Clin Orthop Relat Res (2013) 471:4027–4034
DOI 10.1007/s11999-013-2987-6

Clinical Orthopaedics and Related Research®
A Publication of The Association of Bone and Joint Surgeons®

CLINICAL RESEARCH

Cerebral Desaturation During Shoulder Arthroscopy: A Prospective Observational Study

Dane Salazar MD, Benjamin W. Sears MD, John Andre BS, Pietro Tonino MD, Guido Marra MD

Received: 17 January 2013 / Accepted: 8 April 2013 / Published online: 19 April 2013

Abstract

Background Patients undergoing arthroscopic shoulder surgery in the beach chair position may be at increased risk for serious neurocognitive complications as a result of cerebral ischemia.

Questions/purposes We sought to define the (1) incidence; (2) timing; and (3) magnitude of intraoperative cerebral desaturation events (CDEs) in subjects undergoing arthroscopic shoulder surgery in the beach chair position, as well as whether (4) the length of surgery was an independent risk factor for intraoperative CDEs.

Methods 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. Intraoperative decreases in rSO_2 of 20% or greater were defined as CDEs.

Results The incidence of intraoperative CDEs in our series was 18% (nine of 51). Among the patients demonstrating CDE (n = 9), the mean time to onset of initial CDE was 18 minutes 38 seconds postinduction. Of those experiencing CDEs, the mean maximal decrease in rSO_2 was 32% from preoperative baseline per patient. Additionally, the mean number of separate CDE instances was 1.89 in this patient population with an average duration of 3 minutes 3 seconds per instance. There was no statistically significant difference (p = 0.202) between patients demonstrating CDEs and those without in regard to length of surgery (95 versus 88 minutes).

Conclusions The degree and duration of cerebral ischemia required to produce neurocognitive dysfunction in this patient population remains undefined; however, cerebral oximetry with near-infrared spectroscopy allows prompt identification and treatment of decreased cerebral perfusion. We believe protocols aimed at detecting and reversing CDE may improve patient safety.

Level of Evidence Level III, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

The Walgreen's Foundation donated USD 5000.00 for this investigation. One or more of the authors (GM) is a consultant for Zimmer (Warsaw, IN, USA). One or more of the authors (PT) owns stock in Regeneration Technologies, Inc (Alachua, FL, USA).
All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research* editors and board members are on file with the publication and can be viewed on request.

Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

D. Salazar (✉), B. W. Sears, J. Andre, P. Tonino
Department of Orthopaedic Surgery and Rehabilitation, Loyola University Health System, 2160 South First Avenue, Maywood, IL 60153, USA
e-mail: dsalazar@post.com

G. Marra
Department of Orthopaedic Surgery, Northwestern University, Chicago, IL, USA

Introduction

The beach chair position is commonly used for both arthroscopic and open shoulder surgery. This technique positions the shoulder in an anatomic upright position, facilitating shoulder access and visualization [34]. The beach chair position also provides improved airway access, diminished bleeding, and reduced risk of brachial plexus injury [31].

Despite these advantages, there are multiple reports of significant neurologic complications, including severe brain damage and death [1, 7, 24, 26]. The definitive etiology of these complications remains unclear, but is hypothesized to occur secondary to cerebral ischemia [5, 9, 14, 17, 22–27, 30, 33, 34]. The upright position is associated with hypotension leading to an increased risk of cerebral hypoperfusion [5, 9, 14, 17, 22, 32]. Reduction in cerebral perfusion pressure below critical thresholds of duration and severity may result in permanent neurologic injury [7, 24, 26, 27]. It has been recommended that patients undergoing surgery in the beach chair position be continuously monitored, and intraoperative cerebral oxygenation optimized, to avoid potential neurologic complication [14, 17, 22, 23, 34].

