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**Diagnostic accuracy of central venous saturation in estimating mixed  
venous saturation is proportional to cardiac performance among  
cardiac surgical patients**

Hrvoje Gasparovic<sup>a</sup>, Rajka Gabelica<sup>b</sup>, Zvonimir Ostojic<sup>a</sup>, Tomislav Kopjar<sup>a</sup>, Mate  
Petricevic<sup>a</sup>, Visnja Ivancan<sup>b</sup>, Bojan Biocina<sup>a</sup>

<sup>a</sup>Department of Cardiac Surgery, University Hospital Center Zagreb, University of  
Zagreb, Zagreb, Croatia

<sup>b</sup>Department of Anesthesiology, University Hospital Center Zagreb, University of  
Zagreb, Zagreb, Croatia

Correspondence:

Hrvoje Gasparovic. M.D., PhD, FETCS

Department of Cardiac Surgery

University Hospital Center Zagreb

Kispaticeva 12

10 000 Zagreb

Croatia

Tel: +385-1-236-7517

Fax: +385-1-236-7531

E-mail: [HGASPAROVIC@GMAIL.COM](mailto:HGASPAROVIC@GMAIL.COM)

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## Abstract

**Purpose—** Advanced hemodynamic monitoring in cardiac surgery translates into improvement in outcomes. We evaluated the relationship between central venous (ScvO<sub>2</sub>) and mixed venous (SvO<sub>2</sub>) saturations over the early postoperative period. The adequacy of their interchangeability was tested in patients with varying degrees of cardiac performance.

**Methods—** In this prospective observational study we evaluated 156 consecutive cardiac surgical patients in an academic center. ScvO<sub>2</sub> and SvO<sub>2</sub> data were harvested from 468 paired samples taken preoperatively (T0), after weaning from cardiopulmonary bypass (CPB, T1) and on postoperative day 1 (T2).

**Results—** The relationship between ScvO<sub>2</sub> and SvO<sub>2</sub> was inconsistent, with inferior correlations in patients with lower cardiac indices (CI), (Pearson's  $r^2=0.37$  if  $CI \leq 2.0$  L/min/m<sup>2</sup> vs.  $r^2=0.73$  if  $CI > 2.0$  L/min/m<sup>2</sup>, both  $P < 0.01$ ). Patients with lower CI also had wider 95% limits of agreement between SvO<sub>2</sub> and ScvO<sub>2</sub>. The proportion of patients with a negative SvO<sub>2</sub>–ScvO<sub>2</sub> gradient increased over time (48/156 (31%) at T0 to 73/156 (47%) at T2,  $P < 0.01$ ). This subgroup more frequently required inotropes at T2 than patients with a positive SvO<sub>2</sub>–ScvO<sub>2</sub> gradient (odds ratio 6.46 [95% CI 0.81-51.87],  $P=0.06$ ), and also had higher serum lactate levels ( $1.5 \pm 0.8$  vs.  $1.0 \pm 0.4$ ,  $P < 0.01$ ).

**Conclusions—** The diagnostic accuracy of ScvO<sub>2</sub> for estimating SvO<sub>2</sub> is proportional to cardiac performance. A negative SvO<sub>2</sub>–ScvO<sub>2</sub> gradient at T2 correlated with inotropic support requirement, higher operative risk score, age, lactate level and duration of CPB.

**Key words:** mixed venous saturation, central venous saturation, pulmonary artery catheter, cardiac surgery

## 1. Introduction

Global tissue hypoxia portends poor outcomes. Detection and prompt intervention designed to counter its effects are paramount in optimizing patient outcomes.

Pulmonary artery catheters (PACs) have historically been the mainstay of hemodynamic monitoring [1]. PACs provide left and right-sided filling pressures [1]. While filling pressures are suboptimal correlates of the volume status, they are often used to guide fluid resuscitation [2]. Moreover, pulmonary capillary wedge pressure has been found to be a predictor of adverse outcomes following acute myocardial infarction [3,4]. In the contemporary cardiac surgical arena the PAC provides important information about the hemodynamic performance of the right ventricle and the resistance in the pulmonary vascular bed. The former is relevant in identifying candidates for long-term left ventricular mechanical circulatory assistance, while the latter is invaluable in evaluating cardiac transplant candidacy. The potential benefits of PACs notwithstanding, there is substantial evidence to support their inefficiency in reducing mortality in both intensive care unit (ICU) and high-risk surgical patients [5]. Furthermore, PAC insertion is an invasive procedure, which requires manipulation of the catheter across the tricuspid and pulmonary valves. The incidence of complications is low, and these are mainly related to line insertion [6]. Unselective PAC insertion to all cardiac surgical patients has been found to be deleterious among patients undergoing isolated coronary artery bypass grafting [7].

