Association of low mixed venous oxygen saturations during early ICU stay with increased 30-day and 1-year mortality after cardiac surgery: a single-center retrospective study

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Abstract

Background  Low postoperative mixed venous oxygen saturation (SvO₂) values have been linked to poor outcomes after cardiac surgery. The present study was designed to assess whether SvO₂ values of < 60% at intensive care unit (ICU) admission and 4 h after admission are associated with increased mortality after cardiac surgery.

Methods  During the years 2007–2020, 7046 patients (74.4% male; median age, 68 years [interquartile range, 60–74]) underwent cardiac surgery at an academic medical center in Finland. All patients were monitored with a pulmonary artery catheter. SvO₂ values were obtained at ICU admission and 4 h later. Patients were divided into four groups for analyses: SvO₂ ≥ 60% at ICU admission and 4 h later; SvO₂ ≥ 60% at admission but < 60% at 4 h; SvO₂ < 60% at admission but ≥ 60% at 4 h; and SvO₂ < 60% at both ICU admission and 4 h later. Kaplan–Meier survival curves, Cox regression models, and receiver operating characteristic curve analysis were used to assess differences among groups in 30-day and 1-year mortality.

Results  In the overall cohort, 52.9% underwent coronary artery bypass grafting (CABG), 29.1% valvular surgery, 12.1% combined CABG and valvular procedures, 3.5% surgery of the ascending aorta or aortic dissection, and 2.4% other cardiac surgery. The 1-year crude mortality was 4.3%. The best outcomes were associated with SvO₂ ≥ 60% at both ICU admission and 4 h later. Hazard ratios for 1-year mortality were highest among patients with SvO₂ < 60% at both ICU admission and 4 h later, regardless of surgical subgroup.

Conclusion  SvO₂ values < 60% at ICU admission and 4 h after admission are associated with increased 30-day and 1-year mortality after cardiac surgery. Goal-directed therapy protocols targeting SvO₂ ≥ 60% may be beneficial. Prospective studies are needed to confirm these observational findings.

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Keywords  Pulmonary artery catheter, Cardiac surgery, Goal-directed therapy, Mixed venous oxygen saturation, Postoperative care

Background
Advanced hemodynamic monitoring to detect disturbed tissue oxygenation, impaired perfusion, and low cardiac output syndrome is crucial during and after cardiac surgery. Pulmonary artery catheter (PAC) has been used in clinical practice since the 1970s [1] and is still considered the gold standard in monitoring cardiac output and pulmonary artery pressures. PAC is the only percutaneous method for obtaining mixed venous oxygen (SvO₂) samples [2, 3].

PAC-guided goal-directed therapy (GDT) protocols are linked to decreased risk of end-organ dysfunction, such as renal failure, in high-risk surgical patients [4, 5]. Tissue hypoperfusion is usually detected by decreased SvO₂ and/or increased serum lactate levels. SvO₂ is among the best markers of tissue perfusion [6]. In one randomized controlled trial, GDT targeting SvO₂ values >70% up to 8 h after ICU admission following coronary artery bypass grafting (CABG) was associated with reduced complications and shorter hospital stay [7]. However, the level of SvO₂ to target after cardiac surgery remains unclear. In a retrospective study, SvO₂ <60% on ICU admission after CABG was associated with increased 30-day mortality, higher incidence of complications, and prolonged mechanical ventilation and ICU stay [8]. Similarly, in a retrospective analysis of patients undergoing aortic valvular surgery, SvO₂ <58% at ICU admission was associated with increased all-cause mortality [9]. Observational data highlight the value of low central venous oxygen saturation (ScvO₂) in predicting increased mortality after cardiac surgery [10, 11], but ScvO₂ is not interchangeable with SvO₂ in absolute values or trends [12].

In our institution, PAC is routinely used in patients undergoing cardiac surgery. SvO₂ values <60% are considered low and constitute a threshold for initiating the local GDT protocol for cardiac surgery. We designed the present study to assess the clinical relevance of our practice, specifically to determine whether SvO₂ values <60% at ICU admission and 4 h later are associated with increased mortality after cardiac surgery. Our hypothesis was that mortality outcomes at 30 days and 1 year would be associated with SvO₂ levels in the 4-hour postoperative interval.