Near-infrared spectroscopy (NIRS), a noninvasive technique that allows continuous monitoring of cerebral oxygenation, has been demonstrated to accurately recognize desaturation episodes that would remain undetected with conventional intraoperative monitoring [2, 3, 5, 6, 11–13, 15, 18, 20, 21, 23, 28, 30, 33]. The INVOS system (Somanetics, Troy, MI, USA) is designed specifically to measure oxygen levels in the blood of the brain in areas underlying the sensor using two wavelengths, 730 and 810 nm, to measure changes in regional hemoglobin oxygen saturation by differentiating the absorption spectra of deoxygenated and oxygenated hemoglobin [20]. This US Food and Drug Administration-approved technology is extensively used in patient populations undergoing procedures at high risk for adverse neurologic outcomes such as cardiac, vascular, transplant, and major abdominal surgery [3, 20, 33]. Multiple small case series and case reports have documented intraoperative cerebral desaturation episodes and rare catastrophic neurocognitive complications from shoulder surgery in the semiupright position [1, 5, 7, 9, 16, 22, 23, 26, 34].

The aim of this prospective observational study is to investigate (1) the incidence; (2) timing; and (3) magnitude of intraoperative cerebral desaturation events (CDEs) in subjects undergoing arthroscopic shoulder surgery in the beach chair position as well as to determine whether (4) the length of surgery is an independent risk factor for CDEs.

Patients and Methods

After 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. All surgeries were performed at an outpatient ambulatory surgical center from October 2010 to April 2011. Exclusion criteria included age younger 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, sex, height, weight, smoking, and preexisting medical conditions, were recorded and used for comparisons to determine whether any of them were associated with CDEs.

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 intravenously) titrated to effect and placed on 2 L of continuous oxygen through a simple facemask. After cleansing the forehead with an alcohol wipe, two noninvasive NIRS sensors (INVOS 5100; Somanetics) 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. Frontal lobe oxygenation was monitored continuously and 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 ipsilateral to the operative upper extremity.

Patients were then transported to the operating suite. Bilateral sequential compression devices (AirCast VenaFlow; DJO Global, Vista, CA, USA) were applied to the lower extremities and the patients were transferred to the operating table (Ultra Shoulder; Mizuho OSI, Union City, CA, USA). 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 through NIRS.

Anesthesia was induced with 2.5 to 3.0 mg/kg 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 4 mg dexamethasone after induction and 4 mg ondansetron was given to all patients within 30 minutes of extubation. A lower body forced-air warming device (Bair Hugger; Augustine Medical, Minneapolis, MN, USA) 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. To avoid cerebral vascular injury, all such cerebral desaturation episodes were treated with a defined protocol that included ephedrine (5 mg), phenylephrine (80 ug), fluid bolus, and returning the patient to a supine position as clinically indicated. The type of intervention and the time for each CDE were recorded. All surgeries were performed by a single experienced surgeon (GM). The rSO_2 levels were measured continuously throughout the surgery and data recorded digitally.

Results

The incidence of intraoperative CDE in our series was 18% (nine of 51). Among the patients experiencing CDEs, the mean time to onset of the initial CDE was 18 minutes 38 seconds postinduction, which transpired an average of 8 minutes 9 seconds after transitioning to the semiupright position (Table 1). The mean number of independent instances of intraoperative CDEs was 1.89 (range, 1–4) per patient. The mean maximal desaturation in rSO_2 from preoperative baseline was 32% (range, 21%–63%) with each desaturation event lasting an average of 3 minutes 3 seconds (range, 32 seconds to 8 minutes 3 seconds). This data is presented individually for each of the nine subjects in the CDE group in intraoperative regional perfusion profiles (Fig. 1).

There was no difference between the non-CDE and the CDE group in terms of the length of surgery (LOS) ($p = 0.2$). The mean LOS in the non-CDE group was 87.7 minutes (range, 55–115 minutes) and 95.1 minutes (range, 75–112 minutes) in the CDE group (Fig. 2).