The widespread use of central venous catheters in the ICU makes the acquisition of central venous saturations (ScvO<sub>2</sub>) simple and inexpensive. Despite the considerable

investigational effort that has been spent on evaluating the relationship between ScvO<sub>2</sub> and mixed venous saturation (SvO<sub>2</sub>), the controversy surrounding their interchangeability remains unresolved [8]. While they are clearly interlinked, the former is also dependent on oxygen content in the splanchnic and coronary circulations. The low oxygen extraction from the kidneys may account for high venous saturation in the inferior vena cava (IVC). Conversely, the very low oxygen content from the coronary sinus mirrors the highly efficient oxygen utilization in the heart. During hypoperfusion blood may be diverted away from the splanchnic circulation while oxygen demand may increase. Both of these events could result in lower saturation in the IVC, and therefore lead to a negative SvO<sub>2</sub>-ScvO<sub>2</sub> gradient.

Our study aimed to explore the correlation between SvO<sub>2</sub> and ScvO<sub>2</sub> under both optimal hemodynamic settings and during low cardiac output among cardiac surgical patients. We hypothesized that the diagnostic accuracy of ScvO<sub>2</sub> in predicting SvO<sub>2</sub> would be compromised in the setting of inferior myocardial performance. Furthermore, we investigated the dynamics of the relationship between SvO<sub>2</sub> and ScvO<sub>2</sub> over the immediate perioperative period.

## **2. Materials and methods**

### **2.1. Setting**

We evaluated patients undergoing cardiac surgery at a single academic center in Croatia (University Hospital Center Zagreb). Upon completion of the surgical procedure patients were transferred to a dedicated surgical intensive care unit. The study was approved by the Ethics committee of the University Hospital Center Zagreb. Ethical standards in line with the Declaration of Helsinki were adhered to. Written informed consent was obtained from all patients prior to enrollment.

### **2.2. Study population**

Patient enrollment for this observational cohort study commenced in April 2013 and was completed in July 2013. All consecutive patients undergoing cardiac surgery with the use of CPB for acquired heart disease were evaluated for eligibility. Exclusion criteria included congenital pathology, emergent cases, heart transplantation, off-pump coronary artery bypass grafting and inability to provide consent. Additionally, patients requiring mechanical circulatory assistance were also excluded, as their impact on group homogeneity would have been profound.

### **2.3. Hemodynamic monitoring**

The standard monitoring protocol in our study included a pulmonary artery catheter (Argon Medical Devices, Singapore), which was almost universally inserted via the right jugular vein. We relied on pressure tracings for the correct positioning of PACs.

Thermodilution cardiac indices and other hemodynamic data were obtained in triplicate



and then averaged. An additional central venous line was placed through either a jugular or subclavian vein. Continuous arterial monitoring was typically performed via a right radial catheter. One of the femoral arteries was used for arterial access in the unlikely event that the radial arterial route was inadequate.

#### **2.4. Measurement of mixed venous and central venous saturations**

Samples used for determining SvO<sub>2</sub> and ScvO<sub>2</sub> were drawn simultaneously from the distal port of the PAC and a separately placed central venous line, respectively. They were subjected to a blood gas analysis without delay. The blood gas analyzer (RAPIDlab 1265, Siemens, Germany) was calibrated on a daily basis. Blood sampling was performed after induction of anesthesia (T0), immediately upon weaning from CPB (T1) and on postoperative day 1 (T2).

#### **2.5. Cardiopulmonary bypass and perioperative management**

The anesthetic regime included induction and maintenance of anesthesia with midazolam, fentanyl and pancuronium bromide. This was coupled with sevoflurane inhalation. The initial ventilator settings included a tidal volume of 8 ml/kg, and a respiratory rate of 12 breaths per minute. Typically, the FiO<sub>2</sub> was set at 50%. The ascending aorta and right atrium were cannulated for CPB. Myocardial protection consisted of both antegrade and retrograde cardioplegia. Systemic heparinization aiming at an ACT > 480 seconds was used, followed by full reversal with protamine after decannulation. A CPB flow of greater than 2.0 L/min/m<sup>2</sup> was targeted. The target mean arterial pressure during CPB was 60-70 mmHg. If necessary, norepinephrine was employed to reach the aimed blood pressure.

