Effect of Head and Neck Positioning on Cerebral Perfusion During Shoulder Arthroscopy in Beach Chair Position

Dane Salazar, MD[1]; Benjamin Sears, MD[1]; Anna Acosta, MD[1]; Bayan Aghdasi, BA[1]; Audrice Francois, MD[2]; Pietro Tonino, MD[1]; and Guido Marra, MD[3]

The aim of this prospective cohort study was to investigate the effect of head and neck positioning on cerebral perfusion during shoulder arthroscopy in the beach chair position. Regional cerebral tissue oxygen saturation (rSO_2) was monitored intraoperatively using near-infrared spectroscopy on 51 consecutive patients undergoing arthroscopic shoulder surgery in the beach chair position. The head of each subject was manipulated by the examiner and sequentially positioned for 45 seconds in terminal flexion, extension, bilateral rotation, and bilateral lateral bending. Decreases in rSO_2 of 20% or greater from baseline were defined as a cerebral desaturation event (CDE). The association between head and neck position and cerebral perfusion was assessed. Eight percent of patients (4/51) experienced CDE during head and neck positioning. Body mass index was found to be a risk factor for CDE ($p = .05$). When comparing preoperative baseline rSO_2 to intraoperative supine and intraoperative upright rSO_2, there was no significant decrease in saturation levels for any of the six tested positions. Frequent intraoperative evaluations of the head and neck position as well as careful preoperative positioning may reduce the risk of position-related complications in patients undergoing elective shoulder arthroscopy in the beach chair position. In this study's patient population, however, head and neck position was not found to cause significant cerebral desaturation for the time period tested compared to preoperative baselines. (Journal of Surgical Orthopaedic Advances 23(2):83–89, 2014)

The beach chair position is widely utilized for arthroscopic and open surgery, accounting for the preferred position in approximately two-thirds of shoulder surgeries performed in the United States (1, 2). The upright position enables visualization, improved airway access, diminished bleeding, and reduced risk of brachial plexus injury (3). Surgery performed in this position requires stabilization of the patient's head throughout the procedure. Despite careful preoperative positioning, the head and neck position may be altered during the course of surgery as a result of manipulation of the upper extremity. These factors may cause the anesthetized patient to experience an irregular head and neck position for an extended period of time.

Several small case series and individual case reports have documented intraoperative cerebral desaturation episodes and catastrophic neurocognitive complications from shoulder surgery in the semi-upright position (4–7). Complications attributed to incorrect head position during surgery in the upright position have ranged in severity from cutaneous neuropraxias to complete quadriplegia (8–10). Previous studies have demonstrated that mechanical impingement secondary to neck rotation and hyperextension can produce overt signs of cerebral ischemia in patients (11). This finding has led to recommendations of extra-auricular padding, frequent intraoperative position checks, and maintenance of the neutral head position in patients undergoing surgery in the semi-upright position (8). However, the effect of head and neck position on cerebral perfusion in patients undergoing elective arthroscopic shoulder surgery in the beach chair position has not been investigated.

Near-infrared spectroscopy (NIRS), a noninvasive technique that allows continuous monitoring of cerebral oxygenation, has been demonstrated to accurately recognize desaturation episodes that would otherwise elude detection with conventional intraoperative monitoring

(12–14). This technology is approved by the Food and Drug Administration and extensively used in patients undergoing other procedures at high risk for adverse neurologic outcomes, such as cardiac, neurosurgical, vascular, transplant, and major abdominal surgery (15). The aim of this prospective cohort study was to investigate the effect of head and neck positioning on cerebral perfusion during shoulder arthroscopy in the beach chair position using NIRS technology. The authors hypothesized that head and neck positions away from neutral would cause a measurable difference in cerebral perfusion.

Materials and Methods

Following institutional review board approval, informed consent was obtained from all subjects. Fifty-one consecutive patients scheduled to undergo elective arthroscopic shoulder surgery in the beach chair position were enrolled. Exclusion criteria included age less than 18 years, documented carotid stenosis (90% occlusion), prior neck surgery, cervical stenosis, cervical disc herniation, or a history of stroke, transient ischemic attack, neurologic event, syncope, myocardial infarction, spinal cord injury, or sudden vision loss. Patient demographic data, including age, gender, height, weight, smoking, and preexisting medical conditions, were recorded.

