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# The effectiveness of cerebral oxygenation monitoring during arthroscopic shoulder surgery in the beach chair position: a randomized blinded study

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**Background:** Beach chair positioning for shoulder surgery is associated with measurable cerebral desaturation events (CDEs) in up to 80% of patients. Near-infrared spectroscopy (NIRS) technology allows real-time measurement of cerebral oxygenation and may minimize the frequency of CDEs. The purpose of this study was to investigate the incidence of CDEs when anesthetists were aware of and blinded to NIRS monitoring and to determine the short-term cognitive effects of surgery in the beach chair position.

**Methods:** NIRS was used to monitor cerebral oxygenation saturation in 41 consecutive patients undergoing arthroscopic shoulder surgery in the beach chair position. Patients were randomized to 2 groups, anesthetists aware of or blinded to NIRS data. The Montreal Cognitive Assessment (MoCA) was used to assess cognitive function preoperatively, immediately postoperatively, and at 2 and 6 weeks postoperatively.

**Results:** Overall, 7 (17.5%) patients experienced a CDE, 5 (25%) in the aware group and 2 (10%) in the blinded group. There was no significant difference in MoCA scores between the aware and blinded groups preoperatively (27.9.1 vs. 28.2; $P = .436$), immediately postoperatively (26.1 vs. 26.2; $P = .778$), 2 weeks postoperatively (28.0 vs. 28.1; $P = .737$), or 6 weeks postoperatively (28.5 vs. 28.4; $P = .779$). There was a correlation of NIRS with systolic blood pressure ($r = 0.448$), diastolic blood pressure ($r = 0.708$), and mean arterial pressure ($r = 0.608$).

**Conclusion:** In our series, the incidence of CDEs was much lower than previously reported and was not lowered by use of NIRS. Patients did not have significant cognitive deficits after arthroscopic surgery in the beach chair position, and there was a correlation between NIRS and intraoperative brachial blood pressure.

**Level of evidence:** Level II; Randomized Controlled Trial; Treatment Study



**Keywords:** Cerebral oxygenation; near-infrared spectroscopy; beach chair position; arthroscopic shoulder surgery; rotator cuff repair; capsular release

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Surgeons and anesthesiologists remain concerned about the increased risk of cerebral hypoperfusion that may occur in the beach chair position.[12] The reported incidence of cerebrovascular events in the beach chair position is <0.1%;

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however, the reported incidence of cerebral desaturation events (CDEs) in the beach chair position ranges from 0% to 80.3% when general anesthesia is used.[15] There is concern that CDEs could lead to ischemic brain or spinal cord injury, vision loss, and postoperative nausea and vomiting.[1,2,4,12,15,16] It remains unclear whether the degree and duration of these CDEs are associated with short- or long-term cognitive deficits.[1,10,19]

Current standard of care for patients undergoing shoulder surgery in the beach chair position does not involve any direct measurement of cerebral tissue oxygenation saturation. Instead, cerebral perfusion is estimated by measuring brachial blood pressure and adjusted by titrating the level of anesthesia and administering intravenous medications to maintain brachial blood pressure within a desired range. Near-infrared spectroscopy (NIRS) is a noninvasive method to measure regional cerebral tissue oxygenation ($rSO_2$). This technology has been studied during various surgical procedures, including orthopedic, transplant, cardiac, vascular, and abdominal surgery.[3,7,12,19,24] In orthopedic surgery, this technology has been studied most extensively in patients undergoing shoulder surgery in the beach chair position.[7,10,13,15] Another method to estimate cerebral tissue perfusion is estimated cerebral mean arterial pressure (eTMAP), measured with an arterial transducer at the temporal artery. Changes in eTMAP do not correlate well with changes in $rSO_2$ measured by NIRS during desaturation events but do correlate with brachial blood pressure.[23,24] Alternatively, real-time intraoperative electroencephalography has been used to detect cerebral ischemia during shoulder surgery in the beach chair position; however, this method requires a neurophysiologist to be present to interpret the electroencephalography recordings.[5] The use of NIRS to measure cerebral tissue oxygenation saturation may help anesthesia teams minimize the frequency and duration of CDEs during shoulder surgery in the beach chair position.

The primary purpose of this study was to determine whether NIRS monitoring decreases the incidence of CDEs during arthroscopic shoulder surgery in the beach chair position. Secondarily, we sought to quantify the effect of CDEs on short-term cognitive function. We hypothesize that patients in the blinded group would have a greater incidence of CDEs and worse postoperative cognitive function compared with the control group.

