Discrepancy Between Superior Vena Cava Oxygen Saturation and Mixed Venous Oxygen Saturation Can Predict Postoperative Complications in Cardiac Surgery Patients

Koichi Suehiro, MD, Katsuaki Tanaka, MD, PhD, Tadashi Matsuura, MD, PhD, Tomoharu Funao, MD, PhD, Tokuhiro Yamada, MD, PhD, Takashi Mori, MD, PhD, and Kiyonobu Nishikawa, MD, PhD

Objective: To determine if increases in discrepancy between $ScvO_2$ and SvO_2 ($ScvO_2 - SvO_2 = \Delta SO_2$) during surgery in cardiac surgery patients can predict postoperative complications.

Design: Prospective, observational study.

Setting: University hospital.

Participants: One hundred two patients undergoing cardiac surgery were enrolled.

Interventions: None.

Measurements and Main Results: Central venous oxygen saturation ($ScvO_2$) and mixed venous oxygen saturation (SvO_2) values during surgery automatically were collected. The average value of ΔSO_2 for every minute was calculated. The area under the receiver operating characteristic curve for prolonged postoperative ICU stay (≥3 days) was 0.745 for ΔSO_2, which was significantly different from those of $ScvO_2$ and SvO_2 ($p < 0.05$) ($ScvO_2$; 0.584, SvO_2; 0.598). The optimal threshold value of ΔSO_2 to predict prolonged ICU stay (≥3 days) was 12% (sensitivity: 72.0%, specificity: 76.9%). Postoperative ICU duration, ventilation time, and hospital stay were significantly longer in Group D patients (intraoperative maximum ΔSO_2 ≥12%) than those in Group N patients (intraoperative maximum ΔSO_2 <12%). As for postoperative complications, the number of patients with postoperative use of intra-aortic balloon pumping, delirium, respiratory failure requiring tracheotomy, and severe complications was significantly higher in Group D patients. Multivariate logistic regression models were used to evaluate the independent effects of perioperative variables on the risk of developing prolonged ventilation (>24 hours) and prolonged ICU stay (≥3 days). A discrepancy in intraoperative ΔSO_2 was an independent risk factor for prolonged postoperative ventilation and ICU stay.

Conclusion: The discrepancy between $ScvO_2$ and SvO_2 during cardiac surgery is an independent risk factor of postoperative complications such as prolonged ICU stay and ventilation time.

KEY WORDS: superior vena cava oxygen saturation, mixed venous oxygen saturation, complication, cardiac surgery

HEART FAILURE after cardiac surgery can lead to organ failure and death. Therefore, adequate monitoring of the hemodynamic state in cardiac surgery patients is very important.[1,2] Maintaining adequate oxygen delivery is essential to preserve organ function. Monitoring of mixed venous oxygen saturation (SvO_2) with a pulmonary artery catheter (PAC) is used to evaluate oxygen delivery, and has been indicated as a prognostic predictor in cardiac surgery patients.[3] However, catheterization with a PAC is costly and places patients at risk for various complications, including pulmonary artery rupture, arrhythmia, pneumothorax, and air embolism.[4] Measuring central venous oxygen saturation ($ScvO_2$) was suggested as a more accessible and simpler monitor of global tissue oxygenation.[5–10] Maintaining $ScvO_2$ at more than 70% by an aggressive hemodynamic management protocol has been shown to reduce mortality in septic patients.[5] As central venous catheterization is less invasive than pulmonary artery catheterization, many trials have been conducted to investigate if $ScvO_2$ could be an alternative to SvO_2. However, in critically ill patients, an agreement between $ScvO_2$ and SvO_2 was inconsistent and unsatisfactory.[11–14]

$ScvO_2$ measures oxygen saturation of the venous mixture in the upper body while SvO_2 determines oxygen saturation of the venous mixture in the whole (upper and lower) body, including coronary sinus circulation.[11] Therefore, in healthy subjects, the value of $ScvO_2$ has been shown to be slightly lower than that of SvO_2.[15] In critically ill patients, this situation is reversed. In recent studies, the average value of $ScvO_2$ was shown to be approximately 4.0% to 7.0% higher than that of SvO_2 because of changes in the distribution of cardiac output that occurred in patients with shock states such as cardiac failure and sepsis.[6,16,17]

The aim of this study was to test the hypothesis that increases in discrepancy between $ScvO_2$ and SvO_2 (ΔSO_2) during surgery in cardiac surgery patients could predict postoperative complications. Assessing the capability of ΔSO_2 to predict complications after cardiac surgery is an issue of great importance, as it may lead to a new perioperative hemodynamic management protocol.