The lungs were open to atmosphere during CPB. Weaning from CPB was initiated once the patient's rhythm had been stabilized and the patient was re-warmed and de-aired. We universally followed a goal-oriented strategy targeting a cardiac index of greater than 2.0 L/min/m<sup>2</sup> for the entire duration of postoperative hemodynamic monitoring. Active interventions to achieve that goal included volume replacement and inotropic support. The preferred inotropic agent was dobutamine, but milrinone, epinephrine and levosimendan were used sporadically. A further upgrade of hemodynamic support in patients resistant to the aforementioned interventions included extracorporeal membrane oxygenation (ECMO). One patient in whom ECMO support was employed postoperatively was excluded from the study, due to the fact that PAC data is difficult to interpret in this setting.

## **2.6. Statistical analysis**

The continuous data are presented as mean values  $\pm$  standard deviation or medians with their respective interquartile range. Categorical variables are shown as absolute numbers with percentages. Continuous data between different groups were compared with the Mann-Whitney U-test. Differences between categorical variables were evaluated with Fisher's exact test. A two-tailed P-value  $<0.05$  was considered to be significant. Pearson product-moment correlation coefficients ( $r$ ) were used to explore the relationships between continuous data. The comparisons between ScvO<sub>2</sub> and SvO<sub>2</sub> also included a mean bias and 95% limits of agreement in line with a Bland-Altman analysis. Furthermore, the diagnostic accuracy of ScvO<sub>2</sub> for predicting SvO<sub>2</sub> was assessed under different hemodynamic conditions. Venous saturation data harvested from patients with a

$CI \leq 2.0$  L/min/m<sup>2</sup> were compared to data taken from patients with a  $CI > 2.0$  L/min/m<sup>2</sup>. In order to minimize bias and to account for different sample sizes between these datasets, a 1:1 propensity score matching was performed. The covariates used in the matching process were age, operative risk score (EuroSCORE 2), duration of CPB, use of inotropic agents, and serum lactate concentrations at the time of sample acquisition. The data were processed using the IBM SPSS 22.0 software package (Somers, New York, USA).

### **3. Results**

#### **3.1. Study participants**

A total of 156 non-emergent consecutive patients undergoing cardiac surgery with the use of CPB were included in this prospective observational study. Venous saturation data were harvested from 468 paired samples acquired at 3 predetermined time-points. The median ICU stay was 45 (interquartile range: 43,47) hours. The observed mortality of 2.6% compared favorably to the predicted mortality of 6.6%, as projected by EuroSCORE II. The list of comorbidities in our study cohort was representative of the contemporary cardiac surgical population. The baseline demographic and clinical profiles of the entire cohort, as well as the operative details, are presented in Table 1.

#### **3.2 Interchangeability of SvO<sub>2</sub> and ScvO<sub>2</sub> across the entire patient cohort**

The relationship between SvO<sub>2</sub> and ScvO<sub>2</sub> was inconsistent across the study period. Overall, the ScvO<sub>2</sub> overestimated SvO<sub>2</sub> by a mean bias of -1.2%. The 95% limits of agreement were wide (lower -14.2; upper 11,8; Figure 1A). The discrepancy between the SvO<sub>2</sub> and ScvO<sub>2</sub> was observed at all studied time points. Bland-Altman plots were constructed to illustrate the agreements between the SvO<sub>2</sub> and ScvO<sub>2</sub> at each individual data acquisition point. These are shown in Figure 1 (panels B, C and D).

