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Tissue Oxygenation in Postoperative Patients: A Pilot Study

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ABSTRACT

Aims: In the absence of a gold standard for the clinical diagnosis of shock, clinicians traditionally rely on measurements of vital signs, arterial oxygen saturation of hemoglobin (SaO_2), serum lactate, and arterial base deficit. Yet values derived from these measurements may remain relatively normal during the early stages of shock while the patient's condition is indeed deteriorating, and the evolution from mild to severe shock can be subtle or extremely rapid. Tissue oxygen saturation (StO_2) monitoring is a noninvasive technology that has been reported to function as an early warning sign of tissue hypoxia, as systemic blood flow is redistributed to critical organs, primarily in patients with hemorrhagic and traumatic shock, but also in patients with septic shock and in those undergoing cardiac surgery. This pilot study examined the strength of the relationship between initial postoperative StO_2 values and the development of complications in adult patients.

Methods: This observational, prospective study was carried out in a convenience sample of 31 hemodynamically stable, postoperative adults admitted to the Post-Anesthesia Care Unit (PACU) and Cardiothoracic Care Intensive Care Unit (CTICU) at a 643-bed Level I trauma medical center in the Northeastern region of the United States during 2012. Institutional Review Board approval was obtained from the university and the medical center. Patients were approached in the preoperative holding area, the study was explained, and patients were shown the equipment that would be used in the study. After the patient had been admitted to either the PACU or CTICU, the investigators waited until the bedside nurse performed an initial assessment of hemodynamic stability. Following calibration of the in spectra monitor, the StO2 probe was placed adhesively on the thenar eminence of the patient's hand. The StO2 data was monitored continuously, downloaded to a laptop computer, and recorded manually every 15 minutes for at least 2 hours.

Results: The first, last, and average StO2 values were, respectively: 80.71%+9.16; 80.94%+7.07; and, 80.56% +7.18. However, the mean minimum values of the first, last, and average StO2 values were, respectively: 55%, 67%, and 65%. When minimum StO2 values were tested for differences in the incidence of postoperative complications, there was a significant difference (x=76.9+7.44, range 59-92; Chi Sq, df 18, p=0.020).

Conclusions: While postoperative patients maintained a stable level of StO2 values during their early recovery, a case report illustrates that sudden drops in StO2 values may be sensitive to the detection of the potential for complications.

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1. Introduction

Critical care nurses are concerned with accurate assessment of tissue perfusion in critically ill patients. They rely on seasoned clinical judgment to estimate end-organ perfusion. This includes appraisal of mental status, peripheral skin color and warmth, capillary refill, pulse strength, vital signs, urinary output, and percent oxygen saturation of arterial hemoglobin (SaO2) in the form of continuous pulse oximetry (SpO2). At the most fundamental level, the adequacy of tissue oxygenation is defined as the balance between the supply of and the demand for oxygen required for cellular function and metabolism at the cellular, organ, and systems levels. When tissue perfusion falls below the critical point at which blood flow to individual organs can no longer be maintained, the clinical diagnosis of shock is made. In adult patients, shock is diagnosed by the progressive onset of hypotension despite fluid resuscitation and in septic normotensive adults, increasing trends in lactate concentration [1].

In the absence of a gold standard for the clinical diagnosis of shock, clinicians rely on measurements of vital signs, arterial oxygen saturation of hemoglobin (SaO2), and serum lactate. Yet values derived from these measurements may remain relatively normal during the early stages of shock while the patient's condition is indeed deteriorating, and the evolution from mild to severe shock can be subtle or extremely rapid [2]. Near infrared spectroscopy (NIRS) is an optical, noninvasive method of measuring differential forms of hemoglobin. The measurement of tissue oxygen saturation (StO2) is derived from calibrated wavelengths of near infrared light to illuminate oxygenated and deoxygenated hemoglobin in the muscle [3]. Previous investigators have examined whether decreases in StO2 could function as an early indicator of peripheral vasoconstriction and hypoperfusion that accompanies the early stages of shock, primarily in studies of patients admitted with hemorrhagic and traumatic shock to large teaching medical centers [2 and 4], but also in patients with septic shock [5-6] and undergoing cardiac surgery [6]. Normal StO2 values in healthy volunteers have been reported to average 87+6 % [6 and 8]. Yet the patterns of sequential StO2 values in a relatively stable population of adult patients in the immediate postoperative period have not been studied.