Methods
This single-center retrospective cohort study was conducted in Oulu University Hospital, Oulu, Finland. The data were collected completely from ICU digital medical records. Records for adult patients who had undergone cardiac surgery from January 1, 2007, through December 31, 2020, were reviewed. We chose 2007 as the starting point for data collection because all patient data collected before, during, and after the surgeries, laboratory values, and mortality data were completely digitized at the beginning of 2007.

Each patient was monitored by PAC. Patients were identified using appropriate Acute Physiology and Chronic Health Evaluation (APACHE) II–IV categories during ICU admission and appropriate ICD-10 diagnosis codes. Preoperative risk factors were identified from the Higgins–Cleveland scoring system [13] (years 2007–2012) or the Euroscore [14] (year 2013) or Euroscore II [15] (years 2014–2020) scoring systems. Risk scores were entered by the attending cardiac anesthesiologist before ICU admission. Risk factors identified as common and compatible in each of the three scoring systems were as follows: (1) any type and grade of acute kidney injury, (2) any type of diabetes with insulin therapy, (3) ejection fraction <35% (or <30% in Euroscore and Euroscore II), (4) previous cardiac surgery and (5) emergency surgery. These preoperative risk factors were used to adjust the statistical analysis. APACHE II [16] and Sequential Organ Failure Assessment (SOFA) [17] scores on ICU admission also were collected for use in adjusted analyses. The local GDT protocol for cardiac surgery is described in Table S1.

Altogether, 7046 patients were identified. SvO₂ values at ICU admission and 4 h later were available for 6535 patients. Patients with SvO₂ >80% were excluded, as those values are likely to be associated with abnormally low oxygen extraction capacity [18], leaving 6282 patients for the final analysis. Data for these remaining patients were analyzed in four groups based on SvO₂ values at ICU admission and 4 h later: SvO₂ ≥60% at both time points; SvO₂ ≥60% at ICU admission but <60% 4 h later; SvO₂ <60% at ICU admission but ≥60% 4 h later; and SvO₂ <60% at both time points. Data on the preoperative risk factors described above were available for 5833 patients, and data on APACHE II and SOFA scores were available for all 6282 patients. Surgical procedures were classified into five categories: ascending aortic repair and aortic dissection, CABG, valvular procedures (single valvular operation), combined procedures (multi-valvular operation or valvular surgery and CABG), and other cardiac surgery (e.g., for various diagnoses such as septal defects, restrictive pericarditis etc.).

Statistics
We used Kaplan–Meier survival curves with log-rank test values and Cox regression models to assess the
differences in 1-year mortality among the groups. Cox regression models were adjusted and analyzed in two ways: with APACHE II score ≥25 or <25 and SOFA score ≥8 or <8 at ICU admission, as well as by sex; or with age, sex, and the preoperative risk factors described above. We give hazard ratios (HRs) with 95% confidence intervals with the Cox models. Receiver operating characteristic (ROC) analysis was conducted to further assess the prognostic value of SvO₂ values for 30-day mortality. Categorical data are expressed as numbers (n) and percentages (%). Continuous variables are presented as medians with 25th and 75th percentiles. Categorical data were analyzed using Pearson's chi-square and continuous variables using the non-parametric Kruskal–Wallis H-test.

Results
Patient characteristics and clinical data are presented in Table 1. Of the 6282 patients, 74.4% were male, and the median age was 68 (interquartile range, 60–74) years. At ICU admission, 3.0% of the patients had an Apache II score ≥25, and 19.4% had a SOFA score ≥8. The 1-year crude mortality of the whole cohort was 4.3%.

The groups differed in demographic and clinical data. The group with low SvO₂ at both time points had the greatest proportions of patients with preoperative ejection fraction <35% (9.1%), insulin-dependent diabetes (21.5%), emergency procedures (12.8%), combined procedures (26.1%), and surgery for ascending aortic repair or aortic dissection (5.7%). This group also had the longest time on mechanical ventilation (median, 0.63 days), the highest frequency of renal replacement therapy, the highest proportion of patients with maximum vasoactive index scores, highest maximum weight gain (6 kg), and highest amount of red blood cells administered (4 units). They also had the longest stays in the ICU (2.8 days) and hospital (10 days) (Table 1).

