ORIGINAL ARTICLE

STABLE INTRAOPERATIVE PULSE OXIMETRY VALUES DO NOT PROTECT AGAINST A DECREASE IN REGIONAL CEREBRAL OXYGEN SATURATION IN PATIENTS UNDERGOING PRIMARY HIP ARTHROPLASTY. A PILOT STUDY

Dariusz TOMASZEWSKI [1], Mariusz BAŁKOTA [2], Zbigniew RYBICKI [2], Marcin WAŚKO [3]

1 Department of Anesthesiology and Intensive Therapy, Military Institute of Aviation Medicine, Warsaw, Poland

2 Department of Anesthesiology and Intensive Therapy, Military Institute of Medicine, Warsaw, Poland

3 Department of Radiological Diagnostics and Medical Imaging, The Medical Center for Postgraduate Education in Warsaw, Otwock, Poland

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Author's address: D. Tomaszewski, Department of Anesthesiology and Intensive Therapy, Military Institute of Aviation Medicine, Krasińskiego 54/56 Street, 01-755 Warsaw, Poland, e-mail: dariusz.tomaszewski@wiml.waw.pl

Background and Study objective: Continuous perioperative monitoring of blood oxygen saturation via pulse oximetry is an established standard of care. The incidence of postoperative cognitive dysfunction (POCD) in orthopedic patients is higher when compared to any other group of hospitalized patients. Although its etiology remains unclear, factors such as thromboembolic complications may play a role. Thromboembolic material, including that released from the surgery site, enters the bloodstream and then travels to the brain. The decrease in blood flow in the involved cerebral vessels may decrease cerebral oxygen saturation. Considering this, we decided to determine if the regional cerebral saturation monitored by near-infrared spectroscopy corresponds with readings of blood oxygen saturation monitored by pulse oximetry in patients who underwent primary total hip arthroplasty.

Methods: A total of 20 patients scheduled for elective total hip arthroplasty were enrolled in the study. All orthopedic procedures were performed under spinal anesthesia and intravenous sedation. Monitoring of regional cerebral oxygen saturation (rSO2) was carried out from the time of the initiation of spinal anesthesia until the end of the surgery, using the near-infrared spectroscopy method. In all, 15 patients were analyzed.

Results and Conclusions: We found the following: (1) rSO2 values decreased continuously over the surgery, and (2) rSO2 value changes were not related to mean arterial pressure variations or to hemoglobin saturation as analyzed by pulse oximetry.

Keywords: blood pulse oximetry, regional cerebral oxygen saturation, primary hip arthroplasty

INTRODUCTION

The protection against hypoxemia is one of the main reasons why blood oxygen saturation is continuously monitored during anesthesia. We believe that when pulse oximetry remains within a normal range, the oxygenation of the patient's body, including his or her brain, is also normal.

The incidence of postoperative cognitive dysfunction (POCD) in patients after big joint arthroplasty varies from 16% to 45% [15], although it was reported [3] as high as 72% at six days and 30% at six months, postoperatively. These values are higher in comparison to any other group of hospitalized patients [12]. Its etiology remains unclear. According to some authors [15,17], one factor which may contribute in the development of POCD is thromboembolic complications. Colonna et al. [2] concluded that the incidence of cerebral embolization after lower extremity arthroplasty was between 40% and 60%. A possible explanation is that thromboembolic material, including that released from the surgery site, enters the bloodstream and then travels to the brain. The decrease in blood flow in the involved cerebral vessels may lead to a decrease in oxygen delivery. As a result, oxygen saturation may be decreased.

The objective of the study was to determine if the regional cerebral saturation monitored by near-infrared spectroscopy (NIRS) corresponds with readings of blood oxygen saturation monitored by pulse oximetry in patients who underwent primary total hip arthroplasty.

MATERIAL AND METHODS

This project was designed as a prospective study. After commencement of the study, its design was not modified.

The protocol of the study was approved by the local ethical committee (ref: 31/WIM/2013), and written informed consent was obtained from all subjects. The study was conducted in the Department of Orthopedics and Traumatology of the Military Institute of Medicine, Warsaw, Poland.

A total of 20 patients scheduled for elective total hip arthroplasty under spinal anesthesia were screened in the study. No control group was employed in the study design; preoperative values of the patients were considered as controls.

After the patients' admittance to the operating theatre, monitoring that included heart rate (HR), blood pressure (BP), pulse oximetry (SpO2), and regional cerebral oxygen saturation (rSO2) was begun. These measurements were stopped at the end of the surgery.