## Materials and methods

### Study design and patients

Patients between the ages of 18 and 85 years undergoing arthroscopic shoulder surgery in the beach chair position by the senior author (J.A.A.) were screened for eligibility. Preoperative diagnoses included rotator cuff tears, adhesive capsulitis, and glenohumeral arthritis. Procedures performed included rotator cuff repair (with or without acromioplasty and biceps tenodesis), capsular release, débridement, and chondroplasty. All procedures were performed at an outpatient surgery center. The exclusion criteria were minors, diagnosis of chronic neurologic conditions (ie, dementia, Parkinson disease, multiple sclerosis), and preoperative Montreal Cognitive Assessment (MoCA) score <26. Eligible patients were contacted preoperatively by telephone for study inclusion. Informed written consent was obtained before surgery. Demographic data of the patients including age, gender, height, weight, and pre-existing medical conditions were recorded.

### Randomization

All subjects underwent real-time regional cerebral tissue oxygenation saturation monitoring by NIRS during the surgical procedure. Patients were randomized into 1 of 2 groups by a computer random number generator. In the study group, the anesthesia staff was aware of the NIRS monitor recordings during surgery. In the control group, the anesthesia staff was blinded to the NIRS monitor recordings. The research staff, responsible for recording the NIRS monitor data and blood pressure readings, was aware of the randomization assignments.

### Intraoperative monitoring and treatment

A Nonin Medical Inc. (Plymouth, MN, USA) SenSmart Model X-100 Universal Oximetry System was used to measure regional cerebral tissue oxygenation saturation. Two NIRS sensors (SenSmart 8004CB EQUANOX; Nonin Medical Inc.) were applied bilaterally to the frontotemporal area, with the medial margins approximately 0.5 cm from the midline of the forehead and the lower margins approximately 1 cm above the eyebrow (Fig. 1, *A*). Baseline $rSO_2$ values along with heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), and arterial oxygenation saturation ($Spo_2$) were obtained in the preoperative holding area with the patient sitting upright in a hospital bed and breathing room air. These baseline values were obtained before any anesthetic medications were administered. The same measurements were recorded immediately after anesthesia induction in the operating room with the patient in the supine position and immediately after the patient was placed in the beach chair position. Frontal lobe oxygenation was continuously recorded every 4 seconds throughout the case, and SBP, DBP, and MAP were recorded at 5-minute intervals using a brachial automated sphygmomanometer. A CDE was defined as a decrease in $rSO_2$ of 20% or greater from baseline or an absolute $rSO_2$ <55% (Fig. 1, *B*).[12] A hypotensive event was defined as a drop in SBP below 90 mm Hg. The $rSO_2$, SBP, DBP, and MAP were recorded during each desaturation or hypotensive event. Events were categorized as CDEs isolated to the right or left side, bilateral CDEs, hypotensive only, or simultaneous CDE and hypotensive event. Treatment interventions for desaturation and hypotensive events were standardized to 5 mg of ephedrine or 80 µg of phenylephrine. The specific treatment administered was dependent on the patient's hemodynamics and at the discretion of the anesthesia team. Intraoperative hypertension was treated with 2.5 mg or 5 mg of metoprolol. At the end of each case, the surgeon was asked to rate the case difficulty and bleeding problems on a 10-cm visual analog scale.

### Anesthesia protocol

The anesthesia protocol was standardized. All patients received an interscalene brachial plexus blockade using 31 mL of 0.5%


**Figure 1** (**A**) Photograph displaying sensor placement on patient. (**B**) Photograph of monitor during cerebral desaturation event.

ropivacaine with 2 mg of dexamethasone placed by ultrasound guidance by 1 of 3 anesthesiologists experienced in ultrasound-guided regional anesthesia. After the patient was brought to the operating room, 200 mg of propofol was used for anesthesia induction. Maintenance anesthesia was standardized to be sevoflurane 1.5%-2.0% expired.

## Cognitive function assessment protocol

Each subject was administered the MoCA on the day of surgery preoperatively (before receiving any anesthetic medications), postoperatively (before being discharged from the surgery center), and at the 2- and 6-week postoperative clinic visits. This test is routinely used by physicians to screen for mild cognitive impairment.[13] To avoid recall bias, 3 different versions of the assessment were administered to patients (MoCA version 7.1 preoperatively and at 6 weeks postoperatively, MoCA version 7.2 immediately postoperatively, and MoCA version 7.3 at 2 weeks postoperatively). Patients were notified if their MoCA score at their 2-week postoperative clinic visit was below the abnormal threshold of 26 points, requiring further evaluation.

