Original Article

Tissue Oximetry during Cardiac Surgery and in the Cardiac Intensive Care Unit: A Prospective Observational Trial

Abstract

Background: Cerebral oximetry using near-infrared spectroscopy (NIRS) has well-documented benefits during cardiac surgery. The authors tested the hypothesis that NIRS technology can be used at other sites as a tissue oximeter during cardiac surgery and in the Intensive Care Unit (ICU). **Aims:** To establish feasibility of monitoring tissue oximetry during and after cardiac surgery, to examine the correlations between tissue oximetry values and cerebral oximetry values, and to examine correlations between oximetry values and mean arterial pressure (MAP) in order to test whether cerebral oximetry can be used as an index organ. **Settings and Designs:** A large, single-center tertiary care university hospital prospective observational trial of 31 patients undergoing cardiac surgery with cardiopulmonary bypass was conducted. **Materials and Methods:** Oximetry stickers were applied to both sides of the forehead, the nonarterial line forearm, and the skin above one paraspinal muscle. Data were collected from before anesthesia induction until extubation or for at least 24 h in patients who remained intubated. **Statistical Analysis:** Categorical variables were evaluated with Chi-square or Fisher's exact tests, while Wilcoxon rank-sum tests or student's *t*-tests were used for continuous variables. **Results:** The correlation between cerebral oximetry values and back oximetry values ranged from $r = 0.37$ to 0.40. The correlation between cerebral oximetry values and forearm oximetry values ranged from $r = 0.11$ to 0.13. None of the sites correlated with MAP. **Conclusions:** Tissue oximetry at the paraspinal muscle correlates with cerebral oximetry values while at the arm does not. Further research is needed to evaluate the role of tissue oximetry on outcomes such as acute renal failure, prolonged need for mechanical ventilation, stroke, vascular ischemic complications, prolonged ICU and hospital length of stay, and mortality in cardiac surgery.

Keywords: *Anesthesia, intraoperative, monitoring, near-infrared, oximetry, spectroscopy*

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Introduction

Cerebral oximetry is a noninvasive monitor that has been commonly used for many years in cardiac surgery as a marker for cerebral perfusion.[1-3] Studies have looked at cerebral oxygenation in cardiac surgery and have demonstrated that patients with lower cerebral oxygen saturations have poorer outcomes.[4,5] Cerebral oximetry is believed to be a possible first alert monitor to changes in oxygenation, ventilation, mixed venous oxygen saturation, and cardiac output,[6] and it has been shown to effectively identify vulnerable periods during cardiac surgery.[7] The technology used in these oximeters is near-infrared spectroscopy (NIRS) and it has been shown to be extremely safe. Its' utility is expanding, with formal algorithms that have been instituted to help minimize cerebral desaturation events.[3,8] There is now a growing effort to see if NIRS technology can be introduced into other surgeries and at other locations on the body.

Patients who undergo cardiac surgery are at risk of hypoperfusion to multiple organs, not just the brain. While the brain is sometimes thought of as an index organ, its unique physiology and cerebral autoregulation may not make this an ideal assessment in all situations. There have been studies evaluating this technology to monitor tissue oxygenation at other sites, such as the thenar eminence, paraspinal muscles, kidneys, and gut.[9] There are data that demonstrate that NIRS-derived tissue oxygenation saturation (at the thenar eminence) reflects regional changes in oxygen delivery earlier than lactate or base deficit in patients undergoing cardiopulmonary bypass; however, these data are purely intraoperative and at one site.[10]

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The main purpose of this study was to evaluate tissue oximetry, specifically at the forearm and the paraspinal muscles. The goal was to establish feasibility of monitoring tissue oximetry during and after cardiac surgery and see if tissue oximetry values correlated to cerebral oximetry values and/or mean arterial pressure (MAP). This was a prospective, observational trial where cerebral oximetry monitors were placed to observe the effect of the surgery and hemodynamic interventions upon different tissue oxygen saturations, and to investigate if there was any clinical correlation of these values. Our primary endpoint in the study was to evaluate the trends in tissue oximetry values as compared to cerebral oximetry values both intraoperatively and postoperatively and compare them to MAP. Secondary outcomes included the incidence of acute renal failure, prolonged need for mechanical ventilation, stroke, vascular ischemic complications, prolonged Intensive Care Unit (ICU) and hospital length of stay, and mortality. Our hypothesis was that NIRS technology can be used as a tissue oximeter at other sites on the body during cardiac surgery and in the ICU.