#### **3.2. Correlation between the SvO<sub>2</sub> and ScvO<sub>2</sub> under different hemodynamic conditions**

Samples for 468 paired comparisons between SvO<sub>2</sub> and ScvO<sub>2</sub> from 156 patients were harvested at three different time points (T1, T2 and T3). One-hundred and one paired samples were obtained while the CI was less than or equal to 2.0 L/min/m<sup>2</sup> at the time of data acquisition, while the remaining 367 paired samples were harvested under optimal hemodynamic settings (CI>2.0 L/min/m<sup>2</sup>). Since one patient provided 3 datasets (T1, T2 and T3), the same patient could be represented with multiple paired samples but at different time-points and, consequently, with different hemodynamics. Propensity scores were calculated, and then used to match data obtained from patients with a CI≤2.0 L/min/m<sup>2</sup> with samples harvested from patients with a CI>2.0 L/min/m<sup>2</sup>, in a 1:1 fashion. The final propensity-score matched analysis included 101 samples from 90 patients with a CI≤2.0 L/min/m<sup>2</sup>, and 101 samples from 84 patients with a CI>2.0 L/min/m<sup>2</sup> at the time of sample acquisition. The calculated measures of cardiac performances (CI) in the propensity-score matched cohorts were 1.8±0.2 and 2.9±0.5 L/min/m<sup>2</sup>, respectively (*P*<0.001). There were no statistically significant differences between the studied subgroups in age, gender, operative risk, preoperative comorbidities, inotrope use and surgical complexity (all *P*>0.10). The correlations between SvO<sub>2</sub> and ScvO<sub>2</sub> were affected by the underlying cardiac performance (Figure 2). Central venous saturation exhibited a moderate-high level of correlation with SvO<sub>2</sub> in patients with a cardiac output exceeding 2.0 L/min/m<sup>2</sup> (Pearson's *r*<sup>2</sup>=0.73). Within this propensity matched cohort of patients with a CI>2.0 L/min/m<sup>2</sup>, the mean bias was -1.6, while the upper and lower limits of agreement were -11.4% and 8.2%, respectively.

The relationship between the SvO<sub>2</sub> and ScvO<sub>2</sub> among patients with a calculated cardiac index ≤2.0 L/min/m<sup>2</sup>, however, was much less robust (Pearson's *r*<sup>2</sup>=0.37). While both

correlation analyses revealed statistically significant relationships ( $P < 0.01$ ), the diagnostic accuracy of ScvO<sub>2</sub> to predict SvO<sub>2</sub> was clearly compromised in patients with inferior cardiac performance (Figure 2). This was further corroborated by wider 95% limits of agreement between SvO<sub>2</sub> and ScvO<sub>2</sub> in the propensity-score matched patients with a cardiac output  $\leq 2.0$  L/min/m<sup>2</sup> (bias 0.08; lower limit: -14.2%; upper limit: 14.4%).

### **3.3. Temporal changes in the SvO<sub>2</sub>–ScvO<sub>2</sub> gradient**

In order to follow the trends in the differences between mixed venous and central saturations over the study period, patients were divided into tertiles based on the SvO<sub>2</sub>–ScvO<sub>2</sub> gradients obtained from the first paired blood samples (T0). The 33<sup>rd</sup> and 66<sup>th</sup> percentile of the SvO<sub>2</sub>–ScvO<sub>2</sub> gradient were -3% and +3%, respectively. The two aforementioned percentile boundaries were utilized to isolate patients into three groups (Table 2). Patients with an SvO<sub>2</sub>–ScvO<sub>2</sub> gradient that was lower than -3% were considered to have a negative gradient, and were aggregated in group 1. Patients in whom the SvO<sub>2</sub>–ScvO<sub>2</sub> differences were between -3% and +3% comprised the group 2, and were considered to have negligible gradients. Patients in whom the ScvO<sub>2</sub> was greater than SvO<sub>2</sub> by more than 3% were clustered in group 3, and were classified as having a positive SvO<sub>2</sub>–ScvO<sub>2</sub> gradient.

The same percentile boundaries were utilized for the duration of the data acquisition period. This allowed for observation of the SvO<sub>2</sub>–ScvO<sub>2</sub> gradient trends across the study period. We found that the proportion of patients with a negative SvO<sub>2</sub>–ScvO<sub>2</sub> gradient increased over time (48/156 (31%) at T0 to 73/156 (47%) at T2,  $P < 0.01$ ). Contrariwise, the number of patients with a positive SvO<sub>2</sub>–ScvO<sub>2</sub> gradient decreased over the studied

period (52/156 (33%) at T0 to 17/156 (11%).  $P<0.01$ ). When evaluating the entire cohort including all 156 patients, we found that the SvO<sub>2</sub>–ScvO<sub>2</sub> gradient widened toward incrementally more negative values over time (Figure 3). The SvO<sub>2</sub>–ScvO<sub>2</sub> gradient was  $0.78\pm 7.66$  at T0,  $-1.44\pm 6.4$  at T1 and  $-2.89\pm 5.07$  at T2 (T0 vs. T1,  $P<0.01$ ; T0 vs. T2,  $P<0.001$ ; T1 vs. T2,  $P=0.12$ ).