**Table I** Demographic information of patients and randomization results

| Variable | NIRS aware (n = 20) | NIRS blinded (n = 20) | *P* value |
|---|---|---|---|
| Age, y | 55 ± 11 | 55 ± 12 | .946 |
| Gender | | | .333 |
| Male | 14 | 10 | |
| Female | 6 | 10 | |
| BMI, kg/m$^2$ | 26.4 ± 4.1 | 29.9 ± 6.1 | .042 |
| ASA score | 2.0 ± 0.5 | 2.2 ± 0.5 | .316 |
| Preoperative diagnosis | | | .661 |
| Rotator cuff tear | 16 | 18 | |
| Adhesive capsulitis | 2 | 1 | |
| Glenohumeral arthritis | 1 | 1 | |
| AC joint arthritis | 1 | 0 | |

*NIRS*, near-infrared spectroscopy; *BMI*, body mass index; *ASA*, American Society of Anesthesiologists; *AC*, acromioclavicular.
Categorical variables are presented as number. Continuous variables are presented as mean ± standard deviation.

## Statistical analysis

Using a paired *t*-test, a power analysis determined that a sample size of 9 patients per group would yield 80% power to detect a 3-point difference in postoperative MoCA scores between the study groups.[7] Our target enrollment was 20 patients per group. Comparisons between treatment groups were performed using $\chi^2$ or Fisher exact tests for categorical data, the Wilcoxon rank sum test for ordinal data, and the 2-sample *t*-test for continuous data. The relationship between NIRS and SBP, DBP, and MAP was assessed using Pearson correlation coefficients (*r*). For all statistical tests, a $P$ value < .05 was used to determine significance.

# Results

## Overview

From August to October 2016, there were 51 patients screened for study inclusion, 41 of whom chose to participate and were randomized, with 20 being randomized to the study group and 21 randomized to the control group (Fig. 2). One patient was lost to follow-up after the second follow-up visit because that patient was not given the MoCA test. The remaining 40 patients were included in the analysis.

The groups were similar with regard to age ($P$ = .946), gender ($P$ = .333), American Society of Anesthesiologists physical status classification score ($P$ = .316), and preoperative diagnosis ($P$ = .661; Table I). However, the control group did have a greater body mass index (BMI; 29.9 ± 6.1 vs. 26.4 ± 4.1; $P$ = .042).