Materials and Methods

After receiving institutional review board approval, patients were identified from the preoperative schedule and one of the authors obtained written informed consent several days before their surgery in the preoperative clinic. The inclusion criteria included adult patients undergoing elective cardiac surgery with cardiopulmonary bypass and where tissue oximetry would not interfere with any part of the surgery. The exclusion criteria included patients under the age of 18 years, pregnant patients, prisoners, and patients who were unable to give consent. The authors collected patient demographic and comorbidity data from the patient's electronic medical record. The oximeter for this study was the CASMED FORE-SIGHT monitor (CAS Medical Systems, Inc., 44 East Industrial Road Branford, CT 06405 USA), which is the Food and Drug Administration-approved cerebral oximeter that provides an absolute measurement of regional cerebral oxygen saturation. On the day of surgery, prior to anesthetic induction, the cerebral oximeter probes were applied via stickers to the skin above one paraspinal muscle, 2 cm lateral to the spine at the L1 level, and the medial forearm of the arm that did not have a radial arterial line.

The authors recorded cerebral and tissue oximetry data from prior to induction (baseline) until extubation or for at least 24 h in patients who remained intubated. Other data collected included vital signs, arterial blood gases, length of cardiopulmonary bypass, and the use of vasopressor infusions along with the cerebral oximetry values and tissue oximetry values. Outcomes including length of stay in the ICU, length of stay in the hospital, and time on mechanical ventilation were recorded. Major morbidity was defined as stroke, myocardial infarction, renal replacement therapy, sepsis, gastrointestinal bleed, or vascular complications. Patients were followed for 30 days to assess for mortality [Figure 1].

No interventions were made based on the paraspinal and forearm oximetry values as part of the study protocol. These data were not made available to the anesthesiologists taking care of the patient, and no clinical decisions were made with these values. The device was visible to ensure that it was on and functional. After verifying that the monitor was functional and on, the monitor was covered to avoid altering the standard of care that the patient receives based on this information being visible to the anesthesiologist. All four oximetry stickers were left on at the end of the surgery and followed the patient to the cardiovascular ICU where the values were recorded until extubation, or the next 24 h.

The number of patients to be included was not predetermined. Being a feasibility study, we felt that we would include as many as would consent to be included in the time frame that we were approved for.

Statistical methods

Descriptive data are presented as mean ± standard deviation (SD) and minimum and maximum for continuous data, and *n* (%) for categorical data, as appropriate.

To explore the interrelationships between oximetry values at different sites and with MAP, we examined the cross-correlation functions of the time series data. Initially, oximetry data were measured every 2 s and MAP every 1 min. We defined an epoch as a 1-min interval and the time series data of oximetry and MAP are the sequences of median values from the 1-min epochs during the entire case. Cross-correlation (r) is a measure of similarity of two time