Parameters and treatments affecting oxygen supply and demand during the first 4 h after the ICU admission are shown in Table 2. The group with low SvO₂ at both time points also had the lowest median cardiac index (CI) at ICU admission (2.04 L/min/m²). This group and those with low SvO₂ only at the 4-hour time point both showed increased CI, but values remained lowest in patients with low SvO₂ at both time points (2.11 L/min/m²). Hemoglobin values also were lowest among patients with SvO₂ <60% at both time points, as was the P/F ratio at ICU admission and 4 h later, with no increase in the interval. In addition, cumulative fluid volume administered in the ICU within 4 h was highest in these patients (2000 mL), and this group had the greatest proportion of patients with maximum vasoactive index scores during the 4-hour period.

Cox regression HRs for 1-year mortality are shown in Table 3. The highest HR was observed in the patients with SvO₂ <60% at both ICU admission and 4 h later. The results of the Kaplan–Meier analysis are shown in Fig. 1. Having SvO₂ values ≥60% at both ICU admission and 4 h later was associated with the best survival, whereas having SvO₂ values <60% at both time points was associated with the poorest survival. Patients with SvO₂ values <60% at ICU admission but ≥60% 4 h later had better survival than those with low values at both time points. Patients with SvO₂ values ≥60% at ICU admission but <60% 4 h later had worse survival than patients with consistently high SvO₂ values but better survival than those with low SvO₂ at admission and SvO₂ ≥60% at 4 h.

The results of the ROC analysis for 30-day mortality are shown in Table 4. SvO₂ <60% either at ICU admission or 4 h later predicted 30-day mortality reasonably well, especially after surgery of the ascending aorta and for aortic dissection and combined procedures. Cox regression HRs for each subgroup of surgical procedures are shown in Table 5, and the results of the Kaplan–Meier analysis are given in the supplementary material (Figures S1–S4). In the group with SvO₂ <60% at both time points, survival declined significantly during the first 2 months postoperatively, and long-term follow-up survival was shorter than for the other groups. Patients who had undergone “other cardiac surgery” were omitted from the whole subgroup analysis because of low numbers of patients and events. Patients who had undergone ascending aortic repair and aortic dissection were omitted from Cox regression analysis also because of low numbers of patients and events, but ROC analysis and Kaplan–Meier curves are presented. Lower SvO₂ values at ICU admission and/or 4 h after admission were associated with higher HRs and decreased survival in these subgroups, as well.

Discussion
The purpose of this retrospective cohort study was to evaluate whether 30-day and 1-year mortality are associated with SvO₂ values at ICU admission and 4 h after admission in cardiac surgical patients treated according to the local GDT protocol. The main finding is that SvO₂ values <60% at both ICU admission and 4 h later were associated with the highest Cox regression HR values and the highest 1-year mortality.

These results suggest the benefit of monitoring SvO₂ and using the values as a GDT parameter for guiding therapeutic measures such as fluids and inotropes to improve macrocirculation and support SvO₂ ≥60% after ICU admission. The findings emphasize the importance of intensive hemodynamic monitoring during the first hours after cardiac surgery. Higher mortality in patients with low SvO₂ on ICU admission, decreasing SvO₂, or
nonresponsive $\text{SvO}_2$ implies that disturbed tissue oxygenation in the hours immediately after cardiac surgery could significantly affect patient outcomes. The results are in accordance with those of a previous larger study showing an association of $\text{SvO}_2 < 60\%$ at ICU admission with worse short- and long-term outcomes and increased perioperative morbidity. The survival benefit with $\text{SvO}_2 \geq 60\%$ at ICU admission has been reported to last up to 2 years (8).