### **3.4. Effects of clinical, operative and hemodynamic data on the SvO<sub>2</sub>–ScvO<sub>2</sub> gradient**

Cardiac performance according to data obtained from the PAC was consistently greater than 2.0 L/min/m<sup>2</sup> in all three subgroups across the entire study period (Table 2). This is a reflection of our postoperative management strategy, which aimed at maintaining the cardiac index above 2.0 L/min/m<sup>2</sup> in all patients. We, consequently, found no correlation between thermodilution cardiac indices and the SvO<sub>2</sub>–ScvO<sub>2</sub> gradient when analyzing the entire pool of 468 paired samples (Pearson's  $r^2=-0.07$ ,  $P=0.15$ ). When evaluating the frequency of inotropic support utilization among the subgroups at T2, however, we found that patients with a positive SvO<sub>2</sub>–ScvO<sub>2</sub> gradient were least likely to depend upon it for optimizing hemodynamics and also had lowest lactate levels (Table 2). Conversely, patients with a negative SvO<sub>2</sub>–ScvO<sub>2</sub> gradient on postoperative day 1 had higher serum lactate levels ( $1.5\pm 0.8$  vs.  $1.0\pm 0.4$  in group 3,  $P<0.01$ ), mirroring the highest subgroup utilization of inotropic support (odds ratio 6.46 [95% CI 0.81 - 51.87],  $P=0.06$ ).

Additionally, these patients were older, came from the highest operative risk stratum, had longer CPB and myocardial ischemic times (Table 2). Patients with a negative SvO<sub>2</sub>–ScvO<sub>2</sub> gradient at T0 had lower stroke volume indices in comparison to patients with a positive SvO<sub>2</sub>–ScvO<sub>2</sub> gradient (Table 2).





## 4. Discussion

The PAC has remained a commonly employed tool for optimizing the hemodynamic profile of cardiac surgical patients. PAC guided volume management is the subject of well-placed criticism. Intravascular pressure correlates poorly with intravascular volume [15], which is the only genuine equivalent of cardiac preload. Cardiac output measurements, however, can differentiate between various etiologies of postoperative hypotension. This distinction is paramount in guiding active therapy. While the information provided by the PAC may still hold value, multiple reports have been published since its inception cautioning its association with worse clinical outcomes [7,9,10]. Sandham et al found that PAC guided algorithms did not alter the outcomes in noncardiac surgical patients using a randomized controlled study design [12]. In the aftermath of these findings the use of PACs in the current medical and surgical practices has declined substantially [11]. The controversy on the efficacy of hemodynamic protocols, however, continues to be fueled by publications encapsulating their benefit in reducing mortality and postoperative organ dysfunction [13,14]. Additionally, SvO<sub>2</sub> has been shown to predict postoperative mortality in patients following valvular surgery [16]. Even though risk adjustments for selection bias were performed in some of these conflicting studies, the rigors of large prospective randomized trials examining the role of right heart catheterization in cardiac surgical patients are sorely needed to definitively determine its role in modern practice [7].

The ubiquitous utilization of central venous catheters in the ICU makes the temptation to substitute ScvO<sub>2</sub> for SvO<sub>2</sub> difficult to resist. Both mixed venous and central venous

saturations are indicators of the balance between oxygen consumption and delivery [5,17]. Difficulties in interpreting ScvO<sub>2</sub> are persuasively illustrated by the fact that values outside the normal range at either extreme, correlate with inferior outcomes [5]. In our study, the relationship between ScvO<sub>2</sub> and SvO<sub>2</sub> was found to be inconsistent, thereby negating reliability in using the former parameter to estimate the latter. Our data is in line with similar observations in diverse clinical settings [8,17,18,19]. We also specifically investigated the impact of the underlying hemodynamic status on the interchangeability of ScvO<sub>2</sub> and SvO<sub>2</sub> by dichotomizing patients based on a cardiac index cut-off point of 2.0 L/min/m<sup>2</sup>. We found ScvO<sub>2</sub> to be an increasingly less reliable substitute for SvO<sub>2</sub> as the cardiac performance worsened. One may infer that during hypoperfusion, which is the very scenario when a less invasive marker of tissue oxygenation would be of greatest benefit, ScvO<sub>2</sub> is also least effective in predicting SvO<sub>2</sub>. The wide limits of agreement across all comparisons between ScvO<sub>2</sub> and SvO<sub>2</sub> observed in our study parallel those seen in other publications [18,20,21] and reinforce the notion of a modest mutual association.