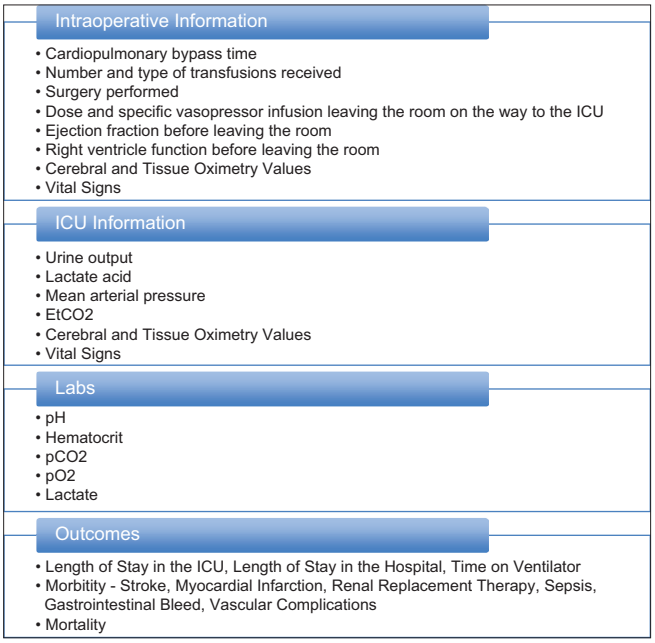

Figure 1: Information collected for each patient in the study

series as a function of a time-lag applied to one of them. Lag 0 indicates the concurrent time point between the two series. Because we hypothesized that $SctO_2$ will change as a consequence of changes in perfusion pressure, we chose MAP as the leading series and $SctO_2$ as the response series. Thus, the cross-correlation of oximetry data and MAP across time is temporal cross-correlation. Cross-correlation analyses were performed at the subject-level and the correlation estimates were then averaged across all 31 individuals. All analyses were performed in SAS 9.4® (SAS Institute Inc., Cary, NC, USA) and statistical significance level is set at the 0.05 level.

Results

Thirty-one patients were included in the study. The demographic and clinical characteristics of the cohort are described in Table 1**.** Our cohort included 19 male patients and 12 female patients. An exact number for postoperative ejection fraction was not recorded for two patients.

Summary statistics of the oximetry data at the various locations are shown in Table 2. Average oximetry data across the entire case were similar, regardless of location. However, within a subject, the oximetry data were much more stable in the brain compared to back and then arm, i.e., right and left brain values were similar, and the variability (described by SD) increased about 80% for arm compared to brain.

There was an expected strong correlation between left and right brain oximetry values of r = 0.85 (95% confidence interval [CI]: 0.80–0.90). The correlation between cerebral oximetry values and back oximetry values ranged from r = 0.37 (95% CI: 0.27–0.47) for left brain to right back to 0.40 (95% CI: 0.30–0.49) for right brain to right back. The correlation between cerebral oximetry values and arm oximetry values ranged from r = 0.11 (95% CI: −0.03–0.25) for left brain to right arm to 0.13 (95% CI: −0.01–0.26) for right brain to right arm. The correlation between back and arm oximetry values was r = 0.24 (95% CI: 0.09–0.38). These data are summarized in Table 3.

Morbidity and mortality data are summarized in Table 4. There was no correlation between oximetry values and any of these outcomes. Specifically, in the two patients who suffered from a stroke, no decreases were seen in cerebral oximetry values that would have demonstrated that they were suffering a stroke. As the stroke did not involve the frontal lobe, this is not unexpected.

Cross-correlation values were calculated to evaluate the relationship between end-tidal carbon dioxide concentration ($EtCO_2$), MAP, and oximetry values as shown in Table 5. There was no significant correlation between $EtCO_2$ values and tissue oximetry values. There was no significant correlation between MAP and arm oximetry values. There was a small positive correlation between MAP and paraspinal oximetry values.

Table 1: Patient and surgical characteristics (n=31)

Variable	Mean±SD	Minimum	Maximum
Age (years)	57.90±12.11	36.00	80.00
Preoperative ejection fraction, *n* (%)	58.32±9.95	20.00	83.00
Aortic cross-clamp time (min)	92.74±41.17	33.00	231.00
Cardiopulmonary bypass time (min)	122.61±52.79	59.00	302.00
Time to extubation (min)	536.77±300.11	0.00	1313.00
ICU length of stay (days)	2.61±3.25	1.00	18.00
Postoperative ejection fraction (n=29), *n* (%)	58.52±11.13	20.00	74.00
Hospital length of stay (days)	7.87±5.47	4.00	32.00

SD: Standard deviation, ICU: Intensive Care Unit

Table 2: Summary statistics of oximetry data

Summary statistic	Location	*n*	Mean±SD
Mean	Left brain	31	69.8±3.9
	Right brain	31	70.4±4.1
	Right back	31	68.3±4.7
	Right arm	31	69.9±9.3
SD	Left brain	31	4.9±1.5
	Right brain	31	5.1±1.5
	Right back	31	6.8±3.2
	Right arm	31	9.1±3.8
Minimum	Left brain	31	54.4±7.1
	Right brain	31	55.3±6.4
	Right back	31	49.8±11.4
	Right arm	31	45.3±13.5
Maximum	Left brain	31	86.7±5.2
	Right brain	31	87.4±6.2
	Right back	31	86.9±6.5
	Right arm	31	92.0±3.7
Range	Left brain	31	32.4±9.3
	Right brain	31	32.2±8.9
	Right back	31	37.1±13.2
	Right arm	31	46.6±15.3