METHODS

Approval was obtained from the ethics committee of the authors' hospital, and informed consent was obtained from all enrolled patients. One hundred two patients scheduled for cardiac surgery with cardiopulmonary bypass (CPB) were included in this study. Exclusion

From the Department of Anesthesiology, Osaka City University Graduate School of Medicine, 1-5-7 Asahimachi, Abenoku, Osaka City, Osaka, 545-8586, Japan.

This study does not have any potential conflicts of interest including commercial relationships such as consultation and equity interests. Only departmental funds were used for this study.

Address reprint requests to Koichi Suehiro, MD, Osaka City University Graduate School of Medicine, Department of Anesthesiology, 1-5-7 Asahimachi, Abenoku, Osaka City, Osaka, 545-8586, Japan. E-mail: suehirokoichi@yahoo.co.jp

1053-0770/2601-0001$36.00/0
http://dx.doi.org/10.1053/j.jvca.2013.03.002

criteria were hemodialysis and intracardiac shunts. No premedication was administered. General anesthesia induction was performed using midazolam (0.05-0.1 mg/kg), propofol (1-2 mg/kg), fentanyl (2-3 μg/kg), and rocuronium (0.6-1 mg/kg). After tracheal intubation, all patients were ventilated with a tidal volume of 8 to 10 mL/kg of ideal body weight. The authors controlled the frequency of mechanical ventilation to keep end-tidal carbon dioxide between 35 to 40 mmHg and inspired oxygen concentration to maintain intraoperative $PaO_2 > 100$ mmHg. Anesthesia was maintained with sevoflurane (1.5-2.0%) and fentanyl (20-40 μg/kg per case as the total dose). During CPB, anesthesia was given with continuous propofol administration (2-3 mg/kg/h). The depth of anesthesia was controlled to keep the bispectral index (BIS) (v4.0, Aspect Medical System Inc, Natick, MA) value between 40 and 60. Rocuronium (15-30 mg/h) was administered to obtain muscle relaxation. After the induction of general anesthesia, the authors inserted an arterial pressure catheter into the radial artery and a central venous catheter (PreSep catheter, Edwards Lifesciences, Irvine, CA) and thermodilution pulmonary artery catheter (Edwards Lifesciences, Irvine, CA) into the right internal jugular vein. The position of the catheter was confirmed by transesophageal echocardiography and its pressure wave. The PreSep catheter is a triple-lumen catheter with an added capability for continuous $ScvO_2$ monitoring. This catheter is equipped with fiberoptics and connected to the Vigileo monitor (Edwards Lifesciences, Irvine, CA). The connection between the Vigileo monitor and catheter needs a specific cable with an optical module. The Vigileo monitor works with the Presep catheter for continuous $ScvO_2$ measurement. After insertion of these catheters, continuous measurement of $ScvO_2$ and SvO_2 was started. $ScvO_2$ and SvO_2 were measured continuously before and after CPB.

Standard CPB procedures were performed in all patients. Standard flow rates of 2.6 L/min/m^2 were utilized to maintain a mean arterial pressure between 50 and 80 mmHg. The authors maintained $PaCO_2$ at 40 mmHg or greater by alpha-stat management and hematocrit above 22%. Mild hypothermia (at a rectal temperature of 32°C) and antegrade and retrograde crystalloid cardioplegia were used. Circulatory arrest and cerebral perfusion were utilized in patients with thoracic aortic aneurysms. Circulation was arrested at a rectal temperature below 26°C. Right-side cerebral perfusion via the right axillary artery was maintained at 700 mL/min. Selective left-side cerebral perfusion to the left common carotid artery and subclavian artery was maintained at 250 mL/min. Mean arterial pressure during cerebral perfusion was managed between 40 and 50 mmHg at the right radial artery. After the separation from CPB, intra-aortic balloon pumping (IABP) was used when hypotension (systolic blood pressure <80 mmHg) and low cardiac index (<2.0 L/min/m^2) were seen despite the administration of inotropic drugs.