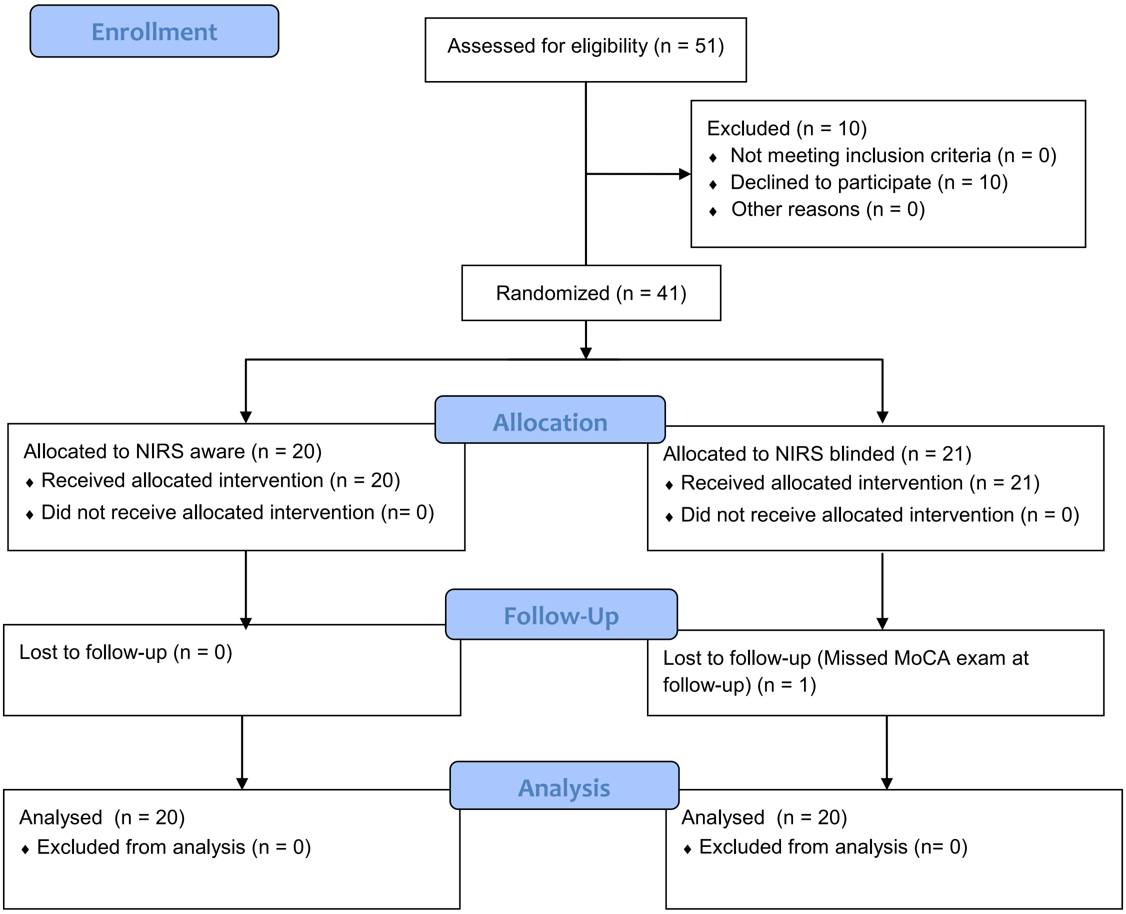


**Figure 2** Consolidated Standards of Reporting Trials (CONSORT) flow chart for screening and enrollment. *NIRS,* near-infrared spectroscopy; *MoCA*, Montreal Cognitive Assessment.

## Vital signs and cerebral tissue oxygenation saturation

There were no significant differences in vital signs (HR, SBP, DBP, MAP, $Spo_2$; $P > .05$) or cerebral tissue oxygenation saturation ($P > .05$) at any time point between groups (Table II).

## Cerebral desaturation events and hypotensive events

Seven (17.5%) patients experienced a CDE, 5 (25%) in the study group and 2 (10%) in the control group ($P = .212$; Table III). There were no significant differences between the study and control groups in the number of right CDEs (0.2 ± 0.5 vs. 0.2 ± 0.5; $P = .766$), left CDEs (0.7 ± 1.4 vs. 0.2 ± 0.7; $P = .272$), bilateral CDEs (0.2 ± 0.5 vs. 0.2 ± 0.5; $P = 1.000$), hypotensive events (2.9 ± 3.4 vs. 2.3 ± 2.1; $P = .493$), or simultaneous CDE and hypotensive events (0.8 ± 1.5 vs. 0.2 ± 0.7; $P = .158$; Table III). No patients required any other interventions, such as a return to the supine position or early extubation. Only 1 patient enrolled in the study required treatment for intraoperative hypertension and received 2 doses of metoprolol. There was no significant difference in surgery duration (78.1 ± 33.4 minutes vs. 75.7 ± 27.2 minutes; $P = .722$) or anesthesia duration (129.8 ± 31.2 minutes vs. 128.0 ± 32.3 minutes; $P = .786$) between the study and control groups. There was no significant difference in surgeon-rated case difficulty between groups (4.0 ± 1.9 cm vs. 3.4 ± 1.9 cm; $P = .201$); however, the study group had significantly higher surgeon-rated bleeding problems than the control group (3.3 ± 1.4 cm vs. 2.1 ± 1.0 cm; $P = .016$).

## Cognitive function assessments

There were no significant differences in MoCA scores between the study and control groups preoperatively (27.9 ± 1.3 vs. 28.2 ± 1.1; $P = .436$), before discharge (26.1 ± 1.4 vs. 26.2 ± 1.9; $P = .778$), at 2 weeks postoperatively (28.0 ± 1.4 vs. 28.1 ± 1.4; $P = .737$), or at 6 weeks postoperatively (28.5 ± 1.1 vs. 28.4 ± 1.1; $P = .779$; Table IV). There were also no significant differences in changes from baseline between groups postoperatively (–1.8 ± 1.7 vs. –2.0 ± 1.4; $P = .762$), at 2 weeks postoperatively (0.1 ± 1.5 vs. –0.1 ± 1.6; $P = .758$), or at 6 weeks postoperatively (0.6 ± 1.5 vs. 0.2 ± 1.0; $P = .321$). No patients required referral to a neurologist for significant cognitive impairment. There were no significant