A standardized anesthesia protocol was used in all patients. An intravenous line was inserted in the preoperative holding area, and all patients were given midazolam (2–6 mg IV), titrated to effect, and placed on 2 L of continuous oxygen via simple facemask. After cleansing the forehead with an alcohol wipe, two noninvasive near-infrared spectroscopy sensors (INVOS 5100; Somanetics, Troy, Michigan) were applied bilaterally to the frontotemporal area, with the medial margin at the midline of the forehead and the lower margin 1 cm above the eyebrow, thus avoiding the temporalis muscle. The INVOS system is designed specifically to measure oxygen in the blood of the brain in the area underlying the sensor and uses two wavelengths, 730 and 810 nm, to measure changes in regional hemoglobin oxygen saturation by differentiating the absorption spectra of deoxygenated and oxygenated hemoglobin (16). Frontal lobe oxygenation was continuously recorded every 5 seconds. After 1 minute, a preoperative regional cerebral tissue oxygen saturation (rSO_2) baseline was obtained and recorded for both hemispheres. Once the cerebral saturation baseline was established, an ultrasound-guided interscalene block using 30 mL of 0.5% bupivacaine was performed on the side of the operative upper extremity.

Patients were then transported to the operating suite. Bilateral sequential compression devices (AirCast Vena-Flow; DJO Global, Vista, California) were applied to the lower extremities and the patients were transferred to the operating table (Ultra Shoulder; Mizuho OSI, Union City, California). Intraoperative monitoring consisted of electrocardiography, automatic arterial blood pressure assessment using a cuff placed on the nonoperative upper extremity, pulse oximetry, capnography, axillary temperature measurement, and cerebral tissue oxygen saturation via NIRS.

Anesthesia was induced with 2.5 to 3.0 mg/kg of propofol. The airway was secured and maintained using a laryngeal mask airway. Maintenance of anesthesia consisted of sevoflurane with nitrous oxide and a fraction of inspired oxygen of 50%. For postoperative nausea and vomiting prophylaxis, nondiabetic patients were given dexamethasone 4 mg after induction and ondansetron 4 mg was given to all patients within 30 minutes of extubation. A lower body forced-air warming device (Bair Hugger; Augustine Medical, Minneapolis, Minnesota) was used to maintain core temperature above 35.0°C.

The NIRS monitoring system was set to alarm with rSO_2 decreases of 20% or greater from baseline. While supine, the head of each subject was manipulated by the examiner and placed into terminal flexion, extension, right and left rotation, and right and left lateral bending. Each position was maintained for 45 seconds or until there was a reduction in cerebral saturation of 20% or greater from the preoperative baseline. Cerebral saturation levels were collected continuously and marked at the termination of each position. At the conclusion of the supine movements, the patients were positioned into the semi-upright beach chair position (70° from horizontal). Once sitting, the patient was again manipulated into the six head and neck positions (terminal flexion, extension, right and left rotation, and right and left lateral bending). After completing the measurements in the upright position, the patient was prepped and draped in the usual sterile fashion and the planned surgery was conducted. All surgeries were performed by a single experienced surgeon. At the conclusion of the surgery, cerebral saturation was again monitored as the head was manipulated into the same six positions.

Results

Complete data sets were obtained from 51 consecutive patients who met the inclusion criteria. Based on cerebral desaturation event as the primary outcome variable, chi-square testing indicated a power of 99% ($p < .001$) using this sample size. The incidence of intraoperative cerebral desaturation event (CDE) during head and neck manipulation in our series was 7.8% (4/51). To investigate the association of CDE with patient risk factors, the dichotomous variables of gender, smoking, diabetes, hypertension, coronary artery disease, obstructive sleep apnea, peripheral vascular disease, and pulmonary disease where

TABLE 1 Relationship of risk factors to cerebral desaturation events: frequency, proportion, and significance

Risk Factor	No. of Pts with RF	No. of Pts with RF and CDE	Proportion of Pts with RF who had CDE (%)	Fisher Exact p Value*
CAD	4	0	0	1.00
Diabetic	7	0	0	1.00
Gender: Male	34	3	6	1.00
Gender: Female	17	1	9	1.00
HTN	21	3	14	0.29[a]
OSA	8	1	13	0.51[a]
Pulmonary	3	1	33	0.22[a]
Smoker	18	1	6	1.00

RF, risk factor; Pts, patients; CDE, cerebral desaturation event; CAD, coronary artery disease; HTN, hypertension; OSA, obstructive sleep apnea.
*A p value of less than .05 was considered significant.
[a] Indicates a trend toward significance.