SD: Standard deviation

Table 3: Cross-correlation between oximetry values at different sites

Monitored sites	Correlation (*r*)	95% CI
Left brain/right brain	0.85	0.80-0.90
Left brain/back	0.37	0.27-0.47
Right brain/back	0.40	0.30-0.49
Left brain/arm	0.11	−0.03-0.25
Right brain/arm	0.13	−0.01-0.26
Back/arm	0.24	0.09-0.38

CI: Confidence interval

Discussion

Our study found that it is feasible to monitor tissue oximetry during cardiac surgery, that tissue oximetry over

Table 4: Morbidity and mortality data

Morbidity and mortality	Frequency (%)
Reintubation due to pneumonia, sepsis, and respiratory failure	1 (3.23)
Complete heart block	1 (3.23)
Stroke	2 (6.45)
Cardiac arrest, reintubation, thrombosis of foot, pericardial effusion, pleural effusion	1 (3.23)
Mortality	0
None	26 (83.87)

Table 5: Correlation between oximetry values at different sites and end-tidal carbon dioxide concentration and mean arterial pressure

Monitored sites	Correlation (*r*)	95% CI
$EtCO_2$/left brain	0.24	0.09-0.40
$EtCO_2$/right brain	0.23	0.09-0.36
$EtCO_2$/back	0.13	−0.01-0.26
$EtCO_2$/arm	0.08	−0.02-0.17
MAP/left brain	0.15	0.05-0.25
MAP/right brain	0.13	0.04-0.23
MAP/back	0.16	0.07-0.25
MAP/arm	0.07	−0.00-0.15

$EtCO_2$: End-tidal carbon dioxide concentration, MAP: Mean arterial pressure, CI: Confidence interval

the paraspinal muscles positively correlated with cerebral oximetry while at the forearm it did not, and that there was no correlation with MAP at any of the sites. The cohort did not include enough patients to determine if tissue oximetry is correlated with outcomes.

Tissue oximetry has experienced increased utility in the past few years, and there are now several novel uses in the literature. NIRS has been used extensively in neonates, including as a regional tissue oximeter to help predict adverse events in critically ill neonates and to optimize outcomes.[11] Furthermore, NIRS is being used extensively throughout pediatric ICUs in Europe.[12] There is a hope that NIRS can be utilized in premature infants in intensive care to minimize poor neurological outcomes.[13] In adults, one group utilized NIRS for prone position spine surgery, and patients who were monitored with NIRS had fewer postoperative cognitive deficiencies than those that were not monitored with NIRS.[14]

There have been other locations studied as sites for tissue oximetry, although not necessarily during cardiac surgery, including the kidneys, intestines, liver, and muscle.[15] The thenar eminence has been recognized as one site for peripheral tissue oxygenation.[16,17] However, there are some data to suggest that NIRS at the thenar eminence is not reflective of changes in outcomes, although these are early data in a small sample size.[18] The forearm is a site of vasoconstriction in times of stress,[16] and has been identified as another location of tissue oxygenation.[19,20] Some data suggest that the forearm may be a more sensitive marker of hemodynamic changes;[21] this is one of the reasons it was selected for this study. The flank has now been recognized as a marker for renal perfusion; however, there are conflicting data.[22] One study showed a weak correlation between renal NIRS and continuous central venous oxygen saturation via oximetry catheter,[23] but in some centers, it is now routine monitoring in pediatric cardiac surgeries.[24] Another study determined that renal NIRS could identify acute kidney injury (AKI) in infants undergoing cardiopulmonary bypass,[25] while another study showed that renal NIRS was able to predict postoperative AKI in adult cardiac surgery.[26] Furthermore, there has been growing interest in splanchnic oximetry due to the guts' ability to clamp down during times of stress.[22]

One of the concerns with NIRS technology is the high degree of variability that can make it difficult to decipher, more commonly seen in adults because the sensors only penetrate a few centimeters deep.[22] As a result, there is significant intrapatient and interpatient variability.[27] This is why the authors picked multiple sites for this study. Another disadvantage is that some clinicians believe that these oximeters can only be used as trend monitors, and were not created to evaluate oxygenation at noncerebral sites.[28] This is one of the reasons the authors wanted to prove feasibility and to possibly establish baselines for oximetry at these sites in adults.