With the numbers available, none of the nominal patient variables demonstrated a statistically significant difference between the desaturation group (n = 9) and the nondesaturation group (n = 42) (Table 2). The mean body mass index (BMI) was greater among subjects who experienced CDE than those who did not. The mean BMI of patients who had a CDE was 37 kg/m^2 (range, 24–49 kg/m^2) compared with 29 kg/m^2 (range, 19–43 kg/m^2) in those who did not (mean difference −8.72, $p < 0.001$). The odds ratio for patients with a BMI of 34 kg/m^2 or greater of experiencing an intraoperative CDE was calculated to be 12.4. There was no difference in mean age between patients who had a CDE and those who did not (53 versus 48, $p = 0.25$).

Discussion

Multiple case reports and series of patients undergoing surgery in the seated position have reported unanticipated postoperative neurologic complications in previously healthy patients with no known risk factors [24, 26, 27]. Beach chair positioning during surgical procedures has been implicated in cerebral hypoperfusion, leading to cerebral ischemia [6, 23, 34]. These changes in cerebral perfusion pressure are believed to be the major determinant of poor neurological outcomes. Such reports have exposed the potential need for heightened vigilance, alternative anesthesia techniques, and improved monitoring. The exact etiology of the central nervous system injuries in this patient population is incompletely understood and is likely multifactorial. Thus, the aim of this prospective observational study was to investigate the incidence, timing, and magnitude of intraoperative CDEs as well as whether the length of surgery was an independent risk factor for CDEs. The incidence of intraoperative CDEs in our series was 18% (nine of 51). Among the patients demonstrating CDE (n = 9), the mean time to onset of initial CDE was 18 minutes 38 seconds postinduction. Of those experiencing CDEs, the mean maximal decrease in rSO_2 was 32% from preoperative baseline per patient. Additionally, the mean number of separate CDE instances was 1.89 in this patient population with an average duration of 3 minutes 3 seconds per instance. There was no statistically significant difference ($p = 0.202$) between patients demonstrating CDEs and those without in regard to length of surgery (95 versus 88 minutes).

One of the limitations of our study is the sample size. The results may be underpowered for our outcome measures, which include patient risk factors and operative time. Additionally, our exclusion criteria narrowed our patient population and as such may have underrepresented the incidence of CDE by omitting patients with certain medical comorbidities. Because our study did not include invasive blood pressure monitoring, we do not have accurate mean arterial blood pressure data for the time points corresponding to patient CDEs.

The series is a prospective observation study; therefore we do not have a control group consisting of patients undergoing shoulder surgery in another position or patients undergoing other types of surgery in the semiupright position. This may affect the generalizability of our conclusions. However, in a prospective cohort study, Murphy et al. found that there were sizeable and frequent episodes of intraoperative cerebral desaturation in the seated position when compared with patients in the lateral decubitus position (80% beach chair versus 0% lateral decubitus) in a series of 124 patients undergoing elective arthroscopic shoulder surgery under general anesthesia [23]. Despite multiple case reports and small series of catastrophic neurocognitive complications after elective arthroscopic shoulder surgery, the clinical relevance of intraoperative cerebral desaturation episodes is not well understood.[5, 6, 26, 34]. Thus, for this patient population, the severity and duration of desaturation that causes cerebral ischemia and the relationship with mean arterial blood pressure at the level of the brain remain undefined.

Table 1. Demographics, desaturation characteristics, and interventions for patients experiencing CDE