**Table II** Patients' vital signs and cerebral tissue oxygenation saturation at various time points

| Variable | NIRS aware (mean ± SD) | NIRS blinded (mean ± SD) | *P* value |
|---|---|---|---|
| Baseline vitals | | | |
| HR, beats/min | 69.9 ± 11.6 | 71.9 ± 12.0 | .587 |
| SBP, mm Hg | 140.7 ± 19.2 | 139.2 ± 22.1 | .820 |
| DBP, mm Hg | 80.0 ± 11.7 | 74.9 ± 10.8 | .157 |
| MAP, mm Hg | 100.2 ± 12.3 | 96.3 ± 13.1 | .323 |
| Arterial oxygenation, $Spo_2$ | 98.4 ± 1.3 | 97.7 ± 2.1 | .194 |
| Baseline NIRS | | | |
| Right NIRS, $rSO_2$ | 76.2 ± 3.5 | 74.1 ± 4.3 | .096 |
| Left NIRS, $rSO_2$ | 77.3 ± 6.4 | 74.5 ± 4.6 | .128 |
| Mean NIRS, $rSO_2$ | 76.7 ± 4.6 | 74.3 ± 4.0 | .084 |
| Postinduction vitals | | | |
| HR, beats/min | 77.9 ± 15.1 | 81.6 ± 16.4 | .468 |
| SBP, mmHg | 126.4 ± 30.2 | 123.4 ± 27.5 | .749 |
| DBP, mmHg | 78.2 ± 19.8 | 76.3 ± 17.1 | .748 |
| MAP, mmHg | 94.2 ± 22.2 | 92.0 ± 19.4 | .746 |
| Arterial oxygenation, $Spo_2$ | 98.3 ± 2.0 | 98.5 ± 1.5 | .789 |
| Postinduction NIRS | | | |
| Right NIRS, $rSO_2$ | 83.9 ± 4.7 | 83.5 ± 4.4 | .810 |
| Left NIRS, $rSO_2$ | 83.6 ± 4.4 | 83.9 ± 4.4 | .831 |
| Mean NIRS, $rSO_2$ | 83.7 ± 4.5 | 83.7 ± 3.7 | .468 |
| Initial beach chair vitals | | | |
| HR, beats/min | 87.9 ± 16.4 | 90.3 ± 14.7 | .629 |
| SBP, mmHg | 105.8 ± 32.0 | 111.1 ± 28.9 | .589 |
| DBP, mmHg | 68.8 ± 21.2 | 72.3 ± 23.2 | .616 |
| MAP, mmHg | 81.1 ± 24.4 | 85.2 ± 24.5 | .595 |
| Arterial oxygenation, $Spo_2$ | 98.1 ± 1.4 | 98.2 ± 1.5 | .828 |
| Initial beach chair NIRS | | | |
| Right NIRS, $rSO_2$ | 80.1 ± 6.3 | 82.1 ± 5.7 | .300 |
| Left NIRS, $rSO_2$ | 79.9 ± 6.6 | 82.0 ± 5.7 | .301 |
| Mean NIRS, $rSO_2$ | 80.0 ± 6.3 | 82.0 ± 5.3 | .280 |
| Extubation vitals | | | |
| HR, beats/min | 74.1 ± 14.1 | 77.3 ± 19.0 | .525 |
| SBP, mmHg | 108.8 ± 14.7 | 105.4 ± 14.9 | .321 |
| DBP, mmHg | 66.6 ± 12.3 | 66.1 ± 14.3 | .777 |
| MAP, mmHg | 80.7 ± 12.3 | 79.2 ± 13.5 | .586 |
| Arterial oxygenation, $Spo_2$ | 98.6 ± 0.7 | 98.4 ± 0.6 | .466 |
| Extubation NIRS | | | |
| Right NIRS, $rSO_2$ | 77.9 ± 5.5 | 76.4 ± 6.7 | .388 |
| Left NIRS, $rSO_2$ | 76.1 ± 6.8 | 76.7 ± 5.8 | .710 |
| Mean NIRS, $rSO_2$ | 77.0 ± 5.8 | 76.6 ± 5.8 | .798 |

*NIRS*, near-infrared spectroscopy; *SD*, standard deviation; *HR,* heart rate; *SBP*, systolic blood pressure; *DBP*, diastolic blood pressure; *MAP*, mean arterial pressure; $Spo_2$, arterial oxygenation saturation; $rSO_2$, regional cerebral tissue oxygenation.

differences in MoCA scores at any time point between patients who experienced a CDE and those who did not experience a CDE (Table IV).