TABLE 2 Summary of patients with cerebral desaturation events

Patient	Age	Gender	Diabetic	Smoker	HTN	CAD	OSA	Pulmonary	PVD	BMI	Baseline rSO$_2$	Head Position[a]	rSO$_2$ Level[a]	Percentage Decrease in rSO$_2$ From Baseline (%)[a]
Patient 12	63	M	No	No	Yes	No	No	Yes	No	34.9	78	RLBPS	54	31%
Patient 16	40	M	No	Yes	Yes	No	Yes	No	No	37.1	74	LLBPS	59	20%
Patient 22	45	F	No	No	Yes	No	No	No	No	46.9	77	RRPS	51	34%
Patient 34	59	M	No	No	No	No	No	No	No	28.2	78	LLBPS	62	21%

HTN , hypertension; CAD, coronary artery disease; OSA, obstructive sleep apnea; PVD, peripheral vascular disease; BMI, body mass index; M, male; F, female; RLBPS, right lateral bend preoperative (preop) sitting; LLBPS, left lateral bend preop sitting; RRPS, right rotation preop sitting.
[a]Indicates a parameter measured during a cerebral desaturation event.

analyzed using Pearson chi-square and Fisher exact tests. These data are presented in Table 1. None of the nominal patient variables demonstrated a statistically significant difference between the desaturation group (4) and the nondesaturation group (47). The risk factors (and number of patients manifesting each) were as follows: positive patient history for coronary artery disease (4), diabetes mellitus (7), male (34) and female (17) gender, hypertension (21), obstructive sleep apnea (8), chronic obstructive pulmonary disease (3), and tobacco use (18).

A total of four (7.8%) out of the 51 surgical subjects sustained intraoperative cerebral desaturation events. Their demographics and details of their CDE are presented in Table 2. The continuous variables of body mass index (BMI) and age were analyzed using a two-tailed t test; these are presented in Table 3. The mean BMI of subjects experiencing CDE ($n = 4$) was 36.77 (range, 28.2–46.9), whereas the mean BMI of subjects free of intraoperative CDE ($n = 47$) was 29.77 years (range, 19.1–28.7; mean difference, −7.00). This difference was statistically significant ($p = .05$). The mean age of subjects experiencing CDE ($n = 4$) was 51.75 years (range, 40–63), whereas the mean age of subjects free of intraoperative CDE ($n = 47$)

TABLE 3 Age and BMI of subjects with and without cerebral desaturation event

Risk Factor	CDE	Sample (n)	Mean ± SD	Minimum	Maximum
Age	No	47	48.0851 ± 13.8357	18	76
	Yes	4	51.7500 ± 10.9962	40	63
BMI	No	47	29.7702 ± 6.7217*	19.1	48.7
	Yes	4	36.7750 ± 7.7388*	28.2	46.9

CDE, cerebral desaturation event; SD, standard deviation.
*Indicates a significant difference between the CDE and non-CDE group means ($p = .05$). No significant difference was observed between the CDE and non-CDE group means for age ($p = .61$).

was 48.08 years (range, 18–76; mean difference, −3.66). This difference was not statistically significant ($p = .61$).