Our finding that there is a positive correlation between well-accepted cerebral oximetry values and tissue oximetry values taken at the paraspinal muscle which was our attempt to represent visceral organ perfusion such as the kidney or spinal cord, as described earlier, gives us reassurance in using the brain as an index organ for other important organs. We believe that this argument is further strengthened by the lack of a strong correlation between cerebral oximetry values and tissue oximetry values taken at the forearm. This may be explained that as the body undergoes significant stressor (i.e., cardiopulmonary bypass), it attempts to perfuse vital organs preferentially over the skeletal muscle of the extremities.

However, of note, there was virtually no relationship between any of the oximetry values and MAP. While this was expected for cerebral oximetry due to autoregulation, this finding at the forearm was surprising. The authors expected the arm oximetry values to decrease as MAP decreased; however, this was not reflected in the results.

The patients included in this investigation were representative of an adult cardiac surgery population seen at a tertiary care hospital. The limitations of the study included its single-center design and that clinical care was not standardized; thus, the effects of unmeasured confounding variables cannot be excluded. Furthermore, being a feasibility study, we did not study enough patients

to determine if our secondary outcomes had a relationship with tissue oximetry.

Conclusion

This prospective, observational trial tested the hypothesis that NIRS technology can be used at other sites as a tissue oximeter during cardiac surgery and in the ICU. The authors found that tissue oximetry at the paraspinal muscle moderately correlates with cerebral oximetry values, thus possibly validating the use of cerebral oximetry as an index organ. Ultimately, more studies need to be completed to establish baseline values, guidelines for management of tissue desaturation events, and validate improvement in outcomes.[29]

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Conflicts of interest

There are no conflicts of interest.