## Cerebral tissue oxygenation saturation vs. blood pressure

There was a direct relationship between $rSO_2$ and SBP, DBP, and MAP throughout the case (Fig. 3). There was a positive correlation between all blood pressure readings and cerebral tissue oxygenation saturation (Table V). Diastolic blood pressure had the strongest correlation ($r = 0.708$), and systolic blood pressure had the weakest correlation ($r = 0.448$).

## Discussion

The beach chair position is commonly used, with survey findings suggesting that two-thirds of shoulder operations are performed in the beach chair position.[4] Critics of the beach chair position point to an increased risk of cerebral hypoperfusion. The physiologic responses to general anesthesia that increase this risk for cerebral hypoperfusion in the

**Table III** Cerebral desaturation events (CDEs), hypotensive events, and operative data

| Variable | NIRS aware | NIRS blinded | *P* value |
|---|---|---|---|
| Patients experiencing CDE | 5 (25%) | 2 (10%) | .212 |
| | (mean ± SD) | (mean ± SD) | |
| CDE and hypotensive events, No. | | | |
| Right CDE | 0.2 ± 0.5 | 0.2 ± 0.5 | .766 |
| Left CDE | 0.7 ± 1.4 | 0.2 ± 0.7 | .272 |
| Bilateral CDEs | 0.2 ± 0.5 | 0.2 ± 0.5 | 1.000 |
| Hypotensive event | 2.9 ± 3.4 | 2.3 ± 2.1 | .493 |
| CDE and hypotensive | 0.8 ± 1.5 | 0.2 ± 0.7 | .158 |
| CDE without treatment | | 0.1 ± 0.2 | |
| Operative time | | | |
| Surgery duration, min | 78.1 ± 33.4 | 75.7 ± 27.2 | .722 |
| Anesthesia duration, min | 129.8 ± 31.2 | 128.0 ± 32.3 | .786 |
| Surgeon ratings | | | |
| Case difficulty, VAS | 4.0 ± 1.9 | 3.4 ± 1.9 | .201 |
| Bleeding problems, VAS | 3.3 ± 1.4 | 2.1 ± 1.0 | .016 |

*NIRS*, near-infrared spectroscopy; *SD*, standard deviation; *VAS*, visual analog scale (cm).

**Table IV** Cognitive function assessments using the Montreal Cognitive Assessment (MoCA)

| Time point | NIRS aware (mean ± SD) | NIRS blinded (mean ± SD) | *P* value |
|---|---|---|---|
| Preoperative | 27.9 ± 1.3 | 28.2 ± 1.1 | .436 |
| Before discharge | 26.1 ± 1.4 | 26.2 ± 1.9 | .778 |
| Change from baseline | −1.8 ± 1.7 | −2.0 ± 1.4 | .762 |
| 2 weeks postoperative | 28.0 ± 1.4 | 28.1 ± 1.4 | .737 |
| Change from baseline | 0.1 ± 1.5 | −0.1 ± 1.6 | .758 |
| 6 weeks postoperative | 28.5 ± 1.1 | 28.4 ± 1.1 | .779 |
| Change from baseline | 0.6 ± 1.5 | 0.2 ± 1.0 | .321 |
| | CDE | No CDE | |
| Preoperative | 28.1 ± 0.7 | 28.0 ± 1.3 | .733 |
| Before discharge | 26.3 ± 1.6 | 26.1 ± 1.7 | .781 |
| Change from baseline | −1.9 ± 1.8 | −1.9 ± 1.5 | .974 |
| 2 weeks postoperative | 28.0 ± 0.8 | 28.0 ± 1.5 | .959 |
| Change from baseline | −0.1 ± 0.7 | −0.1 ± 1.6 | .751 |
| 6 weeks postoperative | 28.7 ± 1.0 | 28.3 ± 1.1 | .414 |
| Change from baseline | 0.6 ± 1.0 | 0.4 ± 1.3 | .697 |

*NIRS*, near-infrared spectroscopy; *SD*, standard deviation; *CDE*, cerebral desaturation event.