Age (years)	Male	DM	Tob	HTN	CAD	OSA	COPD	PVD	BMI (kg/m^2)	Type of surgery	Duration of desaturations (Mean duration)	Maximum desaturation (%rSO_2)	Postinduction latency to CDE	Latency from upright positioning to CDE	Intraoperative intervention
63	Yes	No	No	Yes	No	No	Yes	No	34.9	Capsular release, SAD	2 minutes 11 seconds	30.77	17 minutes 48 seconds	4 minutes 16 seconds	Ephedrine 40 mg × 2 Ephedrine 50 mg × 5
40	Yes	No	Yes	Yes	No	Yes	No	No	37.1	Distal clavicle excision, SAD	1 minute 35 seconds, 4 minutes 48 seconds, 4 minutes 14 seconds, 2 minutes 9 seconds Mean = 3 minutes 11.5 seconds per CDE	62.16	14 minutes 32 seconds, 24 minutes 11 seconds, 63 minutes 53 seconds, 76 minutes 42 seconds	3 minutes 45 seconds	700-mL fluid bolus over 20 minutes, patient maneuvered from upright to supine, phenylephrine GTT initiated, inhaled anesthetic decreased from 3 to 0 for remainder of case, propofol used for sedation
52	No	Yes	Yes	No	No	No	No	No	23.8	Capsular release	1 minute 6 seconds	28.57	0 minute 0 seconds	9 minutes 45 seconds before upright positioning	Ephedrine 10 mg, Ephedrine 5 mg, decreased inhaled anesthetic from 2 to 1.5
52	No	Yes	No	Yes	Yes	Yes	No	No	48.7	RCR, SAD	0 minutes 32 seconds	21.79	13 minutes 52 seconds	6 minutes 22 seconds	Ephedrine 10 mg × 3 Ephedrine 5 mg, decreased inhaled anesthetic from 2 to 1.5
60	Yes	Yes	No	Yes	No	No	No	No	38.0	RCR, SAD	3 minutes 13 seconds, 5 minutes 22 seconds, 8 minutes 3 seconds Mean = 5 minutes 32.7 seconds per CDE	33.80	13 minutes 29 seconds, 35 minutes 56 seconds, 71 minutes 39 seconds	6 minutes 1 second	5 mg ephedrine × 3, decreased inhaled anesthetic from 2 to 1.4
45	No	No	No	Yes	No	No	No	No	46.9	RCR, SAD	4 minutes 19 seconds, 2 minutes 42 seconds Mean = 3 minutes 0.5 seconds per CDE	41.56	10 minutes 47 seconds, 18 minutes 18 seconds	2 minutes 9 seconds	Ephedrine 5 mg × 5, Ephedrine 10 mg × 2, 800 mL of fluid in first 30 minutes of case

Table 1. continued

Age (years)	Male	DM	Tob	HTN	CAD	OSA	COPD	PVD	BMI (kg/m^2)	Type of surgery	Duration of desaturations (Mean duration)	Maximum desaturation (%rSO$_2$)	Postinduction latency to CDE	Latency from upright positioning to CDE	Intraoperative intervention
59	Yes	No	No	No	No	No	No	No	28.2	RCR, SAD	3 minutes 14 seconds	25.00	16 minutes 45 seconds	3 minutes 13 seconds	Decreased inhaled anesthetic from 1.4 to 0.8
43	No	No	No	No	No	No	No	No	44.0	SAD	1 minute 4 seconds	20.78	33 minutes 22 seconds	24 minutes 12 seconds	10 mg ephedrine
65	Yes	No	No	Yes	No	Yes	No	No	34.3	Débridement, RCR	1 minute 36 seconds, 3 minutes 44 seconds, 2 minutes 9 seconds	20.51	47 minutes 10 seconds, 51 minutes 59 seconds, 61 minutes 4 seconds	40 minutes 11 seconds	Phenylephrine 40 μg × 4
											Mean = 2 minutes 9.7 seconds per CDE				

CDE = cerebral desaturation event; DM = diabetes mellitus; Tob = patient is a current smoker; HTN = hypertension; CAD = coronary artery disease; OSA = obstructive sleep apnea; COPD = chronic obstructive pulmonary disease; PVD = peripheral vascular disease; BMI = body mass index (calculated as weight in kg divided by height in meters squared); SAD = patient underwent a subacromial decompression procedure; RCR = patient underwent a rotator cuff repair procedure; GTT = drip.