Measurement of $ScvO_2$ and SvO_2 was discontinued in the operating room. After surgery, all patients were transferred to the intensive care unit (ICU). Postoperative management was performed by surgeons who were blinded to intraoperative $ScvO_2$ and SvO_2 data. Criteria for discharge from the ICU were as follows: (a) respiratory stability defined as maintenance of $SpO_2 > 95\%$ on ≤5L supplemental O_2; (b) hemodynamic stability defined as 1 or fewer intravenous inotropic drugs, removal of arterial and pulmonary artery catheters and absence of unstable arrhythmias; (c) urine output ≥1mL/kg/h; (d) chest tube drainage <10 mL/h.

To compare the severity and incidence of postoperative complications, the incidence of major organ morbidity and mortality (MOMM) was considered as described in previous studies.[18,19] MOMM included prolonged ventilation for more than 48 hours, renal failure requiring dialysis, stroke, re-operation, deep sternal infection, and death. The data of the postoperative course were obtained from the medical records.

$ScvO_2$ and SvO_2 values during surgery (before and after CPB) were collected automatically (electronically by the dedicated computer). The average values of $ScvO_2$ and SvO_2 over a minute were collected, and the absolute ΔSO_2 (= $ScvO_2 - SvO_2$) value for every minute was calculated. To determine the threshold of ΔSO_2 predicting postoperative complications in cardiac surgery, the authors calculated a receiver operating characteristic (ROC) curve to evaluate the prognostic performance of ΔSO_2, $ScvO_2$, and SvO_2 with regard to prolonged ICU stay (≥3 days). The authors divided patients into two groups according to the ΔSO_2 threshold value made by ROC analysis (Group D; discrepancy of ΔSO_2 [≥ the threshold value], Group N; no discrepancy of ΔSO_2 [< the threshold value]). The authors compared these two groups at the point of perioperative complications. Separate multivariate logistic regression models were utilized to investigate the independent effects of perioperative variables on the risk of developing prolonged ventilation (>24 hours) and prolonged ICU stay (≥3 days).

All results were expressed as mean and standard deviation (SD) unless otherwise indicated. Statistical analysis was performed with SigmaPlot 11.2 (Systat Software Inc., San Jose, CA). The authors used the Student's t-test and Mann-Whitney U test to compare demographic data. For all analyses, a p value < 0.05 was considered to be significant.

RESULTS

One hundred two patients undergoing cardiac surgery were enrolled in this study. Preoperative characteristics in these patients are shown in Table 1. There were significant differences between the 2 groups in the New York Heart Association (NYHA) classification and in the number of patients with chronic kidney disease (serum creatinine >1.2 mg/dL) ($p < 0.05$). At first, ROC analysis was performed to evaluate the prognostic performance of ΔSO_2, $ScvO_2$, and SvO_2 with regard to prolonged ICU stay (≥3 days) (Fig 1). The area under the ROC curve was 0.745 for ΔSO_2, which was significantly different from those of $ScvO_2$ and SvO_2 ($p < 0.05$) ($ScvO_2$; 0.584, SvO_2; 0.598). The optimal threshold value of ΔSO_2 to predict prolonged ICU stay (≥3 days) was 12% (sensitivity: 72.0%, specificity: 76.9%). The authors used this threshold of 12% to divide patients into 2 groups (Group D; intraoperative maximum $\Delta SO_2 \geq 12\%$ [n = 48], Group N; intraoperative maximum $\Delta SO_2 < 12\%$ [n = 54]).

Perioperative data in both groups are shown in Table 2. The number of patients with intraoperative use of an IABP was significantly higher in Group D. $ScvO_2$ and SvO_2 values were significantly lower, and ΔSO_2 values were significantly higher in Group D than in Group N. Postoperative ICU duration, ventilation time, and hospital stay were significantly longer in Group D patients than in Group N (Table 3). As for postoperative complications, the number of patients with postoperative use of IABP, delirium, respiratory failure requiring tracheotomy, and MOMM was significantly higher in Group D. The authors used multivariate logistic regression models to evaluate the independent effects of perioperative variables on the risk of developing prolonged ventilation (>24 hours) and prolonged ICU stay (≥3 days), which are shown in Table 4a and 4b. A discrepancy in intraoperative ΔSO_2 was an independent risk factor of postoperative prolonged ventilation and ICU stay.