All the procedures were performed under spinal anesthesia with a 0.5% solution of bupivacaine hydrochloride (Marcaine 0.5% Spinal, Astra, Sweden). A proper level of sedation was achieved with intravenously administered midazolam (Midanium®; Polfa Warszawa S.A., Poland). Intravenous volume was maintained with infusion of crystalloid (Optilyte®; Fresenius Kabi Polska Sp. z o.o., Warszawa, Poland).

The rSO2 was recorded with an INVOS Oximeter 5100C (Somanetics, USA) and SomaSensor® (Covidien Ilc., USA) electrodes. The NIRS-based cerebral oximetry estimates rSO2 by transcutaneous measurement of the brain's cortex using forehead probes. The device utilizes the process of spatial resolution via multiple detectors located at different distances from the light emitter. The longer distance between the light emitter and the sensor, the deeper the tissue assessment is. An automated algorithm subtracts the more superficial reading from the deeper one. Regardless of their proprietary algorithms and calibration, the major cerebral oximetry manufacturers all claim to measure cerebral tissue up to a maximum depth of 20–25 mm (circa 50% of the emitter‑detector distance). For Covidien's INVOS system, which uses wavelengths of 730 and 810 nm, it is 20 mm [11].

Heringlake et al. found that the median normative rSO2 measured with INVOS system was 66% [5].

Our primary outcome measures were: (i) complete record of cerebral oxygen saturation of the patient, and (ii) measurements of blood oxygen saturation monitored by SpO2 at selected time points. Secondary measures were records of the HR and BP values of

the participants.

There were no changes in trial outcomes after the trial commenced.

Sample size calculation. Because of the insufficient number of published papers in this field, sample size of the study was not determined.

Randomization. The participants were enrolled by the authors of the study. There was only one group in the study design, and the same intervention was applied to all participants; because of this, the participants were not randomized and allocated.

Blinding. The study was not blinded.

Statistical methods. The data were analyzed using R statistical software [13]. Demographic information (age, gender, height, and body mass), times of anesthesia and surgery, administered doses of local anesthetic, and levels of anesthesia were analyzed. In addition, HR and BP values at specific time points were analyzed with descriptive statistics.

Because the surgery was performed in different sequential stages, each procedure was divided into ten equal periods. The analyzed data were averaged for each period. Because of the relatively low number of patients in the study, non-parametric tests were used. Variations in HR, BP, SpO2, and rSO2 were analyzed using the Wilcoxon signed rank test. The correlations were analyzed with Spearman rho. $P < 0.05$ was considered statistically significant.

RESULTS

Data were collected from June 2014 to December 2015. The trial ended after completion of the study protocol.

A total of 20 patients were assessed for eligibility. The patients' flow in the project is shown in Fig. 1. Ultimately, data from 15 participants were analyzed.