The incidence of CDE in patients monitored with NIRS undergoing elective shoulder surgery in the beach chair position in the published literature is quite variable and ranges from 8% to 80% [5, 7, 17, 23, 29, 34]. In our patient series, the incidence of CDE was 18% (nine of 51). Because cerebral oximetry values are affected by depth of anesthesia, type of anesthetic administered, arterial carbon dioxide concentration, inspired oxygen content, mean arterial blood pressure, and operative position, there is no consensus in the literature defining the optimal time point at which to measure a patient's baseline [14, 16, 22, 23]. The goal of our protocol was to establish a reference point that most accurately represented the physiologic cerebral saturation baseline unique to each subject. Thus, we obtained our 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 with subsequent episodes requiring a return above that threshold before constituting an independent CDE. This threshold is standard in the international literature and is based on the fact that in conscious patients, a 20% reduction in frontal lobe oxygenation is associated with clinical manifestations of cerebral hypoperfusion such as syncope [20, 30]. Additionally, 20% or greater reduction in rSO_2 during carotid clamping test is associated with a 20-fold increase in developing overt signs and symptoms of cerebral ischemia during carotid endarterectomy [28].

Multiple studies have demonstrated substantial hemodynamic changes that occur both in the waking and anesthetized patient when maneuvering from the supine to seated position [8, 18, 34], including diminished cardiac index, stroke volume, and arterial pressure [32]. Our findings corroborate previous studies that have demonstrated considerable hemodynamic shift when transitioning from the recumbent to the upright position. In our series, six of the nine patients who experienced CDE met the criteria within 6 minutes of being maneuvered into the seated position (Table 1). Additionally, patient operative perfusion profiles (Fig. 1) clearly demonstrate that the majority of patient CDEs occur close to the initiation of the operation. This data underscores the need for attentiveness and accurate monitoring of cerebral perfusion when transitioning from the supine to the beach chair position, especially in the early phase of surgery and in high-risk patients.

The magnitude and duration of cerebral ischemia required to produce neurocognitive dysfunction in this patient population remains unidentified. In conscious patients, a 20% reduction in frontal lobe oxygenation is associated with clinical manifestations of cerebral hypoperfusion such as syncope [20, 30]. In our series, the patients averaged 1.89 CDEs with a mean desaturation

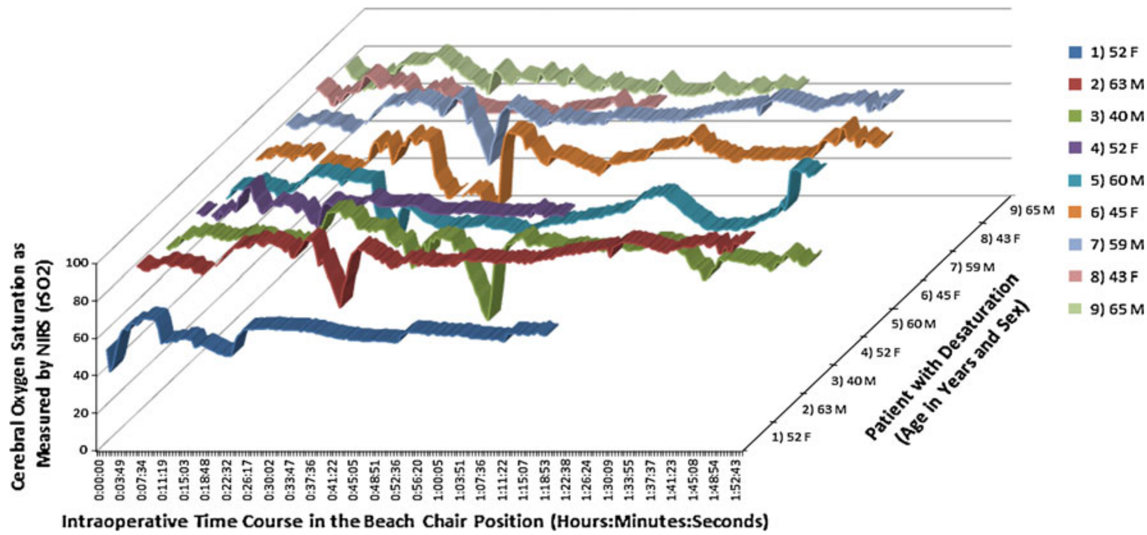

Fig. 1 This is a graphic representation of the intraoperative cerebral perfusion profile of the nine subjects who sustained CDEs. F = female; M = male.