Mean change in regional cerebral O_2 saturation from preinduction baseline to postinduction supine, preoperative upright, and postoperative upright was calculated (Fig. 1). Side-by-side comparison of mean change in rSO$_2$ from baseline to preoperative sitting in six cardinal positions for two hemispheres reveals universally less mean change as compared with baseline-to-supine. Side-by-side comparison of mean change in rSO$_2$ from
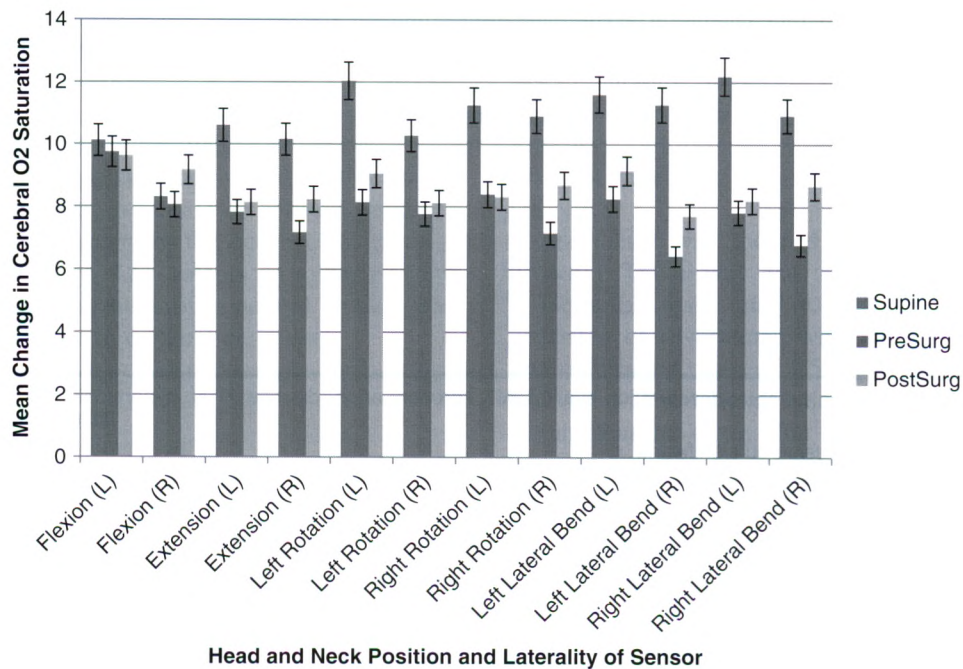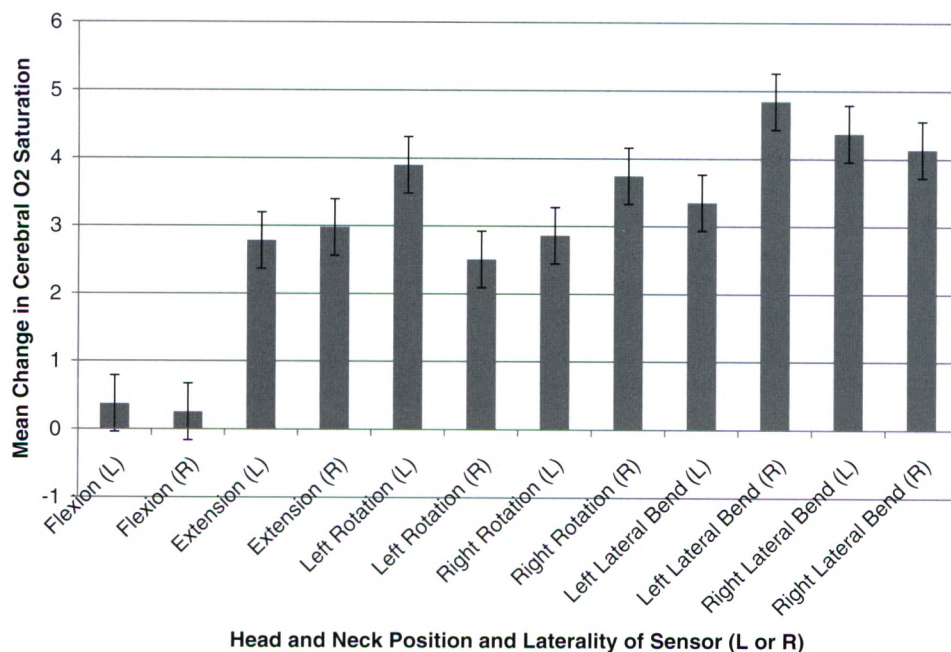
FIGURE 1 Comparison of the mean change in rSO_2 between the preinduction baseline and postinduction supine, preoperative upright, and postoperative upright when the head and neck was positioned into terminal flexion, extension, right and left rotation, and right and left lateral bending. The mean changes for both the right and left hemispheres are presented.

baseline to postoperative sitting in six cardinal positions for two hemispheres reveals universally less change as compared with baseline-to-supine, with the exception of the right hemisphere during flexion. Side-by-side comparison of mean change in rSO_2 from baseline to postoperative sitting in six cardinal positions for two hemispheres reveals universally more change as compared with baseline-to-preoperative sitting except during flexion and right rotation, in the left hemisphere. For this comparison, there was no statistically significant decrease in cerebral O_2 saturation in any of the tested positions compared to preoperative baseline.