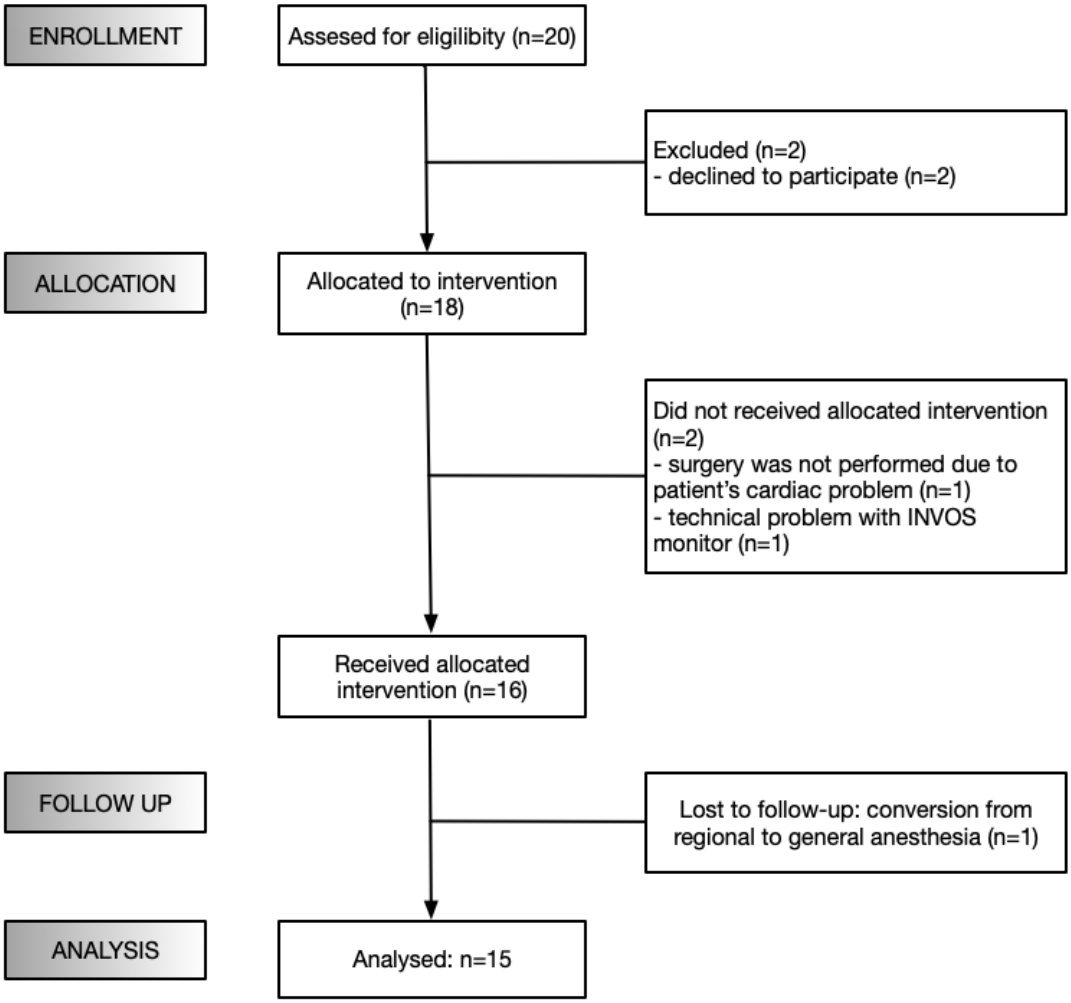

Fig. 1. The flow of the participants in the study.

There were 4 (26.67%) men and 11 (73.33%) women in the study group. Nine of the 15 patients (60%) underwent cementless and 6 out of 15 (40%) underwent cemented total hip arthroplasty. The mean age of the patients was 70 years (95% CI: 65–75), mean height was 163 cm (95% CI: 158–169), and mean weight was 73 kg (95% CI: 65–81).

The mean dose of 16.6 ± 1.5 mg (95% CI: 15.8–17.4 mg) of 0.5% bupivacaine hydrochloride produced a spinal anesthesia to the 10 ± 1 (95% CI: 9–10) thoracic dermatome. The time of the surgery varied from 70 to 130 minutes (95% CI: 83–101).

The values of regional cerebral saturation decreased during the procedure. The precise

readings with their *P* values are presented in Table 1.

Tab. 1. The values of regional cerebral oxygen saturation during the respective periods of the surgery.

Analyzed time point	**Median**	**95% CI**	***P***
T1	67	61–68	-
T2	66	60–67	0.0332
T3	64	58–65	0.0000
T4	61	58–65	0.0083
T5	62	56–64	0.0013
T6	62	55–64	0.0011
T7	63	55–64	0.0007
T8	63	55–64	0.0001
T9	61	55–64	0.0007
T10	57	54–62	0.0007

The *P* values were calculated in comparison to the rSO2 in T1 period.

The values of hemodynamic parameters (HR, mean arterial pressure /MAP/) and SpO2 during the respective periods of the surgery are shown in Table 2.

Tab. 2. Values of hemodynamic and oxygenation parameters during the respective periods of the surgery.

		Time point									
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
HR	Median	72	79	78	72	70	70	68	68	67	64
	95% CI	68–84	68–85	67–82	65–77	62–76	62–77	61–78	62–78	61–77	61–75
	*P**		1.0000	0.706	0.0423	0.0091	0.0134	0.0097	0.0028	0.0058	0.0083
MAP	Median	118	99	94	93	90	88	90	88	88	91
	95% CI	108–121	92–106	89–100	85–97	83–94	81–95	82–95	82–98	82–97	85–98
	*P**		0.0007	0.002	0.0011	0.0001	0.0013	0.0006	0.003	0.002	0.0021
SAT	Median	96	99	99	99	99	99	100	99	100	100
	95% CI	96–98	97–99	98–100	99–100	98–100	98–100	99–100	98–100	99–100	99–100
	*P**		0.0438	0.0017	0.002	0.0034	0.0018	0.0023	0.003	0.0021	0.0023

*in comparison to values in T1 time point
HR – heart rate (1/minute), MAP – mean arterial pressure (mmHg), SAT – pulse oximeter readings (%)

Linear regression analysis showed no relation between rSO2 and MAP values intraoperatively (*P* values = 0.0899, 0.3425, 0.1857, 0.0802, 0.42, 0.876, 0.3972, 0.848, 0.7181, and 0.9016, respectively). Similarly, no relation was shown between rSO2 and SpO2 readings (*P* = 0.1679, 0.2825, 0.2816, 0.7335, 0.8507, 0.8885, 0.3733, 0.566, 0.1504, and 0.2317, respectively).