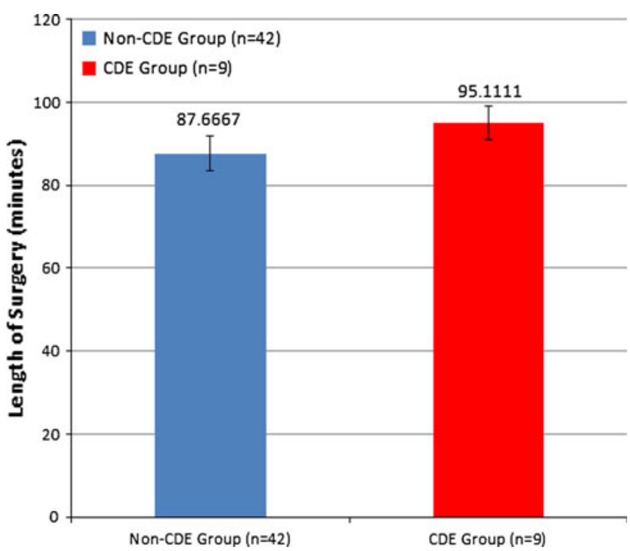

Fig. 2 This is a comparison of the mean operative time between the group that experienced CDE and the group that did not.

from preoperative baseline of 32% with a minimum of 21% and a maximum of 62%. It is likely that these desaturation events would have been more frequent, of longer duration, and more severe had we not identified them early and implemented a predetermined intervention protocol.

Longer operative times have been associated with an increased risk of intraoperative and postoperative complications [4, 10, 19]. We compared the operative times of the patients who experienced CDE and those who did not and found no statistically significant difference. Thus, for our patient population, prolonged surgical time was not an independent risk factor for CDE. We hypothesize that this is true because, as our data shows, the majority of the intraoperative CDEs occur during the first half of the operation and as such, longer operative times would not add increased risk of CDE.

In summary, reports of unanticipated cerebral ischemic events in low-risk patients during shoulder surgery in the

Table 2. Statistical significance of risk factors and demographic characteristics between CDE and non-CDE groups

Group	Risk factor and demographic characteristics									
	Male	DM	Tob	HTN	CAD	OSA	COPD	LOS	Age (years)	BMI (kg/m^2)
Non-CDE (n = 43)	67.4% (29)	9.3% (4)	39.5% (17)	34.9% (15)	7.0% (3)	11.6% (5)	4.7% (2)	88 min	47.5	28.7
CDE (n = 9)	55.6% (5)	33.3% (3)	22.2% (2)	66.7% (6)	11.1% (1)	33.4% (3)	11.2% (1)	95 min	53.2	37.3
p value	0.70	0.09†	0.46	0.13	0.54	0.13	0.44	0.2	0.25	0.0004*

* Statistically significant difference with $p < 0.05$; †trend toward statistical significance with $p < 0.1$; CDE = cerebral desaturation event; DM = diabetes mellitus; Tob = patient is a current smoker; HTN = hypertension; CAD = coronary artery disease; OSA = obstructive sleep apnea; COPD = chronic obstructive pulmonary disease; LOS = mean length of surgery (in minutes); BMI = body mass index (calculated as weight in kg divided by height in meters squared).

beach chair position demonstrate that noninvasive arterial blood pressure monitoring alone does not guarantee adequate cerebral perfusion. In our prospective series of 51 consecutive patients, 18% of subjects experienced intraoperative CDE. Cerebral oximetry with NIRS allows prompt identification and treatment of cerebral hypoperfusion. The degree and duration of cerebral ischemia required to produce neurocognitive dysfunction in this patient population remains unidentified. Alternative patient positions and anesthesia choices may help reduce intraoperative CDE. Additionally, we believe protocols aimed at detecting and reversing CDE may improve patient safety during arthroscopic shoulder surgery performed in the beach chair position.