References

1. Fischer GW, Silvay G. Cerebral oximetry in cardiac and major vascular surgery. HSR Proc Intensive Care Cardiovasc Anesth 2010;2:249-56.
2. Taillefer MC, Denault AY Cerebral near-infrared spectroscopy in adult heart surgery: Systematic review of its clinical efficacy. Can J Anaesth 2005;52:79-87.
3. Deschamps A, Hall R, Grocott H, Mazer CD, Choi PT, Turgeon AF, *et al.* Cerebral oximetry monitoring to maintain normal cerebral oxygen saturation during high-risk cardiac surgery: A randomized controlled feasibility trial. Anesthesiology 2016;124:826-36.
4. Sun X, Ellis J, Corso PJ, Hill PC, Lowery R, Chen F, *et al.* Mortality predicted by preinduction cerebral oxygen saturation after cardiac operation. Ann Thorac Surg 2014;98:91-6.
5. Heringlake M, Garbers C, Käbler JH, Anderson I, Heinze H, Schön J, *et al.* Preoperative cerebral oxygen saturation and clinical outcomes in cardiac surgery. Anesthesiology 2011;114:58-69.
6. Maldonado Y, Singh S, Taylor MA. Cerebral near-infrared spectroscopy in perioperative management of left ventricular assist device and extracorporeal membrane oxygenation patients. Curr Opin Anaesthesiol 2014;27:81-8.
7. Ševerdija EE, Vranken NP, Teerenstra S, Ganushchak YM, Weerwind PW. Impact of intraoperative events on cerebral tissue oximetry in patients undergoing cardiopulmonary bypass. J Extra Corpor Technol 2015;47:32-7.
8. Murkin JM, Adams SJ, Novick RJ, Quantz M, Bainbridge D, Iglesias I, *et al.* Monitoring brain oxygen saturation during coronary bypass surgery: A randomized, prospective study. Anesth Analg 2007;104:51-8.
9. Steppan J, Hogue CW Jr. Cerebral and tissue oximetry. Best Pract Res Clin Anaesthesiol 2014;28:429-39.
10. Putnam B, Bricker S, Fedorka P, Zelada J, Shebrain S, Omari B, *et al.* The correlation of near-infrared spectroscopy with changes in oxygen delivery in a controlled model of altered perfusion. Am Surg 2007;73:1017-22.
11. Sood BG, McLaughlin K, Cortez J. Near-infrared spectroscopy: Applications in neonates. Semin Fetal Neonatal Med 2015;20:164-72.
12. Hoskote AU, Tume LN, Trieschmann U, Menzel C, Cogo P, Brown KL, *et al.* A cross-sectional survey of near-infrared spectroscopy use in pediatric cardiac ICUs in the United Kingdom, Ireland, Italy, and Germany. Pediatr Crit Care Med 2016;17:36-44.
13. Greisen G, Leung T, Wolf M. Has the time come to use near-infrared spectroscopy as a routine clinical tool in preterm infants undergoing intensive care? Philos Trans A Math Phys Eng Sci 2011;369:4440-51.
14. Trafidlo T, Gaszynski T, Gaszynski W, Nowakowska-Domagala K. Intraoperative monitoring of cerebral NIRS oximetry leads to better postoperative cognitive performance: A pilot study. Int J Surg 2015;16(Pt A):23-30.
15. Biedrzycka A, Lango R. Tissue oximetry in anaesthesia and intensive care. Anaesthesiol Intensive Ther 2016;48:41-8.
16. Scheeren TW, Schober P, Schwarte LA. Monitoring tissue oxygenation by near infrared spectroscopy (NIRS): Background and current applications. J Clin Monit Comput 2012;26:279-87.
17. Guye ML, Motamed C, Chemam S, Leymarie N, Suria S, Weil G. Remote peripheral tissue oxygenation does not predict postoperative free flap complications in complex head and neck cancer surgery: A prospective cohort study. Anaesth Crit Care Pain Med 2017;36:27-31.
18. Morel J, Bouchet JB, Vola M, Béraud AM, Clerc M, Awad S, *et al.* Tissue near infra red spectroscopy change is not correlated with patients' outcome in elective cardiac surgery. Acta Anaesthesiol Scand 2014;58:835-42.
19. Soller BR, Ryan KL, Rickards CA, Cooke WH, Yang Y, Soyemi OO, *et al.* Oxygen saturation determined from deep muscle, not thenar tissue, is an early indicator of central hypovolemia in humans. Crit Care Med 2008;36:176-82.
20. Bartels SA, Bezemer R, de Vries FJ, Milstein DM, Lima A, Cherpanath TG, *et al.* Multi-site and multi-depth near-infrared spectroscopy in a model of simulated (central) hypovolemia: Lower body negative pressure. Intensive Care Med 2011;37:671-7.
21. Bezemer R, Karemaker JM, Klijn E, Martin D, Mitchell K, Grocott M, *et al.* Simultaneous multi-depth assessment of tissue oxygen saturation in thenar and forearm using near-infrared spectroscopy during a simple cardiovascular challenge. Crit Care 2009;13 Suppl 5:S5.
22. Bailey SM, Mally PV. Review of splanchnic oximetry in clinical medicine. J Biomed Opt 2016;21:91306.
23. Marimón GA, Dockery WK, Sheridan MJ, Agarwal S. Near-infrared spectroscopy cerebral and somatic (renal) oxygen saturation correlation to continuous venous oxygen saturation via intravenous oximetry catheter. J Crit Care 2012;27:314.e13-8.
24. Scott JP, Hoffman GM. Near-infrared spectroscopy: Exposing the dark (venous) side of the circulation. Paediatr Anaesth 2014;24:74-88.
25. Ruf B, Bonelli V, Balling G, Hörer J, Nagdyman N, Braun SL, *et al.* Intraoperative renal near-infrared spectroscopy indicates developing acute kidney injury in infants undergoing cardiac surgery with cardiopulmonary bypass: A case-control study. Crit Care 2015;19:27.
26. Choi DK, Kim WJ, Chin JH, Lee EH, Don Hahm K, Yeon Sim J, *et al.* Intraoperative renal regional oxygen desaturation can be a predictor for acute kidney injury after cardiac surgery. J Cardiothorac Vasc Anesth 2014;28:564-71.
27. Green MS, Sehgal S, Tariq R. Near-Infrared Spectroscopy: The New Must Have Tool in the Intensive Care Unit? Semin Cardiothorac Vasc Anesth 2016;20:213-24.
28. Bronicki RA. Near-infrared spectroscopy oximetry: Part science, part art. Pediatr Crit Care Med 2016;17:89-90.
29. Bickler P, Feiner J, Rollins M, Meng L. Tissue oximetry and clinical outcomes. Anesth Analg 2017;124:72-82.