Mean change in cerebral O_2 saturation from postinduction supine to preoperative upright was calculated for six cardinal positions and two hemispheres (Fig. 2). Flexion affected rSO_2 least (0.37 and 0.25, left and right hemispheres, respectively). This difference did not reach statistical significance. Extension (2.8 and 2.0, left and right hemispheres, respectively) and rotation (3.9 and 2.5 left rotation, left and right hemispheres, respectively; 2.9 and 3.7 right rotation, left and right hemispheres, respectively) were more influential over rSO_2 than flexion. These differences achieved statistical significance ($p < .05$). Lateral bending was responsible for the largest changes in cerebral O_2 saturation (3.4 and 4.8 left lateral bend, left and right hemispheres, respectively; 4.4 and 4.1 right lateral bend, left and right hemispheres, respectively). These differences achieved statistical significance ($p < .05$).

Discussion

Multiple case reports and series of patients undergoing surgery in the seated position have reported alarming unanticipated postoperative neurologic complications in healthy patients with no associated risk factors (1, 7, 17). Beach chair positioning during surgical procedures has been associated with cerebral hypoperfusion, leading to cerebral ischemia (5, 6, 14). These changes in cerebral perfusion pressure are thought to be the major contributor to poor neurologic outcomes. These events have exposed the need for heightened vigilance and improved safety measures. The exact etiology of the central nervous system injuries in this patient population is incompletely understood and is likely multifactorial. The maintenance of cerebral blood flow depends on the adaptation and complex integration of the circulatory system, autonomic nervous system, and the musculoskeletal system. In the normal physiologic state, the sympathetic nervous system is activated when assuming the seated position, causing increased systemic vascular resistance and heart rate alterations to maintain cardiac output and mean arterial pressure. In anesthetized patients, however, the autonomic nervous system response is blunted by the vasodilating effects of intravenous and volatile anesthetics (6, 14). These hemodynamic responses can be divided into the immediate phase (0 to 30 seconds), the stabilized phase (30 seconds to 20 minutes), and the prolonged phase (20 minutes to several hours) (14). Additionally, several

FIGURE 2 Comparison of the mean change in rSO_2 between postinduction supine and preoperative upright when the head and neck was positioned into terminal flexion, extension, right and left rotation, and right and left lateral bending. The mean changes for both the right and left hemispheres are presented.

studies have demonstrated hemodynamic changes that occur both in the awake and anesthetized patient when going from the supine to seated position (5, 18, 19), including diminished cardiac index, stroke volume, and arterial pressure (20). The mean change in cerebral perfusion levels when going from supine to sitting in our cohort is demonstrated in Figure 2. Our findings corroborate previous studies that have demonstrated considerable hemodynamic shift when going from the recumbent to the upright position.

The current study was designed to investigate any changes to cerebral perfusion caused by head and neck positioning away from neutral alignment while undergoing surgery in the semi-upright position. Each patient was placed into the six cardinal head and neck positions for 45 seconds each to capture the adaptive hemodynamic changes of the immediate phase. The head positions were performed while anesthetized supine before surgery, seated before surgery, and seated after surgery. We found that 4 of 51 patients experienced CDE during head positioning. No one position was found to cause a statistically significant drop in rSO_2 from baseline.

Several authors have recommended the use of cerebral oximetry using NIRS to monitor the adequacy of cerebral perfusion and to guide intraoperative interventions (4–6, 12, 14). NIRS, a noninvasive technique, allows continuous monitoring and has been demonstrated to accurately recognize cerebral oxygen desaturation (12, 13). This technique is used extensively to monitor cerebral perfusion during cardiovascular surgery, neurosurgical procedures, and carotid endarterectomy (21, 22). Changes in cerebral perfusion with head and neck position have not previously been investigated for arthroscopic shoulder surgery in the beach chair position.

Evidence suggests that changes from baseline rather than absolute values are a more important predictor of cerebral ischemia and that the oxygen saturation trend has more clinical validity (18, 23–25). In conscious patients, a 20% reduction in frontal lobe oxygenation is associated with clinical manifestations of cerebral hypoperfusion, such as syncope (16, 26). Because cerebral oximetry values are affected by depth of anesthesia, type of anesthetic administered, arterial carbon dioxide concentration, inspired oxygen content, and mean arterial blood pressure, there is no consensus in the literature defining the optimal time point at which to measure a patient's baseline (4–6, 14). The goal of our protocol was to establish a reference point that most accurately represented the physiologic cerebral saturation unique to each subject. Thus we obtained baseline rSO_2 readings in the supine position before intubation and positioning. In accordance with the standard of practice at our institution, we defined a CDE as a drop in rSO_2 of 20% or greater from baseline for any time period.