In contrast to our study, previous studies have used only intraoperative [10] or single postoperative $\text{SvO}_2$ [8, 9] measurement to predict outcomes after cardiac surgery.
**Table 2** Parameters and treatments affecting oxygen supply and demand during the first 4 h after ICU admission

| Parameter | All (N = 6282) | SvO₂ ≥ 60% at admission + at 4 h | SvO₂ ≥ 60% at admission, < 60% at 4 h | SvO₂ < 60% at admission, > 60% at 4 h | SvO₂ < 60% at admission + at 4 h | P |
|-----------|----------------|-------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|---|
| CI on admission (L/min/m²) | 2.36 (2.03–2.77) | 2.43 (2.09–2.83) | 2.35 (2.0–2.72) | 2.09 (1.8–2.39) | 2.04 (1.73–2.36) | < 0.001 |
| CI at 4 h (L/min/m²) | 2.47 (2.15–2.84) | 2.55 (2.23–2.92) | 2.28 (2.0–2.59) | 2.39 (2.12–2.74) | 2.11 (1.87–2.42) | < 0.001 |
| HB on admission (g/L) | 105 (96–114) | 106 (98–115) | 101 (94–110) | 101 (91–111) | 99 (91–108) | < 0.001 |
| HB at 4 h (g/L) | 102 (94–112) | 104 (95–114) | 98 (90–107) | 99 (90–107) | 95 (86–102) | < 0.001 |
| Lactate on admission (mmol/L) | 1.4 (1.1–1.8) | 1.3 (1.1–1.7) | 1.4 (1.1–1.8) | 1.6 (1.2–2.3) | 1.8 (1.4–2.7) | < 0.001 |
| Lactate at 4 h (mmol/L) | 1.3 (1.0–1.8) | 1.3 (1.0–1.7) | 1.5 (1.2–2.0) | 1.5 (1.1–2.1) | 1.8 (1.4–2.7) | < 0.001 |
| P/F ratio on admission | 38 (29–48) | 39 (30–49) | 36 (28–45) | 34 (23–44) | 32 (22–43) | < 0.001 |
| P/F ratio at 4 h | 40 (30–48) | 41 (32–49) | 39 (29–48) | 37 (27–47) | 33 (25–42) | < 0.001 |
| SpO₂ on admission (%) | 97 (95–99) | 97 (95–99) | 97 (94–98) | 96 (93–98) | 96 (92–98) | < 0.001 |
| SpO₂ at 4 h (%) | 97 (96–99) | 98 (96–99) | 97 (96–99) | 98 (96–99) | 98 (96–99) | 0.07 |
| PaO₂ on admission (kPa) | 15.6 (12.7–19.4) | 15.9 (12.9–19.7) | 15.3 (12.8–19.0) | 14.5 (11.1–17.8) | 14.2 (11.5–18.9) | < 0.001 |
| PaO₂ at 4 h (kPa) | 15.2 (12.7–18.2) | 15.5 (12.9–18.4) | 14.1 (11.4) | 15.4 (12.8–19.3) | 14.5 (11.9–17.7) | < 0.001 |
| Fluids 0–4 h (mL) | 1500 | 1450 (950–2000) | 1700 | 1650 | 2000 | < 0.001 |
| Red blood cell transfusions 0–4 h (units) | 1 (1–1) | 1 (1–1) | 1 (1–1) | 1 (1–1) | 0.67 |

Max VI/S category 0–4 h, % (n)

- 0–5: 16.7 (528) 18.7 (859) 12.7 (95) 146 (59) 5.7 (30) < 0.001
- 5–15: 29.3 (1838) 30.6 (1402) 26.7 (199) 27.6 (111) 23.9 (126) < 0.001
- 15–30: 12.8 (804) 12.1 (556) 12.9 (96) 164 (66) 163 (86) < 0.001
- 30–45: 2.7 (172) 2.4 (112) 3.1 (23) 3.2 (13) 4.5 (24) < 0.001
- >45: 38.4 (2405) 36.1 (1656) 44.6 (333) 38.2 (154) 49.6 (262) < 0.001

Values are medians (interquartile ranges) unless otherwise specified.

CI, cardiac index; HB, hemoglobin; PaO₂, arterial oxygen partial pressure; P/F, arterial oxygen partial pressure to fractional inspired oxygen ratio; SpO₂, oxygen saturation; VI/S, vasoactive index score.