2. Methods

Institutional Review Board approval was obtained from both the University and a 643-bed Level I Trauma Medical Center. Patients were transferred to either the Post-Anesthesia Care Unit (PACU) or Cardiothoracic Care Intensive Care Unit (CTICU). Patient consent was performed in the preoperative holding area. Following transfer to the PACU or CTICU, the investigators placed the StO2 probe adhesively on the thenar eminence of the patient's hand. The in Spectra Spectrometer (Hutchinson Technology Inc., Hutchinson, Minn.) quantifies tissue oxygen saturation (StO2) based on four wavelengths of light at 680, 720, 760, and 800 nanometers (nm). The spectrometer yields a percentage value of StO2 derived from optical light paths absorbed by hemoglobin chromophores, including: oxyhemoglobin concentration [HbO2], deoxyhemoglobin concentration [HHb], and total hemoglobin concentration [HbO2] [2].

The StO2 data was monitored continuously, downloaded to a laptop computer, and recorded on hard copy every 15 minutes for at least 2 hours. Additional patient data included admitting diagnosis, past medical history, body mass index (BMI), surgical procedures, anesthesia and analgesia, estimated blood loss, duration of operation, vital signs, central hemodynamic parameters, intravenous and blood product therapy, supplemental oxygenation, ventilator settings, endotracheal intubation status, patient activity state, and laboratory data. Following data collection, the

StO2 probe was removed without incident from the thenar muscle. Patients were monitored for postoperative complications until discharge.

Per cent agreement was used to achieve inter-rater reliability of transcribed data on every third medical record.

In the event that the percent agreement fell below 95%, an investigation of the cause of the lack of agreement was conducted. Descriptive and demographic data were analyzed for evidence of normality and homogeneity of variance. StO2 data was analyzed for measures of central tendency, including the first, last and mean values (over 2 hours) (IBM SPSS Statistics 20). Based on the work of Cohn and colleagues [2], the mean value was coded as either greater or less than 75%. Frequency of complications was categorized based on organ system [9] and time of onset [10].

Organ system categories included cardiovascular, respiratory, gastrointestinal, wound, neurological, or urinary systems. Time of onset of complications was categorized as absent, occurring immediately (within 24 hours), early (within 3 days), or late (after 3 days). The number of complications was determined for each patient, and complications were coded absent or present. Non-parametric correlation coefficients were calculated in order to determine the strength of the relationship between StO2 values and patient outcomes. Results are reported as mean and standard deviation (SD) values. A non-directional p value of <0.05 was considered statistically significant.

3. Results

A convenience sample of 32 adult patients 18 years or older consented to participate in the study (Table 1). Spectrometer malfunction eliminated StO2 data on one patient (#14), leaving a total sample size of 31. Patient age ranged from 23 to 84 years of age (57.52+17.52). The sample consisted of 15 females (47%), 17 males (53%); Whites 15 (47%), Blacks 4 (12.5%), Hispanics 4 (12.5%), other 2 (0.94%). The duration of surgical procedures was 285.39 (SD+172.79) minutes. The estimated intraoperative blood loss was 293 (SD+269) milliliters (mL). Recorded mean intravenous fluid intake was 1900 (SD+2528) mL. Initial serum lactate levels were 2.157 (SD+1.70) mmol/L. Initial oral temperature of 97.9 degrees F and first StO2 values correlated (Pearson's: 0.345, p=0.051). The mean BMI of 31.19+8.4) negatively correlated with the first StO2 value (Pearson's -0.544, p=0.002). The operative and disposition data are presented in Table 1.

The first, last, and average StO2 values were, respectively: 80.71%+9.16; 80.94%+7.07; and, 80.56%+7.18 (Table 2). Mean StO2 values ranged from 65% to 93%; however, only 3 patients had a mean StO2 less than 75%. The hospital length of stay (LOS) was 7.26 (SD+7.54) days (Table 1). Most postoperative complications (68%) occurred within 24 hours, while 7 patients experienced complications within 3 days, and two patients had complications after 3 days.

One cardiothoracic patient experienced multiple complications with a length of stay of 40 days. No relationship between the incidence of complications and the first, last, and mean StO2 values was found, respectively, p=0.459, 0.216, 0.319.