Multiple series and case reports have confirmed the occurrence of CDEs in patients undergoing elective shoulder arthroscopy in the seated position, but to date

only one has established patient risk factors (27). In our series, increased BMI was found to have a statistically significant association with intraoperative CDE during head and neck positioning (mean BMI 36.7 versus 29.7, $p = .05$). This corresponds with a previous cohort that also identified a BMI of greater than 34 to be an independent risk factor for intraoperative CDE during arthroscopic shoulder surgery (27). In our series, 75% (3/4) of the patients who sustained a CDE had a BMI greater than 34, compared to only 29.7% (14/47) in the group that did not. Additionally hypertension ($p = .29$) and pulmonary disease ($p = .22$) demonstrated a trend toward statistical significance.

This study has several limitations. In spite of our exclusion parameters, we did not obtain screening carotid duplex scans, computed tomography angiography, or magnetic resonance angiography. This would have identified asymptomatic, previously undiagnosed carotid or vertebral artery disease in our patient population. Mechanical impingement by neck rotation and hyperextension can produce vertebral artery hypoperfusion and occlusion, most pronounced in subjects with severe stenosis and preexisting vascular risk factors (11). It remains unclear if the drop in cerebral perfusion in the four patients who experienced CDE during head and neck positioning was from undiagnosed vascular disease. Additionally, patients were kept in each respective position for only 45 seconds; therefore, it is unclear if prolonged time in any given position would have caused further or more pronounced decrease in cerebral perfusion. However, most hemodynamic changes and autoregulation occur in the first 30 seconds after change in position (20).

A power analysis was performed to establish the number of patients needed to capture changes in cerebral perfusion during arthroscopic shoulder surgery. However, because previous cohorts have varied widely in the reported incidence (18%–80%), the power analysis is rendered less reliable (14). Thus it remains unclear whether a statistically significant decrease in cerebral saturation would have been demonstrated had the patient cohort been larger.

In summary, reports of unanticipated cerebral ischemic events in low-risk patients during shoulder surgery in the beach chair position demonstrate the need to maintain intraoperative cerebral perfusion. In our cohort, 7.8% (4/51) of patients experienced a CDE during head and neck positioning; however, none of the positions showed a statistically significant drop in rSO_2 from preoperative baseline. Thus, in our patient population, head and neck positioning did not exhibit a statistically significant decrease in cerebral perfusion.

Because positioning of the head away from neutral may cause ocular injury and nerve compression from mechanical pressure, we continue to recommend extra-auricular padding, frequent intraoperative position checks, and maintenance of the neutral head position (1, 16, 20). Additionally we believe protocols aimed at detecting and reversing CDE improve patient safety during arthroscopic shoulder surgery performed in the beach chair position.

