This measure not only delays and reduces shivering, it also facilitates closure of the sternum in obese and large patients. If benign causes can be excluded, more serious conditions such as tamponade, recurrent myocardial ischemia, or evolving myocardial infarction, should be considered. In this respect, transoesophageal echocardiography may be an underutilized modality in the ICU, and SvO2 measurements can help to identify patients who are likely to derive advantage from this technique. Occasionally, valuable time can be gained by such a strategy [22], as, in agreement with other investigators [20,21], we have found that changes in SvO2 often occur before changes in blood pressure, heart rate or atrial filling pressures [20–22].

Although we find the weak correlation between SvO2 and cardiac output more of an asset than a problem in the clinical management of patients, the use of SvO2 is not without pitfalls. In conditions with intra-cardiac left to right shunts, systemic arterio-venous shunting and disturbances in oxygen delivery/utilization (such as in septic conditions, lactic acidosis and end-stage hepatic failure) SvO2 may be high in spite of inadequate hemodynamics [23–26]. However, these conditions are rarely encountered early after adult cardiac surgery.

Another argument against the usefulness of SvO2 measurements is that considerable regional differences in venous oxygen saturation may exist, and hence SvO2 may
not detect hypoperfusion of vital organs such as the splanchnic system. To reduce this risk SvO₂ is assessed together with other clinical and laboratory data. If SvO₂ and diuresis are acceptable and there is no significant acidosis, we have found that the risk of clinically important hypoperfusion of the splanchnic system or kidneys is small. In the present series, where low cardiac outputs were accepted and inotropes were rarely used, there was no case of renal failure requiring dialysis and no case of intestinal ischemia requiring surgery. The rate of renal impairment defined as an increase of serum-creatinine postoperatively by 50% compared with preoperative values was 2.3% which is considerably lower than the 16% incidence reported from a center with a comparable subset of patients undergoing CABG surgery.

The widespread use of fiberoptic catheters for continuous monitoring of SvO₂ seems to have been restrained by doubt regarding the cost-effectiveness of these catheters [1,2]. In this respect a major advantage of the surgical PA catheter is its simplicity and low cost (40 SEK = approximately 4.5 Euro). The insertion of the catheter only takes a few minutes and as it is done during rewarming of the patient it does not prolong the operation. Due to the prognostic value of SvO₂ measurements and its specificity with respect to cardiopulmonary problems, Swan Ganz catheters can be reserved for high risk patients. Consequently, intermittent SvO₂ measurements by this method can contribute to cost containment in perioperative care. The overall results from the present study with a mortality of 0.8% and low rate of complications related to heart failure suggest that a reliance on intermittent SvO₂ measurements for routine hemodynamic monitoring can be safely employed. Furthermore, as there is data suggesting that routine use of Swan Ganz catheters lead to increased use of vasoactive infusions and prolonged ICU stay [3,4], a change towards simplified strategies for postoperative monitoring may be desirable also with respect to clinical outcome. Prospective randomized studies comparing simplified routine monitoring such as surgical PA catheters (or central venous catheters) with routine use of Swan Ganz catheters are warranted.

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References