The variability between the SvO<sub>2</sub> and ScvO<sub>2</sub> was evident at all studied time points in our study. The overall SvO<sub>2</sub>–ScvO<sub>2</sub> gradient shifted from a slightly positive one preoperatively to increasingly more negative values over the ensuing data acquisition points. The proportion of patients with a negative SvO<sub>2</sub>–ScvO<sub>2</sub> gradient increased from 31% at T0 to 47% at T2. We found no correlation between the SvO<sub>2</sub>–ScvO<sub>2</sub> gradient and hemodynamic data obtained from the PAC. One must recognize that we universally followed a goal-oriented strategy targeting a cardiac index of greater than 2.0 L/min/m<sup>2</sup> for the duration of hemodynamic monitoring. Active interventions to achieve that goal

included volume replacement or inotropic support, as well as packed red blood cell transfusions aiming at increasing the oxygen carrying capacity. When considering the high postoperative inotrope utilization among patients with a negative  $SvO_2-ScvO_2$  gradient as a surrogate for a suboptimal hemodynamics, however, one may extrapolate that this subgroup had inferior pre-treatment cardiac indices. Gutierrez et al documented an association between a positive  $ScvO_2-SvO_2$  gradient and survival in a cohort of 106 critically ill patients [22]. The authors suggested that increasingly positive  $ScvO_2-SvO_2$  gradients reflected superior oxygen utilization [22]. While our study was larger in size than the aforementioned one, it was still underpowered to look at survival due to the excellent survival rates in the contemporary cardiac surgical practice. Our own data seemingly contradict the observations by Gutierrez and co-workers [22]. Patients in whom the central venous exceeded the mixed venous saturations (in our study denoted as a negative  $SvO_2-ScvO_2$  gradient) had inferior indicators of their hemodynamic status. We believe that the reasons for this discrepancy lie in the multiple covariates that influence the saturation content within different venous pools, many of which cannot be reliably reproduced in dissimilar patient subpopulations. Primarily, the degree of cardiac oxygen utilization during and following hypothermic cardioplegic arrest remains unpredictable. Its assessment would require direct cannulation of the coronary sinus, which collects approximately 85% of coronary venous blood [23]. While this procedure is routinely performed in order to deliver retrograde cardioplegia, keeping the catheter in place beyond the period of aortic cross clamping for longitudinal sampling is potentially hazardous. Moreover, the normally low oxygen extraction from the kidneys may increase in order to offset a reduction in blood flow that may occur during systemic

hypoperfusion. Both of these events will only affect SvO<sub>2</sub>. Conversely, anesthesia and sedation reduce cerebral oxygen consumption [20], which will impact both SvO<sub>2</sub> and ScvO<sub>2</sub>. All of the above mentioned issues consolidate the theoretical context of our observation that the individual variability between SvO<sub>2</sub> and ScvO<sub>2</sub> is erratic and unpredictable.

The limitations of our study stem from its non-randomized design. The insertion of PACs in our practice is a part of the standard monitoring protocol, and is applied non-selectively to all patients scheduled for cardiac surgery. Any bias in their application can, therefore, be excluded. More precise preload management in our practice could have been implemented with more liberal use of echocardiography. While echocardiography is implemented in the majority of patients intraoperatively, only a small fraction of them would have volumetric data available in the early postoperative period. We, therefore, rely on pressure recordings for optimizing volume management, understanding the inherent drawbacks of this strategy.

## **5. Conclusions**

Our study confirms that ScvO<sub>2</sub> is an unreliable substitute for SvO<sub>2</sub> among patients undergoing cardiac surgery. The wide limits of agreement between these parameters at baseline are further amplified by hemodynamic compromise. Consequently, the accuracy of ScvO<sub>2</sub> to predict SvO<sub>2</sub> is lowest in patients in whom this information would potentially be of greatest benefit. Basing therapeutic decisions on ScvO<sub>2</sub> based algorithms is, therefore, inappropriate in the cardiac surgical domain. Patients exhibiting negative SvO<sub>2</sub>-ScvO<sub>2</sub> gradients postoperatively were more likely to require inotropic support for maintaining optimal hemodynamics. Furthermore, they were found to have a higher risk profile and higher serum lactates, as well as longer aortic cross-clamp and CPB times.