However, the minimum values of the first, last, and average StO2 values were, respectively: 55%, 67%, and 65%. When the minimum StO2 for each patient was tested for differences in outcome, there was a significant difference in StO2 values between patients who did or did not develop complications (x=76.9+7.44, range 59-92; Chi Sq, df 18, p=0.020).

Following StO2 data collection, patient disposition consisted of 3 locations: 1) 14

Table 1: Description of the Sample

Patient Code	Gender	Age	Diagnosis	Procedure/Surgery	Complications	Disposition
1	F	43	Morbid obesity	Laparoscopic roux-in-y gastric bypass; liver biopsy; upper endoscopy.	None	Discharge within 3 days.
2	M	40	Hepatitis C	Liver resection (resection of single lesion; no metastases).	None	Discharge within 3 days.
3	M	23	Ventral abdominal hernia s/p stab wound	Repair of ventral abdominal hernia.	Oliguria post op day #2 resolved with intravenous fluid bolus.	Discharge within 3 days.
4	F	65	Gastric cancer (antrum)	Gastrectomy 95% near total; total antrectomy; Roux-en-y gastro jejunostomy.	Return to OR for chest tube placement for pneumothorax; Atelectasis; Oliguria; Paralytic ileus; Fever; PTT 41.8; Possible DVT.	Discharge day 7.
5	M	25	Exploratory laparotomy with removal of mesh	Repair of recurrent incisional hernia.	None	Discharge within 3 days.
6	F	64	Exploratory lap; possible gastrectomy.	Antrectomy; Bilroth 2; appendectomy; truncal vagotomy.	None	Discharge within 3 days.
7	M	78	CAD	Coronary Artery Bypass Graft (CABG) x 3.	None	Discharge within 3 days.
8	M	77	Coronary Artery Disease.	Coronary Artery Bypass Graft x 3.	None	Discharge within 3 days.
9	F	70	Rule out colorectal anastomotic stricture s/p Hartman for diverticulitis; Chronic *C. Difficile* infection; ventral hernia.	Colon resection.	Bradycardia post-extubation.	Discharged same day.
10	M	66	Bowel Obstruction	Exploratory laparotomy; Gastroscopy tube placement.	Bradycardia post-extubation.	D/C home within 3 days on hospice.

Legend: s/p = status post; OR = operating room; DVT = deep vein thrombosis; CABG = Coronary Artery Bypass Graft; CAD = Coronary Artery Disease; AVR = aortic valve replacement; CTICU = cardiothoracic intensive care unit; PACU = post anesthesia care unit; OPCAB = Off Pump Coronary Artery Bypass.

- Patient #14 removed from dataset due to spectrometer malfunction.

(45.2%) patients transferred to a surgical floor; 2) 6 patients (19.4%) were transferred from the PACU to an intensive care unit; and, 3) 11 patients (35.5%) who were admitted to the CTICU remained there.

One-way analysis of variance (ANOVA) determined that there were no significant differences in StO2 values among the 3 groups of patients (df 25, F 2.875, p=0.121).

4. Discussion

In an integrative review of the use of StO2 monitoring in critically ill patients, most studies were found to have been observational or retrospective in nature [11]. One exception is a non-randomized, prospective study during which clinicians were blinded to StO2 measurements [2]. Cohn and colleagues compared the sensitivity and specificity of StO2 measurements with maximum base deficit (BD) and minimum systolic blood pressure (SBP) to accurately predict the incidence of multiple organ dysfunction syndrome (MODS) and mortality in severely injured patients (n=383) upon their arrival in the emergency department and for the subsequent 24-hour period. StO2 measurements performed comparatively well with measures of maximum base deficit (BD) in predicting multiple organ dysfunction syndrome (MODS); the sensitivity of both measures for organ failure (minimum StO2 cutoff=75%; BD=6 mEq/L) was 79%, while the specificity was only 34 to 39% (95% CI). The negative predictive value (NPV) for both measures were satisfactory at a range of 88 to 91%; however, the positive predictive value (PPV) was 18 to 20%, indicating that in approximately 80% of patients, both measures would incorrectly predict organ failure when in fact these patients would not develop MODS.