References

1. Papadonikolakis, A., Wiesler, E. R., Olympio, M. A., et al. Avoiding catastrophic complications of stroke and death related to shoulder surgery in the sitting position. Arthroscopy 24:481–482, 2008.
2. Friedman, D. J., Parnes, N. Z., Zimmer, Z., et al. Prevalence of cerebrovascular events during shoulder surgery and association with patient position. Orthopedics 32(4), 2009.
3. Skyhar, M. J., Altchek, D. W., Warren, R. F., et al. Shoulder arthroscopy with the patient in the beach-chair position. Arthroscopy 4:256–259, 1988.
4. Dippmann, C., Winge, S., Nielsen, H. B. Severe cerebral desaturation during shoulder arthroscopy in the beach-chair position. Arthroscopy 26:S148–S150, 2010.
5. Tange, K., Kinoshita, H., Minonishi, T., et al. Cerebral oxygenation in the beach chair position before and during general anesthesia. Minerva Anestesiol. 76:485–490, 2010.
6. Fischer, G. W., Torrillo, T. M., Weiner, M. M., et al. The use of cerebral oximetry as a monitor of the adequacy of cerebral perfusion in a patient undergoing shoulder surgery in the beach chair position. Pain Pract. 9:304–307, 2009.
7. Pohl, A., Cullen, D. J. Cerebral ischemia during shoulder surgery in the upright position: a case series. J. Clin. Anesth. 17:463–469, 2005.
8. Park, T. S., Kim, Y. S. Neuropraxia of the cutaneous nerve of the cervical plexus after shoulder arthroscopy. Arthroscopy 21:631, 2005.
9. Morandi, X., Riffaud, L., Amlashi, S. F., et al. Extensive spinal cord infarction after posterior fossa surgery in the sitting position: case report. Neurosurgery 54:1512–1515; discussion 5–6, 2004.
10. Haisa, T., Kondo, T. Midcervical flexion myelopathy after posterior fossa surgery in the sitting position: case report. Neurosurgery 38:819–821; discussion 21–22, 1996.
11. Weintraub, M. I., Khoury, A. Critical neck position as an independent risk factor for posterior circulation stroke. A magnetic resonance angiographic analysis. J. Neuroimaging 5:16–22, 1995.
12. Pollard, V., Prough, D. S., DeMelo, A. E., et al. Validation in volunteers of a near-infrared spectroscope for monitoring brain oxygenation in vivo. Anesth. Analg. 82:269–277, 1996.
13. Pollard, V., Prough, D. S., DeMelo, A. E., et al. The influence of carbon dioxide and body position on near-infrared spectroscopic assessment of cerebral hemoglobin oxygen saturation. Anesth. Analg. 82:278–287, 1996.
14. Murphy, G. S., Szokol, J. W., Marymont, J. H., et al. Cerebral oxygen desaturation events assessed by near-infrared spectroscopy during shoulder arthroscopy in the beach chair and lateral decubitus positions. Anesth. Analg. 111:496–505, 2010.
15. Casati, A., Spreafico, E., Putzu, M., et al. New technology for noninvasive brain monitoring: continuous cerebral oximetry. Minerva Anestesiol. 72:605–625, 2006.
16. Madsen, P. L., Secher, N. H. Near-infrared oximetry of the brain. Prog. Neurobiol. 58:541–560, 1999.
17. Rains, D. D., Rooke, G. A., Wahl, C. J. Pathomechanisms and complications related to patient positioning and anesthesia during shoulder arthroscopy. Arthroscopy 27:532–541, 2011.

18. Fuchs, G., Schwarz, G., Kulier, A., et al. The influence of positioning on spectroscopic measurements of brain oxygenation. J. Neurosurg. Anesthesiol. 12:75–80, 2000.
19. Lovell, A. T., Owen-Reece, H., Elwell, C. E., et al. Continuous measurement of cerebral oxygenation by near infrared spectroscopy during induction of anesthesia. Anesth. Analg. 88:554–558, 1999.
20. Smith, J. J., Porth, C. M., Erickson, M. Hemodynamic response to the upright posture. J. Clin. Pharmacol. 34:375–386, 1994.
21. Smythe, P. R., Samra, S. K. Monitors of cerebral oxygenation. Anesthesiol. Clin. North Am. 20:293–313, 2002.
22. Carlin, R. E., McGraw, D. J., Calimlim, J. R., et al. The use of near-infrared cerebral oximetry in awake carotid endarterectomy. J. Clin. Anesth. 10:109–113, 1998.
23. Rigamonti, A., Scandroglio, M., Minicucci, F., et al. A clinical evaluation of near-infrared cerebral oximetry in the awake patient to monitor cerebral perfusion during carotid endarterectomy. J. Clin. Anesth. 17:426–430, 2005.
24. Kirkpatrick, P. J., Lam, J., Al-Rawi, P., et al. Defining thresholds for critical ischemia by using near-infrared spectroscopy in the adult brain. J. Neurosurg. 89:389–394, 1998.
25. Henson, L. C., Calalang, C., Temp, J. A., et al. Accuracy of a cerebral oximeter in healthy volunteers under conditions of isocapnic hypoxia. Anesthesiology 88:58–65, 1998.
26. Samra, S. K., Dy, E. A., Welch, K., et al. Evaluation of a cerebral oximeter as a monitor of cerebral ischemia during carotid endarterectomy. Anesthesiology 93:964–970, 2000.
27. Salazar, D., Sears, B. W., Aghdasi, B., et al. Cerebral desaturation events during shoulder arthroscopy in the beach chair position: patient risk factors and neurocognitive effects. J. Shoulder Elbow Surg. 22(9):1228–1235, 2013.