We observed no significant problems or unintended side effects, including neurological complications, in the patients participating in this study.

DISCUSSION

We found that, in patients undergoing total hip arthroplasty, rSO2 values decreased continuously over the course of the surgery, and that changes in rSO2 values were not related to hemoglobin saturation, as determined by SpO2. These are valuable observations which may suggest that intraoperative monitoring of SpO2 does not protect patients against decreased cerebral saturation. Our results may be important in discussions on the mechanism of embolic events in patients who undergo big joint arthroplasty. The decrease in rSO2 can result from a decrease in oxygen delivery to areas of the brain via vessels occluded with embolic material. This explanation may be supported by the increased serum concentration of the S100B protein, a biochemical marker of brain damage. An increased concentration of S100B protein was noted in patients after orthopedic surgery, including big joint arthroplasty [7,14]. However, Soh et al. [16] suggest that the degree and duration of the decrease in perioperative rSO2 values were not associated with delirium in elderly patients after spinal surgery. Those results should be applied to our patients cautiously because of their different positions during the surgery. According to Kato et al. [6], the position of the patient has an impact on the intraoperative readings of rSO2: the measurements of rSO2 were significantly lower when measured in the upright as compared to the supine position.

The lack of correlation between changes in rSO2 and MAP values excludes the possibility that cerebral desaturation was produced by systemic hypoperfusion. In our study, we did not analyze the perioperative changes in hemoglobin concentration; however, the patients' hemoglobin concentrations before surgery were within normal limits. Some authors [8] suggest that hemoglobin concentration may be one factor that interferes with rSO2 measurements. However, McCredie et al. [10] found that, in patients with severe traumatic brain injury, there were no measurable impacts of blood cell transfusion on rSO2 values in a conventionally relevant range of anemia.

We also found no changes between rSO2 and hemoglobin saturation when measured by SpO2. In patients who underwent surgical revascularization of the coronary arteries, Harilall et al. [4] found that hemoglobin oxygen saturation was one of the predictors of cerebral oxygen desaturation. In our study, the values of SpO2 were stable, so the possible influence of intraoperative sedation with benzodiazepine on patients' ventilation and respiratory mechanics may be excluded.

A decrease in blood pressure during spinal anesthesia can result from a pre-ganglionic sympathetic block. In such cases, intravenously administered vasoactive drugs may restore

and maintain the perfusion pressure. In our study, ephedrine was the first-line drug. Koch et al. [9] discovered that ephedrine improves brain blood flow and tissue oxygenation and may be more effective than phenylephrine at improving brain hemodynamics and oxygenation. Thus, we believe that we can omit the influence of vasomotor agents on brain saturation, mainly since we analyzed the relationship between rSO2 and MAP.

An important limitation of our study is the relatively limited number of patients analyzed. The authors found no previous studies on changes in regional cerebral saturation in patients who underwent big joint arthroplasty. Therefore, the proper estimation of sample size was difficult.

Despite some limitations, our study may extend the knowledge on the relation between SpO2 and regional cerebral saturation in patients during big joint arthroplasty. The decrease in rSO2 values may be one of the factors increasing the frequency of POCD in this group of patients. The threshold values for tissue desaturation-related brain injury remain unknown [1]. However, it is important to realize that stable intraoperative values of SpO2 do not protect against a decrease in rSO2. It may indicate that perioperative analysis of rSO2 should become a part of standard monitoring, especially in patients scheduled for major surgical procedures or who are at risk of POCD.

OTHER INFORMATION

The full protocol of the study is available in the Department of Anesthesiology and Intensive Therapy, Military Institute of Aviation Medicine, Warsaw, Poland. Funding was provided by Military Institute of Medicine, Warsaw, Poland.

AUTHORS' DECLARATION

Study conception/design: Dariusz Tomaszewski, Mariusz Bałkota, Zbigniew Rybicki, Marcin Waśko. **Data acquisition/analysis/interpretation:** Dariusz Tomaszewski, Mariusz Bałkota, Zbigniew Rybicki, Marcin Waśko. **Intellectual content development/manuscript preparation/critical review:** Dariusz Tomaszewski, Mariusz Bałkota, Zbigniew Rybicki, Marcin Waśko. **Final version approval:** Dariusz Tomaszewski, Mariusz Bałkota, Zbigniew Rybicki, Marcin Waśko. **Funds collection:** Dariusz Tomaszewski, Zbigniew Rybicki. The Authors declare that there is no conflict of interest.