The greater sensitivity of StO2 measurements for predicting mortality was significantly higher at 91% (range 85 to 97%), when compared to the sensitivity of base deficit of 75% (64 to 86%) (p=0.0175) or the 80% (71 to 89%) sensitivity of minimum systolic blood pressure (p=0.0489). While we suggest that StO2

Table 1: Description of the Sample (continue)

Patient Code	Gender	Age	Diagnosis	Procedure/Surgery	Complications	Disposition
11	F	54	Gastric Carcinoma; Liver metastases	Total gastrectomy; splenectomy; distal pancreatectomy; exploratory laparotomy.	None.	Discharge at 11 days.
12	M	62	Diverticulitis	Laparoscopic colon resection.	Persistent tachycardia, new onset atrial fibrillation, hyperglycemia.	Discharge at 16 days.
13	F	57	Unstable angina; CAD	OPCAB.	None	Discharge at 5 days.
14 *	F	59	Sigmoid diverticulitis; hyperlipidemia	Laparoscopic sigmoid colon resection.	Basal atelectasis with minor lung collapse; Fever; Nausea	Discharge at 10 days.
15	F	59	Pancreatic cyst	Exploratory lap; partial omenectomy; gastrostomy; drainage of pancreatic cyst.	Low-grade fever.	Discharge at 13 days.
16	M	25	Ulcerative colitis with colon stricture	Laparoscopic colon resection.	None	Discharge at 3 days.

monitoring may be most useful in early recognition of tissue hypoperfusion and the early onset of shock in severely injured trauma patients, future research should be implemented using randomized clinical trials to determine the clinical utility of StO2 monitoring for betterment of patient outcomes.

The patients in the current study had initial postoperative StO2 values averaging 80%, close to but less than normal values of 87% reported in human volunteers [6 and 8]. These lower values most likely reflect a transient hypothermia and compensatory peripheral vasoconstriction common in stable postoperative patients. While postoperative patients maintained an overall stable level of StO2 values during their early recovery, patients who did develop complications had episodes of sudden significant decreases in StO2 values, ranging from 55% to 67%, less than the minimum cutoff of 75% recommended by Cohn and colleagues.

More recently, Bazerbashi and colleagues retrospectively identified a 70% cutoff for spot StO2 measurements as a component of emergency center triage and hospital resource allocation in the prediction of ICU admission in 158 emergent oncology patients [12]. Of the 57 patients with StO2 less than 70%, 17 were admitted to critical care, whereas only 14 of the 101 patients with StO2 of 70% to 89% (p=0.01) were admitted there. Controlling for mean arterial pressure, pulse, and temperature, an odds ratio of 2.64 (95% confidence interval, 1.18-5.87) and 2.87 (95% confidence interval, 1.23-6.66) was able to predict ICU admission

Table 1: Description of the Sample (continue)

Patient Code	Gender	Age	Diagnosis	Procedure/Surgery	Complications	Disposition
17	M	74	CAD; Angina; dyslipidemia; mild parkinsonism	CABG x3; radial artery harvest; saphenous vein; mediasternotomy.	Unresponsive to first hour; semi awake 2nd hour and subsequently awake.	Discharge at 4 days.
18	F	57	Exophytic renal lesion on R kidney	Open nephrectomy, right.	None	Discharge within 3 days.
19	F	60	Radiation of ulceration of rectum	Cystoscopy; bilateral resection of rectum; colonoscopy; gastrostomy; lysis of adhesions; mobilization of splenic flexure.	Nausea & vomiting: analgesia or anesthetic related; paralytic ileus; 3 pain consults; Bladder spasms; Rash on back Incontinent of urine; Emesis.	Discharge at 17 days.
20	M	68	CAD; Severe 3 vessel disease; cardiomyopathy	CABG x3.	Chest congestion; pain; Sore throat; cough; shortness of breath; atelectasis.	Discharge at 7 days to acute skilled care facility.
21	M	76	CAD; Aortic valve stenosis	CABG x2; AVR.	None	Discharge at 5 days.
22	M	84	Aortic valve stenosis	AVR.	Acute anxiety; Rapid atrial fibrillation; Confusion; Delirium.	Discharge at 8 days.
23	M	80	CAD; Aortic stenosis	AVR.	None	Discharge at 6 days.

for, respectively, patients with a StO2 less than 70% when compared to those with an StO2 of 70% to 89%. While this study was limited by its retrospective design and the absence of blinded StO2 measurements, these authors suggest that StO2 monitoring may assist in the identification of patients at risk for more detailed and comprehensive critical care. In the following section, we present a real-time bedside case report which points to the potential utility of StO2 monitoring to identify acute changes in peripheral tissue perfusion.