**Table 3** Crude and adjusted hazard ratios (HRs) and 95% confidence intervals for 1-year mortality. See text for the preoperative risk factors.

| Group | HR, crude (N = 6282) | P | HR, adjusted for sex and Apache II and SOFA scores (N = 6282) | P | HR, adjusted for age, sex, and preoperative risk factors (N = 5833) | P |
|-------|----------------------|---|-------------------------------------------------------------|---|-------------------------------------------------------------|---|
| SvO₂ ≥ 60% at admission + at 4 h | 1 | < 0.001 | 1 | < 0.001 | 1 | < 0.001 |
| SvO₂ ≥ 60% at admission, < 60% at 4 h | 1.69 [1.17–2.42] | 0.005 | 1.46 [1.01–2.1] | 0.043 | 1.70 [1.15–2.51] | 0.007 |
| SvO₂ < 60% at admission, > 60% at 4 h | 2.66 [1.8–3.93] | < 0.001 | 2.05 [1.38–3.04] | < 0.001 | 1.89 [1.19–2.96] | 0.006 |
| SvO₂ < 60% at admission + at 4 h | 4.18 [3.1–5.65] | < 0.001 | 2.98 [2.18–4.06] | < 0.001 | 3.19 [2.28–4.45] | < 0.001 |

surgery. For each patient, we retrieved two SvO₂ values flanking the early hours of the postoperative ICU period. Perz et al. explored ScvO₂ levels during the first hours of the ICU stay after cardiac surgery and found that abnormally low ScvO₂ normalized within 4–6 h after ICU admission [11]. Although ScvO₂ values are not interchangeable with SvO₂ values [12] this result suggests that our time points for SvO₂ sampling (ICU admission and 4 h later) were suitable for detecting disturbed tissue perfusion in the early postoperative period after cardiac surgery.

In our study, the best outcome was seen with SvO₂ values maintained above 60% from the time of ICU admission to 4 h later. This group had no overt tissue hypoxemia and had the highest CI levels among all four groups at ICU admission and 4 h after admission. However, even though patients in the other three groups received vasoactive drugs, fluids, and other supportive treatments, decreased survival was noted, and the worst outcome was seen with SvO₂ remaining <60%. The pattern of SvO₂ ≥ 60% at ICU admission but <60% 4 h later most likely indicated a transient condition related to poor cardiac output or oxygenation, such as postoperative myocardial stunning or hypoxemia. Accordingly, this group showed decreased median CI values from admission to 4 h later. This inference is partly supported by analysis of surgical subgroups showing HRs for these patients that were less significant than in the whole study population, especially for those undergoing valvular and combined procedures. We note that patients with...
chronic cardiac failure are adapted to lower SvO₂, which may have had affected our results [19], and measuring preoperative SvO₂ would have been useful in this context. Additionally, a decreased SvO₂ may indicate increased oxygen consumption. For example, a small study of 21 cases showed decreasing SvO₂ in cardiac surgical patients after extubation and that the decline was associated with increased oxygen consumption [20].

SvO₂ is a marker of whole-body oxygenation, and oxygen use can fail at any level, from the macrocirculatory to microcirculatory to mitochondrial. Patients in the group with low SvO₂ values at both time points in the current study also represented the most complicated cases, with a third going through combined or aortic surgical procedures with persisting tissue hypoxia. Those with low ICU admission values but higher values at 4 h had existing tissue hypoxia at ICU admission, and despite the SvO₂ increase during the 4-hour period, mortality remained higher in this group than in patients with sustained SvO₂ ≥ 60% at both time points. The treatments targeted to increased oxygen delivery may not have yielded increased SvO₂ because of ongoing tissue hypoxia or mitochondrial dysfunction. In cardiac surgical patients, mitochondrial dysfunction and ongoing oxygen delivery/consumption mismatch could arise from ischemia/reperfusion injury and increased systemic inflammatory response resulting from exposure to cardiopulmonary bypass and surgical tissue trauma [21]. Furthermore, in a study assessing maintenance of SvO₂ ≥ 60% in high-risk cardiac surgical patients compared with usual care, the protocol group had a higher rate of reintubations and received more fluids, but the duration of norepinephrine infusion was similar between the two groups [22].

