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Shoulder Surgery in the Beach Chair Position Is Associated with Diminished Cerebral Autoregulation but No Differences in Postoperative Cognition or Brain Injury Biomarker Levels Compared with Supine Positioning: The Anesthesia Patient Safety Foundation Beach Chair Study

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BACKGROUND: Although controversial, failing to consider the gravitational effects of head elevation on cerebral perfusion is speculated to increase susceptibility to rare, but devastating, neurologic complications after shoulder surgery in the beach chair position (BCP). We hypothesized that patients in the BCP have diminished cerebral blood flow autoregulation than those who undergo surgery in the lateral decubitus position (LDP). A secondary aim was to examine whether there is a relationship between patient positioning during surgery and postoperative cognition or serum brain injury biomarker levels.

METHODS: Patients undergoing shoulder surgery in the BCP (n = 109) or LDP (n = 109) had mean arterial blood pressure (MAP) and regional cerebral oxygen saturation ($rSco_2$) monitored with near-infrared spectroscopy. A continuous, moving Pearson correlation coefficient was calculated between MAP and $rSco_2$, generating the variable cerebral oximetry index (COx). When MAP is in the autoregulated range, COx approaches zero because there is no correlation between cerebral blood flow and arterial blood pressure. In contrast, when MAP is below the limit of autoregulation, COx is higher because there is a direct relationship between lower arterial blood pressure and lower cerebral blood flow. Thus, diminished autoregulation would be manifest as higher COx. Psychometric testing was performed before surgery and then 7 to 10 days and 4 to 6 weeks after surgery. A composite cognitive outcome was determined as the Z-score. Serum S100β, neuron-specific enolase, and glial fibrillary acidic protein were measured at baseline, after surgery, and on postoperative day 1.

RESULTS: After adjusting for age and history of hypertension, COx (P = 0.035) was higher and $rSco_2$ lower (P < 0.0001) in the BCP group than in the LDP group. After adjusting for baseline composite cognitive outcome, there was no difference in Z-score 7 to 10 days (P = 0.530) or 4 to 6 weeks (P = 0.202) after surgery between the BCP and the LDP groups. There was no difference in serum biomarker levels between the 2 position groups

CONCLUSIONS: Compared with patients in the LDP, patients undergoing shoulder surgery in the BCP are more likely to have higher COx indicating diminished cerebral autoregulation and lower $rSco_2$. There were no differences in the composite cognitive outcome between the BCP and the LDP groups after surgery after accounting for baseline Z-score. (Anesth Analg 2015;120:176–85)

Approximately two-thirds of the >400,000 shoulder surgery procedures performed annually in the United States are performed with the patient's head elevated above the horizontal, a position know as the "beach chair" position (BCP).[1,2] This position affords better intra-articular visualization and less risk of neurovascular trauma than when patients are placed in the lateral decubitus position (LDP).[3] The BCP, however, has been reported to be associated with rare but devastating neurologic complications, including stroke, spinal cord ischemia, and transient visual loss.[1,4–8] The mechanism of these

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complications is unknown. Arterial blood pressure is measured from the brachial artery or even the popliteal artery (when the blood pressure cuff is placed on the lower leg) during shoulder surgery. There is currently intense debate in the anesthesiology community regarding whether cerebral hypotension from failing to consider the gravitational effects of head elevation on cerebral perfusion might increase susceptibility of patients to neurologic complications of surgery in the BCP.[9–13]