Case Report

Table 1: Description of the Sample (continue)

Patient Code	Gender	Age	Diagnosis	Procedure/Surgery	Complications	Disposition
25	M	75	Peripheral vascular disease	Right femoral popliteal bypass; Right popliteal endarterectomy; Right open angiogram & sheathing of Right common iliac and Right eternal iliac artery.	None	Discharge at 6 days.
26	F	64	Mitral stenosis; CAD; tricuspid insufficiency	CABG	Blood transfusions, platelets, fresh frozen plasma, cryoprecipitate; Readmission to CTICU for 2 days.	Discharge at 40 days.
27	F	52	Morbid Obesity	Lap gastric band; liver biopsy.	Possible seizure in PACU.	Discharge within 3 days.
28	F	36	Morbid Obesity	Gastric lap band and hernia repair.	None	Discharge within 3 days.
29	M	54	Unstable angina	CABG x2	Blood transfusion; Oliguria Pulmonary Embolism.	Discharge at 13 days.
30	F	53	Left upper lobe lung nodule	Mediasternoscopy; lymph node biopsy; L anterior thoracotomy; tumor biopsy.	None	Discharge at 3 days.
31	F	27	Anterior mediastinal mass.	Sternotomy; anterior mediastinal mass resection.	None	Discharge at 5 days.
32	M	73	CAD	CABG x3; epi-aortic scan; left endoscopic saphenous vein harvest.	None	Discharge at 5 days.

A 78-year-old male underwent an elective coronary artery bypass grafting times 3. His

Table 2: Study Results

Patient Code	Initial Admission to PACU (1) or CTICU (2)	Initial Oral Temperature (Fahrenheit)	Initial Heart Rate	Final Heart Rate	nitial Pulse Oximetry (SpO2)	Final Pulse Oximetry (SpO2)	Initial Blood Pressure	Final blood Pressure	Initial StO2 % Upon Admission	Final StO2 % Following 2 Hours of Data Collection	Mean StO2 % Values Over 2 Hours of data Collection
1	1	95.8	98	90	99	99	156/98	151/93	68	78	75
2	1	96.9	64	66	99	99	131/71	131/64	77	82	79
3	1	97.1	98	91	100	98	125/69	114/65	91	93	92
4	1	96.5	89	89	100	96	126/54	120/62	78	75	76
5	1	97	88	98	100	98	145/80	123/66	77	83	79
6	1	97.6	77	81	100	100	122/71	123/73	86	85	84
7	2	96.5	87	87	98	95	122/87	93/64	71	67	65
8	2	95	96	90	100	100	97/47	102/47	79	79	78.5
9	1	96	103	97	98	98	175/103	140/70	78	77	77
10	1	97.4	95	105	100	97	142/82	121/70	77	85	80
11	1	96	127	103	100	100	148/79	124/83	81	81	82
12	1	97.9	92	113	100	100	106/66	109/61	90	90	90
13	2	94	126	121	98	98	126/71	121/65	82	79	80
15	1	97.5	87	90	100	99	147/68	142/69	96	86	91
16	1	96.8	109	133	100	100	140/79	133/75	95	87	89
17	2	96.4	84	84	100	99	111/63	123/68	75	76	76.5
18	1	95.36	70	68	97	100	119/62	115/57	91	92	93
19	1	96.98	83	78	99	98	107/54	130/62	78	74	75.8
20	2	96.4	92	91	96	100	123/78	115/71	73	73	73
21	2	97.2	81	84	97	97	130/40	135/36	92	94	93
22	2	93.9	79	99	95	94	125/61	105/57	85	83	80
23	2	96.7	84	84	93	97	107/64	136/69	70	70	70
24	2	97	89	108	99	96	115/30	145/60	80	76	77.8
25	1	96.4	56	82	99	100	77/41	100/42	88	83	87.5
26	2	93.9	101	100	99	97	132/58	131/67	80	67	71.8
27	1	0	69	63	100	96	157/84	119/54	55	76	72.5
28	1	96.4	73	100	99	92	99/46	122/78	75	83	79
29	2	97.8	93	101	97	100	96/46	102/61	70	77	76.7
30	1	0	92	107	96	94	122/81	125/75	82	83	81.6
31	1	96.1	93	93	100	99	106/64	90/47	92	87	83.9
32	2	93.7	84	84	96	98	131/57	114/51	90	88	88.9