SvO₂ samples are usually obtained using PAC, although other techniques have been described, such as a small

Table 4 Receiver operating characteristic curve analysis of SvO₂ for 30-day mortality

| Group                           | SvO₂ < 60% at ICU admission, AUC (95%CI) | SvO₂ < 60% 4 h after ICU admission, AUC (95%CI) |
|---------------------------------|------------------------------------------|-----------------------------------------------|
| All patients                    | 0.71 (0.66–0.76)                         | 0.64 (0.59–0.69)                              |
| Ascending aorta and aortic dissection | 0.76 (0.66–0.87)                         | 0.74 (0.62–0.86)                              |
| CABG                            | 0.66 (0.59–0.74)                         | 0.61 (0.53–0.68)                              |
| Valvular surgery                | 0.68 (0.59–0.78)                         | 0.60 (0.50–0.69)                              |
| Combined procedures             | 0.79 (0.69–0.90)                         | 0.72 (0.61–0.83)                              |

AUC, area under curve; CABG, coronary artery bypass grafting; 95%CI, 95% confidence interval; ICU, intensive care unit; SvO₂, mixed venous oxygen saturation

Fig. 1 Kaplan–Meier survival curves for the different patient groups (N=6282). 1, patients with SvO₂ ≥ 60% at ICU admission and 4 h later (N=4585); 2, patients with SvO₂ ≥ 60% at admission but SvO₂ < 60% 4 h later (N=746); 3, patients with SvO₂ < 60% at ICU admission and SvO₂ ≥ 60% 4 h later (N=403); and 4, patients with SvO₂ < 60% at both time points (N=529)
Table 5  Adjusted hazard ratios (HRs) with 95% confidence intervals for 1-year mortality with different surgical procedures

| Surgical subgroup | SvO₂ status | HR, adjusted for age, sex, and preoperative risk factors (N = 5833) | \( P \) | HR, adjusted for sex and Apache II and SOFA scores (N = 6282) | \( P \) |
|-------------------|-------------|----------------------------------------------------------------|------|----------------------------------------------------------------|------|
| CABG (N = 3311)   | ≥ 60% at admission + at 4 h | 1 | 0.02 | 1 | < 0.001 |
|                   | ≥ 60% at admission, < 60% at 4 h | 1.62 [0.90–2.91] | 0.11 | 1.47 [0.85–2.54] | 0.17 |
|                   | < 60% at admission, ≥ 60% at 4 h | 1.79 [0.91–3.53] | 0.091 | 2.42 [1.40–4.19] | 0.002 |
|                   | < 60% at admission + at 4 h | 2.28 [1.27–4.09] | 0.006 | 2.52 [1.50–4.24] | 0.001 |
| Valvular surgery  | ≥ 60% at admission + at 4 h | 1 | < 0.001 | 1 | 0.002 |
| (N = 1825)        | ≥ 60% at admission, < 60% at 4 h | 1.35 [0.65–2.8] | 0.42 | 1.09 [0.55–2.16] | 0.8 |
|                   | < 60% at admission, ≥ 60% at 4 h | 2.0 [0.84–4.78] | 0.12 | 1.48 [0.69–3.18] | 0.32 |
|                   | < 60% at admission + at 4 h | 3.67 [2.01–6.7] | < 0.001 | 2.97 [1.69–5.22] | < 0.001 |
| Combined procedures (N = 756) | ≥ 60% at admission + at 4 h | 1 | 0.003 | 1 | 0.002 |
|                   | ≥ 60% at admission, < 60% at 4 h | 1.5 [0.47–4.82] | 0.5 | 1.27 [0.4–4.04] | 0.69 |
|                   | < 60% at admission, ≥ 60% at 4 h | 1.5 [0.39–5.83] | 0.56 | 2.08 [0.57–7.56] | 0.27 |
|                   | < 60% at admission + at 4 h | 4.36 [1.92–9.9] | < 0.001 | 4.36 [1.96–9.7] | < 0.001 |

Catheter inserted into the pulmonary artery during surgery [8, 9]. Data are scarce on the benefits of SvO₂ or PAC itself in cardiac surgery outcomes. To our knowledge, only one randomized controlled trial has been published that covered postoperative PAC-guided GDT using SvO₂ as a target parameter in cardiac surgical patients [7]. Studies on the benefit of PAC in cardiac surgery also are scarce, retrospective, or observational, with conflicting results [23–25]. Other major studies of how PAC affects patient outcomes have been conducted in surgical patients, patients with congestive heart failure, or non-cardiac ICU settings [24, 26–30]. However, these studies have not focused on SvO₂ but rather on filling pressures and cardiac output, and the pre-defined target values are highly variable or nonexistent.