Acknowledgments We thank the staff of the Loyola Ambulatory Surgical Center at Oak Brook for their support of this project. Without their hard work and dedication, this endeavor would not have been possible. We also thank Rong Guo for her statistical analysis of our data.

References

1. Bhatti MT, Enneking FK. Visual loss and ophthalmoplegia after shoulder surgery. *Anesth Analg.* 2003;96:899–902, table of contents.
2. Carlin RE, McGraw DJ, Calimlim JR, Mascia MF. The use of near-infrared cerebral oximetry in awake carotid endarterectomy. *J Clin Anesth.* 1998;10:109–113.
3. Casati A, Spreafico E, Putzu M, Fanelli G. New technology for noninvasive brain monitoring: continuous cerebral oximetry. *Minerva Anestesiol.* 2006;72:605–625.
4. Colman M, Wright A, Gruen G, Siska P, Pape HC, Tarkin I. Prolonged operative time increases infection rate in tibial plateau fractures. *Injury.* 2013;44:249–252.
5. Dippmann C, Winge S, Nielsen HB. Severe cerebral desaturation during shoulder arthroscopy in the beach-chair position. *Arthroscopy.* 2010;26:S148–150.
6. Fischer GW, Torrillo TM, Weiner MM, Rosenblatt MA. 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.* 2009;9:304–307.
7. Friedman DJ, Parnes NZ, Zimmer Z, Higgins LD, Warner JJ. Prevalence of cerebrovascular events during shoulder surgery and association with patient position. *Orthopedics.* 2009;32(4). pii: orthosupersite.com/view.asp?rID=38058.
8. Fuchs G, Schwarz G, Kulier A, Litscher G. The influence of positioning on spectroscopic measurements of brain oxygenation. *J Neurosurg Anesthesiol.* 2000;12:75–80.
9. Gillespie R, Shishani Y, Streit J, Wanner JP, McCrum C, Syed T, Haas A, Gobezie R. The safety of controlled hypotension for shoulder arthroscopy in the beach-chair position. *J Bone Joint Surg Am.* 2012;94:1284–1290.
10. Grant JA, Bissell B, Hake ME, Miller BS, Hughes RE, Carpenter JE. Relationship between implant use, operative time, and costs associated with distal biceps tendon reattachment. *Orthopedics.* 2012;35:e1618–1624.
11. Grubhofer G, Tonninger W, Keznickl P, Skyllouriotis P, Ehrlich M, Hiesmayr M, Lassnigg A. A comparison of the monitors INVOS 3100 and NIRO 500 in detecting changes in cerebral oxygenation. *Acta Anaesthesiol Scand.* 1999;43:470–475.
12. Henson LC, Calalang C, Temp JA, Ward DS. Accuracy of a cerebral oximeter in healthy volunteers under conditions of isocapnic hypoxia. *Anesthesiology.* 1998;88:58–65.
13. Imray C, Knickenberg C. Monitors of cerebral oxygenation. *Anaesthesia.* 1997;52:805.
14. Jeong H, Lee SH, Jang EA, Chung SS, Lee J, Yoo KY. Haemodynamics and cerebral oxygenation during arthroscopic shoulder surgery in beach chair position under general anaesthesia. *Acta Anaesthesiol Scand.* 2012;56:872–879.
15. Kirkpatrick PJ, Lam J, Al-Rawi P, Smielewski P, Czosnyka M. Defining thresholds for critical ischemia by using near-infrared spectroscopy in the adult brain. *J Neurosurg.* 1998;89:389–394.
16. Ko SH, Cho YW, Park SH, Jeong JG, Shin SM, Kang G. Cerebral oxygenation monitoring of patients during arthroscopic shoulder surgery in the sitting position. *Korean J Anesthesiol.* 2012;63:297–301.