**Table V** Correlation of blood pressure and cerebral tissue oxygenation saturation

| Blood pressure, mm Hg | Correlation coefficient, *r* |
|---|---|
| SBP | 0.448 |
| DBP | 0.708 |
| MAP | 0.608 |

*SBP*, systolic blood pressure; *DBP*, diastolic blood pressure; *MAP*, mean arterial pressure.

beach chair position include systemic hypotension with decreased baroreceptor response, gravitational positioning of the head above the heart, and decreased middle cerebral artery blood flow velocity.[6,20] Various techniques and instruments have been studied to investigate CDEs with the hope of increasing the ability to detect these events, decreasing their incidence, and improving patient care.[3,5,8,12,19,23,24]

To our knowledge, this is the first study that investigates the incidence of CDEs during shoulder surgery in the beach chair position using NIRS in a random, blinded fashion. We reject our hypothesis, as there were no significant differences between the study and control groups in the number of CDEs or changes in cognitive function. Subject randomization was effective, with the only significant difference between the groups being that patients in the blinded group had a higher BMI. Interestingly, Salazar et al reported that increased BMI was significantly associated with an increased risk of an intraoperative CDE.[19] However, we did not observe the same effect in our study. The study group had significantly higher surgeon-rated bleeding problems (3.3 ± 1.4 cm vs. 2.1 ± 1.0 cm; $P = .016$); however, we do not have a logical reason for this result. As we expected, there was a positive correlation observed between cerebral tissue oxygenation saturation and brachial blood pressure.

Determining the incidence of CDEs in patients undergoing surgery in the beach chair position is difficult. The incidence of patients experiencing a CDE in our study was 17%, with no significant difference between the study and control groups. Pant et al performed a systematic review of studies using NIRS in the beach chair position and found the overall incidence of CDEs measured by NIRS to be 30%.[15] Salazar et al performed a similar review and found the incidence of CDEs to be 39%.[17] No patients in any of the studies included in these reviews had documented neurologic complications or suffered a cerebrovascular event. The incidence