Strengths

This study has several strengths. To our knowledge, it is the largest study to date showing an association of increased short- and long-term mortality with SvO₂<60% at ICU admission and 4 h later among a cohort of mixed cardiac surgical patients. Our center uses PAC in all cardiac surgical cases, so that health care professionals involved in the care of cardiac surgical patients both intra- and postoperatively are familiar with the use of PAC. Our data collecting system in the ICU is fully automatic, making the data for the present study more reliable because no hand-written information was used. Data on mortality and laboratory values were retrieved from fully digitized hospital records. We had full information on the preoperative risk scores in a clear majority of the patients and could retrieve ICU admission APACHE II and SOFA scores for all patients, enhancing the suitability of our adjusted analyses. In addition to SvO₂ values, we could present data on postoperative therapy that affects tissue oxygenation, such as administration of vasoactive agents, intravenous fluids, and red blood cell transfusion. Finally, previous studies of the relation between postoperative SvO₂ values and long-term mortality after cardiac surgery are sparse, and the present study clearly adds to current knowledge.

Limitations

A main limitation of this work is its single-center retrospective cohort design with all the known related pitfalls, so that the findings are at best hypothesis-generating. Moreover, the group with sustained SvO₂<60% had a significantly higher proportion of patients with preoperative risk factors such as low preoperative ejection fraction, diabetes, and emergency surgery. However, we adjusted the Cox regression analysis with the preoperative risk factors to accommodate this limitation. The study period is long, covering 2007–2020, and during this time, surgical, anesthesia, and perfusion techniques, therapies, and protocols and general care of cardiac surgical patients have evolved. Moreover, the study period incorporates three preoperative cardiac surgical risk scores that we could not fully integrate into our adjustments. However, we focused on SvO₂ as a risk factor for poor outcome, which is a surrogate of the acute situation, whereas risk scoring systems focus on the preoperative condition. Intraoperative risk factors such as aortic cross-clamping time and perfusion time were not considered in the present study because they are not available in our postoperative ICU data or in the electronic hospital records. However, despite these confounders, we found a survival benefit with SvO₂≥60% sustained during the first four postoperative hours after cardiac surgery.

Conclusion

PAC-obtained SvO₂ values<60% at ICU admission and 4 h later are associated with increased 30-day and 1-year mortality after cardiac surgery. GDT protocols targeting maintenance of SvO₂≥60% at and following ICU...
admission with the help of PAC may be beneficial. Prospective randomized controlled studies are needed to confirm these observational findings.

List of abbreviations

| Abbreviation | Description                              |
|--------------|------------------------------------------|
| APACHE       | Acute Physiology and Chronic Health Evaluation. |
| CABG         | Coronary artery bypass grafting          |
| CI           | Cardiac index                            |
| GDT          | Goal-directed therapy                    |
| HR           | Hazard ratio                             |
| ICU          | Intensive care unit                      |
| PAC          | Pulmonary artery catheter                |
| ROC          | Receiver operating characteristic       |
| ScvO₂        | Central venous oxygen saturation         |
| SOFA         | Sequential Organ Failure Assessment      |
| SvO₂         | Mixed venous oxygen saturation           |
| 95% CI       | 95% confidence interval                  |

Supplementary Information

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Authors' contribution

TK has contributed substantially to the conception and design of the work, as well as to the acquisition, analysis, interpretation of data, and drafted and revised the manuscript. TI has contributed substantially to the interpretation of data and revised the manuscript. TE has contributed substantially to the interpretation of data and revised the manuscript. JK has contributed substantially to the interpretation of data and revised the manuscript. PO has contributed substantially to the conception and design of the work, as well as to the acquisition, analysis, interpretation of data, and revised the manuscript. All authors have approved the submitted version.

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Data availability

The datasets used and/or analysed during the current study are not publicly available due to local policy but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The need for ethical approval and informed consent was waived by the Institutional Review Board of Northern Ostrobotnia Health District, because of the retrospective nature of the study. Procedures were followed in accordance with the ethical standards of the responsible institutional committee on human experimentation and with the Helsinki Declaration of 1975.

Consent for publication

Not applicable.

Competing interests

All authors declare that they have no conflict of interest.

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