## **Abbreviations**

<b>ScvO<sub>2</sub></b>	central venous saturation
<b>SvO<sub>2</sub></b>	mixed venous saturation
<b>CPB</b>	cardiopulmonary bypass
<b>CI</b>	cardiac index
<b>PAC</b>	pulmonary artery catheter
<b>ICU</b>	intensive care unit
<b>IVC</b>	inferior vena cava
<b>ECMO</b>	extracorporeal membrane oxygenation

### **Competing interests**

The authors declare that they have no competing interests.

## **Authors' contributions**

HG participated in designing the study, performed the statistical analysis and drafted the manuscript. RG participated in designing the study, and revised the drafted manuscript for critically important content. ZO was responsible for acquisition of hemodynamic patient data, and helped draft the manuscript. TK was responsible for acquisition of clinical and operative patient data, and helped draft the manuscript. MP participated in performing the statistical analysis, and revised the drafted manuscript for critically important content. VI participated in designing the study, and revised the drafted manuscript for critically important content. BB provided general support, and revised the drafted manuscript for critically important content. All authors read and approved the final manuscript.



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Figure 1. Bland-Altman plot showing the agreements between ScvO<sub>2</sub> and SvO<sub>2</sub> within the entire sample (Panel A; mean bias -1.2, 95% limits of agreement from -14.2 to 11.8), at T0 (Panel B; mean bias 0.8, 95% limits of agreement from -14.2 to 15.8), T1 (Panel C; mean bias -1.4, 95% limits of agreement from -14.0 to 11.1), and T2 (Panel D; mean bias -2.9, 95% limits of agreement from -12.8 to 7.0)

Figure 2. Correlation between SvO<sub>2</sub> and ScvO<sub>2</sub> during optimal hemodynamic settings (CI>2.0 L/min/m<sup>2</sup>) shows a moderate-high correlation coefficient (Panel A). Low level of correlation between SvO<sub>2</sub> and ScvO<sub>2</sub> is seen when CI≤2.0 L/min/m<sup>2</sup> (Panel B).  
SvO<sub>2</sub>, mixed venous saturation; ScvO<sub>2</sub>, central venous saturation; CI, cardiac index

Figure 3. Box-and-whisker plot depicting the progressive rise in the SvO<sub>2</sub>-ScvO<sub>2</sub> gradient over the data acquisition period

Table 1. Baseline demographic, clinical and operative data

	<b>All patients (N=156)</b>
<b><i>Preoperative patient characteristics</i></b>	
Age, y	65±10
Male, n (%)	106 (68)
EuroSCORE II	6.6±11.0
Body mass index, kg/m <sup>2</sup>	28±5
LVEF, %	53±14
Hyperlipidemia, n (%)	79 (51)
Diabetes mellitus n (%)	40 (26)
Smoking history, n (%)	23 (15)
Chronic obstructive pulmonary disease. n (%)	15 (10)
Hypertension, n (%)	129 (83)
History of AMI, n (%)	41 (26)
Renal impairment	13 (8)
<b><i>Preoperative medications, n (%)</i></b>	
Clopidogrel	34 (22)
Aspirin	116 (74)
Beta blocker	100 (64)
Angiotensin-converting enzyme inhibitor	113 (72)
Statin	107 (69)
<b><i>Perioperative data, n (%)</i></b>	
Isolated CABG	68 (44)
Isolated valve surgery	55 (35)
CABG plus valve surgery	21 (13)
Valve plus aortic surgery	12 (8)
CPB, min	115±58
Aortic cross clamp time, min	81±40
Intensive care unit stay (hours; median, IQR)	45 [43,47]
Stroke	2 (1)
Renal failure requiring RRT	2 (1)
Perioperative AMI	7 (4)
30-day mortality	4 (3)

LVEF, Left ventricular ejection fraction; AMI, acute myocardial infarction; CABG, coronary artery bypass surgery; CPB, cardiopulmonary bypass; IQR, interquartile range; RRT, renal replacement therapy