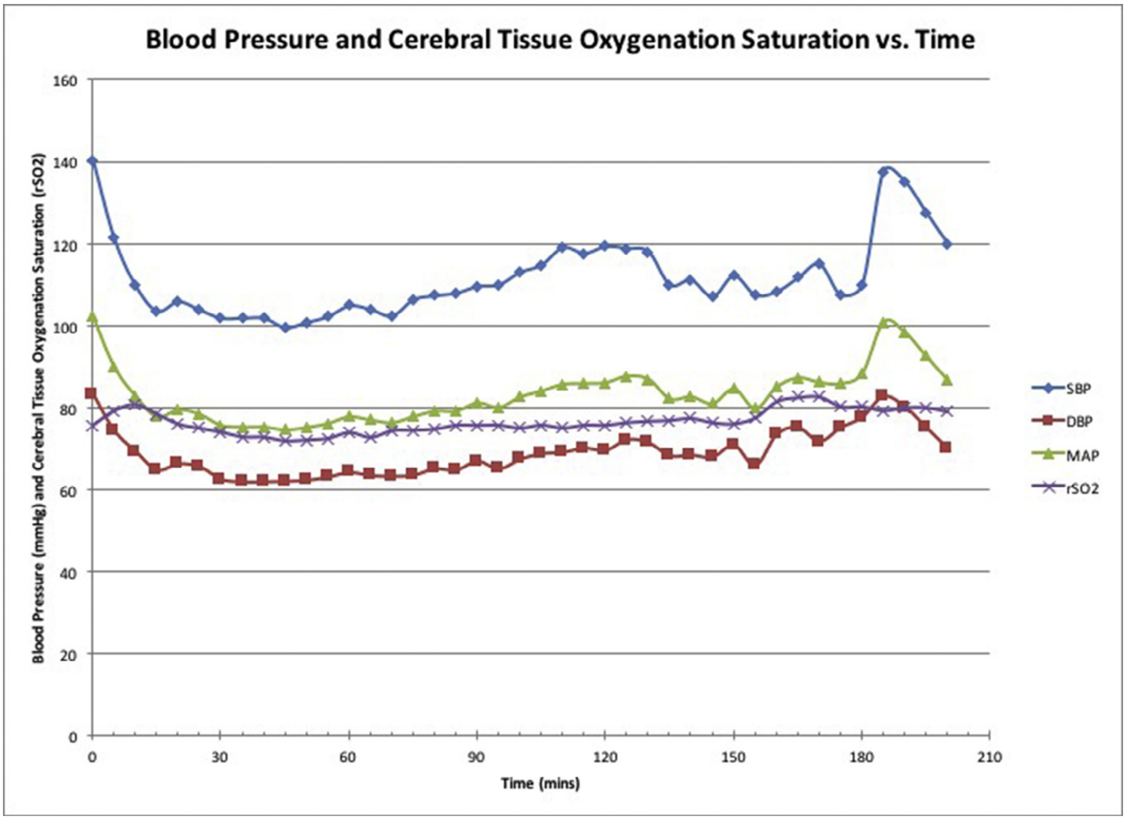


**Figure 3** Plot of blood pressure (systolic blood pressure [*SBP*], diastolic blood pressure [*DBP*], and mean arterial pressure [*MAP*]) and cerebral tissue oxygenation saturation ($rSO_2$) vs. time (minutes).

of CDEs may have been lower in our study because the patients had few medical comorbidities and were candidates for surgery at an outpatient surgery center. Practicing proper head positioning techniques and intraoperative evaluations may decrease the incidence of CDEs.[11,18] Identifying patient factors that increase the risk of intraoperative CDEs is important but may require a large observational study or meta-analysis. As mentioned previously, Salazar et al reported that increased BMI was significantly associated with CDEs, but they did not find any significant association with hypertension, diabetes, or obstructive sleep apnea.[19] There may be too many patient-specific factors to reliably identify at-risk patients, including intraluminal atherosclerosis, carotid stenosis, compression of carotid and vertebral vessels by osteophytes, and variations in vascular anatomy.[9,21,22]

Various different screening tools have been used to investigate the cognitive effects of shoulder surgery in the beach chair position; however, no studies have shown any significant cognitive decline.[1,5,10,19] We chose to use the MoCA to assess cognitive function in our study because a study by Kara et al showed that patients undergoing coronary artery bypass grafting without NIRS monitoring had significantly decreased postoperative MoCA scores compared with patients receiving NIRS monitoring.[7] We did not observe any significant differences in postoperative cognitive function between the groups in our study. One reason for this may be that there are many more hemodynamic changes that occur during cardiac surgery compared with shoulder surgery. Also, the overall incidence of cognitive dysfunction after cardiac surgery is much higher and may occur in 50%-70% of patients 1 week postoperatively.[14] In addition, the patients included in our study had minimal medical comorbidities compared with cardiac surgery patients and were candidates for surgery at an outpatient surgery center.

The results of our continuous monitoring showed that there was a correlation between cerebral tissue oxygenation saturation and SBP, DBP, and MAP. Triplet et al showed there was a correlation between eTMAP and brachial blood pressure at various beach chair position angles.[23] In another study, Triplet et al found that there was no correlation of $rSO_2$ measured by NIRS during desaturation events with eTMAP or brachial blood pressure.[24] The results of these studies, in addition to our study, show that there may not be one perfect method to detect CDEs.

There are several strengths to our study. To our knowledge, the blinded nature of this study allowed our control group to closely replicate the current standard of care while instituting the additional monitoring in the study group. The strength of this study would have been improved if there was an additional group that received only NIRS monitoring; however, using only localized cerebral monitoring may put the patient at risk for other intraoperative complications. In addition, we assessed cognitive function up to 6 weeks postoperatively, which is longer than in any other study previously published. This allowed us to verify that patients did not have any additional cognitive decline outside of the immediate postoperative period. We also used 3 different versions of the MoCA questionnaire to decrease the risk of the patient's recall bias.

Our study certainly also has weaknesses. The patients in this study were all undergoing arthroscopic shoulder surgery at an outpatient surgical center and had relatively few medical comorbidities. Our results may have been different if the patients were undergoing open shoulder surgery or had more significant medical comorbidities. Our study was powered to detect a difference in postoperative MoCA scores between groups. This study would have been stronger if it was powered according to the presumed incidence of CDEs during surgery in the beach chair position. If the true incidence of patients experiencing a CDE is approximately 30% and use of NIRS was able to reduce this incidence to 15%, we would have needed to enroll 37 patients in each group to be adequately powered.

## Conclusion

Our study found the overall incidence of CDEs in the beach chair position to be 17%, with no difference between study and control groups. Patients did not have significant cognitive impairments after arthroscopic shoulder surgery in the beach chair position. There was a correlation between $rSO_2$ and SBP, DBP, and MAP. Therefore, the use of intraoperative brachial blood pressure during arthroscopic shoulder surgery in the beach chair position is a good surrogate to use for minimizing CDEs. Costlier and sophisticated methods for measuring CDE do not appear to be needed.

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