REFERENCES

1. Bickler P, Feiner J, Rollins M, Meng L. Tissue oximetry and clinical outcomes. Anesth Analg, 2017; 124(1):72-82.
2. Colonna DM, Kilgus D, Brown W, Challa V, Stump DA, Moody DM. Acute brain fat embolization occurring after total hip arthroplasty in the absence of patent foramen ovale. Anesthesiology, 2002; 96(4):1027-1029.
3. Deo H, West G, Butcher C, Lewis P. The prevalence of cognitive dysfunction after conventional and computer-assisted total knee replacement. Knee, 2011; 18(2):117-120. doi: 10.1016/j.knee.2010.03.006.
4. Harilall Y, Adam JK, Biccard BM, Reddi A. The effect of optimising cerebral tissue oxygen saturation on markers of neurological injury during coronary artery bypass graft surgery. Heart Lung Circ, 2014; 23(1):68-74. doi: 10.1016/j.hlc.2013.07.002.
5. Heringlake M, Garbers C, Käbler J-H, Anderson I, Heinze H, Schön J, Berger K-U, Dibbelt L, Sievers H-H, Hanke T. Preoperative cerebral oxygen saturation and clinical outcomes in cardiac surgery. Anesthesiology, 2011; 114(1):58-69. doi: 10.1097/ALN.0b013e3181fef34e.
6. Kato S, Yoshitani K, Kubota Y, Inatomi Y, Ohnishi Y. Effect of posture and extracranial contamination on results of cerebral oximetry by near-infrared spectroscopy. J Anesth, 2017; 31(1):103-110. doi: 10.1007/s00540-016-2275-1.
7. Kinoshita H, Iranami H, Fujii K, Yamazaki A, Shimogai M, Nakahata K, Hironaka Y, Hatano Y. The use of bone cement induces an increase in serum astroglial S-100B protein in patients undergoing total knee arthroplasty. Anesth Analg, 2003; 97(6):1657-1660.
8. Kobayashi K, Kitamura T, Kohira S, Torii S, Horai T, Hirata M, Mishima T, Sughimoto K, Ohkubo H, Irisawa Y, Matsushiro T, Hayashi H, Miyata Y, Tsuchida Y, Ohtomo N, Miyaji K. Factors associated with a low initial cerebral oxygen saturation value in patients undergoing cardiac surgery. J Artif Organs, 2017. doi: 10.1007/s10047-016-0941-6.
9. Koch KU, Mikkelsen IK, Espelund US, Angleys H, Tietze A, Oettingen GV, Juul N, Østergaard L, Rasmussen M. Anesthesiology, 2021; 135(5):788-803. doi: 10.1097/ALN. 0000000000003877.
10. McCredie VA, Piva S, Santos M, Xiong W, de Oliveira Manoel AL, Rigamonti A, Hare GM, Chapman MG, Baker AJ. The impact of red blood cell transfusion on

cerebral tissue oxygen saturation on severe traumatic brain injury. Neurocrit Care, 2017; 26(2):247-255. doi: 10.1007/s12082-016-0310-6.

11. Naftalovich R, Chyu D, Denny JT, Hasan A, Pantin EJ. Does cerebral oximetry always measure brain tissue oxygen saturation? An anatomical study utilizing computer tomography. J Anesthesiol Clin Pharmacol, 2021; 37(4):537-541. doi: 10.4103/joacp.JOACP_395_19.
12. Rasmussen LS. Defining postoperative cognitive dysfunction. Eur J Anaesthesiol, 1998; 15:761-764.
13. R Core Team: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, 2016. URL: https://www.R-project.org/.
14. Tomaszewski D, Rybicki Z, Możański M. The influence of bone cement implantation in primary hip arthroplasty on S100B protein serum concentration and patients' cognitive functions as markers of brain damage. Eur J Trauma Emerg Surg, 2010; 36(1):31-43. doi: 10.1007/s00068-009-8084-6.
15. Scott JE, Mathias JL, Kneebone AC. Postoperative cognitive dysfunction after total joint arthroplasty in the elderly: a meta-analysis. J Arthroplasty, 2014; 29(2):261-267.e1. doi: 10.1016/j.arth.2013.06.007.
16. Soh S, Shim JK, Song JW, Kim KN, Noh HY, Kwak YL. Postoperative delirium in elderly patients undergoing major spinal surgery: role of cerebral oximetry. J Neurosurg Anesthesiol, 2016 [Epub ahead of print].
17. Wu CL, Hsu W, Richman JM, Raja SN. Postoperative cognitive function as an outcome of regional anesthesia and analgesia. Reg Anesth Pain Med, 2004; 29(3):257-268.