17. Lee JH, Min KT, Chun YM, Kim EJ, Choi SH. Effects of beach-chair position and induced hypotension on cerebral oxygen saturation in patients undergoing arthroscopic shoulder surgery. *Arthroscopy.* 2011;27:889–894.
18. Lovell AT, Owen-Reece H, Elwell CE, Smith M, Goldstone JC. Continuous measurement of cerebral oxygenation by near infrared spectroscopy during induction of anesthesia. *Anesth Analg.* 1999;88:554–558.
19. Lumawig JM, Yamazaki A, Watanabe K. Dose-dependent inhibition of diclofenac sodium on posterior lumbar interbody fusion rates. *Spine J.* 2009;9:343–349.
20. Madsen PL, Secher NH. Near-infrared oximetry of the brain. *Prog Neurobiol.* 1999;58:541–560.
21. McKeating EG, Monjardino JR, Signorini DF, Souter MJ, Andrews PJ. A comparison of the Invos 3100 and the Critikon 2020 near-infrared spectrophotometers as monitors of cerebral oxygenation. *Anaesthesia.* 1997;52:136–140.
22. Moerman AT, De Hert SG, Jacobs TF, De Wilde LF, Wouters PF. Cerebral oxygen desaturation during beach chair position. *Eur J Anaesthesiol.* 2012;29:82–87.
23. Murphy GS, Szokol JW, Marymont JH, Greenberg SB, Avram MJ, Vender JS, Vaughn J, Nisman M. Cerebral oxygen desaturation events assessed by near-infrared spectroscopy during shoulder arthroscopy in the beach chair and lateral decubitus positions. *Anesth Analg.* 2010;111:496–505.
24. Papadonikolakis A, Wiesler ER, Olympio MA, Poehling GG. Avoiding catastrophic complications of stroke and death related to shoulder surgery in the sitting position. *Arthroscopy.* 2008;24:481–482.
25. Peruto CM, Ciccotti MG, Cohen SB. Shoulder arthroscopy positioning: lateral decubitus versus beach chair. *Arthroscopy.* 2009;25:891–896.
26. Pohl A, Cullen DJ. Cerebral ischemia during shoulder surgery in the upright position: a case series. *J Clin Anesth.* 2005;17:463–469.
27. Rains DD, Rooke GA, Wahl CJ. Pathomechanisms and complications related to patient positioning and anesthesia during shoulder arthroscopy. *Arthroscopy.* 2011;27:532–541.
28. Rigamonti A, Scandroglio M, Minicucci F, Magrin S, Carozzo A, Casati A. A clinical evaluation of near-infrared cerebral oximetry in the awake patient to monitor cerebral perfusion during carotid endarterectomy. *J Clin Anesth.* 2005;17:426–430.
29. Salazar D, Sears B, Aghdasi B, Only A, Francois A, Tonino P, Marra G. Cerebral desaturation events during shoulder arthroscopy in the beach chair position: patient risk factors and neurocognitive effects. *J Shoulder Elbow Surg.* 2013 Feb 15 [Epub ahead of print]. doi: 10.1016/j.jse.2012.12.036.
30. Samra SK, Dy EA, Welch K, Dorje P, Zelenock GB, Stanley JC. Evaluation of a cerebral oximeter as a monitor of cerebral ischemia during carotid endarterectomy. *Anesthesiology.* 2000;93:964–970.

31. Skyhar MJ, Altchek DW, Warren RF, Wickiewicz TL, O'Brien SJ. Shoulder arthroscopy with the patient in the beach-chair position. *Arthroscopy.* 1988;4:256–259.
32. Smith JJ, Porth CM, Erickson M. Hemodynamic response to the upright posture. *J Clin Pharmacol.* 1994;34:375–386.
33. Smythe PR, Samra SK. Monitors of cerebral oxygenation. *Anesthesiol Clin North Am.* 2002;20:293–313.
34. Tange K, Kinoshita H, Minonishi T, Hatakeyama N, Matsuda N, Yamazaki M, Hatano Y. Cerebral oxygenation in the beach chair position before and during general anesthesia. *Minerva Anestesiol.* 2010;76:485–490.