Frequency CTICU = 14PACU =17

Legend: PACU = post anesthesia care unit; CTICU = cardiothoracic intensive care unit; Data collection initiated upon admission to CTICU or PACU.

- Patient #14 removed from dataset due to spectrometer malfunction.

extensive health history included: thoracic aneurysm (measuring 6.5 cm), ascending aneurysm (4.5 cm), aortic arch aneurysm (3.4 cm), descending aneurysm (5.5 cm), left carotid endarterectomy, repair of an abdominal aortic aneurysm, left bundle branch lock, left subclavian stenosis, & coronary artery disease. The patient was born with one functioning kidney. The length of surgery was 8 hours. The estimated blood loss was 675 mL. The patient received a total of 1200 mL IV fluid, and 500 mL of platelets. Per standard protocol, the patient was transferred postoperatively directly to the Cardiothoracic Intensive Care Unit (CTICU).

The tissue oxygen saturation (StO2) monitor sensor was placed on the tenor eminence of the patient's left hand, contralateral to the right radial arterial line. At 1615, the patient's initial vital signs were: core temperature 96.1 ◦, heart rate 87 bpm, blood pressure 127/83 mmHg, MAP 101, cardiac output 3.49 L/minute, cardiac index 1.71, CVP 12 mmHg, 12 breaths per minute, SpO2 100%. The StO2 remained steady at 71%. At 1630, the patient's vital signs remained unchanged, with the exception of a rise in the cardiac output (4.65), cardiac index (2.26), and reduction of SpO2 to 96%. The StO2 decreased to 69%. At the same time, a mixed venous blood gas was obtained; the SvO2 measurement of 69%, nearly identical to the StO2 of 70%. When a second mixed venous blood gas was obtained at 1645, the SvO2 of 68.3% closely approximated the StO2 of 67%. At this point, the patient's BP remained stable during the next hour: 116/78 (93), 108/73 (87), 136/87 (106). However, the StO2 continued to decrease over the next hour from 69% to 65%. At 1800, the patient's StO2 decreased to 58%. The patient's BP decreased to 98/66 (78). The patient's pericardial chest tube output acutely drained 580 mL. The patient's core temperature had increased to 97.1 ◦, the BP further decreased to 94/64 (77).

A fluid bolus was rapidly infused at 1815, while the StO2 progressively increased from 58% to 67% over 15 minutes. Subsequently, the patient received 1 unit of fresh frozen plasma, 10 units of platelets, and 1 unit of packed red blood cells during the next 4 hours. The patient remained in the CTICU for 5 days; in addition to acute hemorrhage, postoperative complications included basal atelectasis on day 2, and acute confusion on day 3. The patient transferred to CT step down after 5 days, and was discharged to home 2 days thereafter. This case study suggests that acute decreases in StO2 measurements may serve as a warning sign that the peripheral redistribution of blood flow to the patient's core blood flow functioned as a compensatory response to a sudden increase in pericardial chest tube output.

5. Conclusions

The technology of StO2 monitoring remains relatively unknown to critical care practitioners in most intensive care units. In the event that future randomized, blinded clinical trials provide positive cost-benefit findings that support its bedside use, more critical care clinicians will need to become familiar with its accuracy, precision, and usefulness in application to specific patient populations. Critical care nurses are especially important as future users of this technology, as nurses are present at the bedside 24 hours a day and have the critical responsibility for notifying the intensivist when patient status worsens. The clinical utility of StO2 monitoring may be most beneficial in rapidly changing, hemodynamically unstable patients. In this observational study, we determined that most postoperative patients maintained a pattern of stable StO2 levels. Sudden drops in StO2, however, did demonstrate a significant relationship with postoperative complications. Future research based on randomized sampling and rigorous controls in design is needed in order to establish evidence-based recommendations for the cost-effective use of StO2 monitoring.

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