Cerebral blood flow (CBF) is normally kept constant over a range of arterial blood pressures by autoregulatory mechanisms that ensure a steady supply of oxygenated blood to the brain. When the head is elevated during shoulder surgery, the gravitational effects on cerebral perfusion should be tolerated if blood pressure remains within the autoregulation range. Cerebral autoregulation can be monitored in real time by processing regional cerebral oxygen saturation ($rSco_2$) signals measured transcutaneously with near-infrared spectroscopy (NIRS).[14–16] In this clinically applicable method, computer software calculates the continuous correlation between low-frequency (20-second to 3-minute) changes in $rSco_2$ and arterial blood pressure to generate the variable cerebral oximetry index (COx). When blood pressure is in the autoregulated range, COx approaches 0 or is negative because there is no correlation between CBF and arterial blood pressure. In contrast, when blood pressure is below the limit of autoregulation, COx is higher (i.e., approaches 1) because there is a direct relationship between lower blood pressure and lower CBF (i.e., flow is pressure passive). Thus, diminished autoregulation would be manifest as higher COx. We have found a wide range of blood pressures at the lower limit of autoregulation (LLA; 40–90 mm Hg) in patients undergoing cardiopulmonary bypass and a relationship between altered autoregulation and risk for stroke and acute kidney injury.[15,17–19] Thus, when usual empirical definitions of tolerance to low pressure are used during surgery, CBF may become pressure passive in some patients who have a higher autoregulation cutoff resulting in a higher COx than those whose blood pressure remains in the autoregulated range. In this study, we hypothesized that patients undergoing shoulder surgery in the BCP are more likely to have diminished CBF autoregulation manifest as higher COx than those having surgery in the LDP. A secondary aim of this study was to determine whether there is a relationship between diminished autoregulation and subtle neurologic changes manifest as postoperative cognitive dysfunction and/or increases in serum biomarkers for brain injury.

METHODS

All study procedures were approved by the IRB of The Johns Hopkins Medical Institutions (jhmirb@jhmi.edu; protocol NA_00036673) and were performed after receiving written informed consent from each patient. Patients were eligible for this study if they were undergoing shoulder surgery by a single surgeon and they had no known allergy to adhesive tape.

Perioperative Care

Preoperative medical history and medications were recorded. Baseline arterial blood pressure was defined as the average of 3 resting blood pressures obtained during the preoperative clinic visit, in the preoperative preparation area on the day of surgery, and before anesthesia induction. The patients received routine institutional perioperative care that included combined regional and general anesthesia. An interscalene brachial plexus regional anesthesia block was performed with ultrasound guidance. Ropivacaine 0.2% was administered in fractionated doses via an indwelling brachial plexus catheter. General anesthesia was then induced with propofol and fentanyl; rocuronium was used to facilitate tracheal intubation. Anesthesia was maintained with a volatile anesthetic and incremental doses of fentanyl. The patient's lungs were mechanically ventilated at a rate and tidal volume that maintained normocapnia as measured with end-tidal capnography. Depth of hypnosis was monitored with a Bispectral Index (BIS™, Aspect Medical/Covidien, Mansfield, MA) beginning before anesthesia induction. Anesthesia was titrated to a BIS target of 40 to 55.

After endotracheal intubation, the patient was positioned either in an approximate 30° to 40° head-up position (BCP) or in the LDP without head elevation. Patient position was not randomized but based on the usual clinical practice. Arterial blood pressure was measured for clinical purposes with a cuff via an oscillometric method from either the arm or the leg. No algorithm was used for managing blood pressure that was based on usual clinical practice. The distance between the horizontal plane estimated to be level with the position of the heart and the tragus of the ear was measured for each patient. Neostigmine and glycopyrrolate were administered at the conclusion of surgery to reverse residual muscle relaxants, and the trachea was extubated. For 2 days after surgery, patients received ropivacaine 0.2% for analgesia at 6 to 8 mL/h with a demand of 3 to 4 mL as needed every 20 minutes via the interscalene catheter. Oxycodone 5–10 mg was administered every 3 to 4 hours as needed for breakthrough pain and for analgesia after the interscalene catheter was removed.

Autoregulation Measurement

Two monitoring sensors were applied to each patient's forehead and connected to an Invos 5100 NIRS device (Somentics/Covidien, Inc., Mansfield, MA) for monitoring of $rSco_2$. Arterial blood pressure was monitored with a continuous noninvasive finger plethysmographic monitor (Finometer Pro®, Finapres Medical Systems, Amsterdam, The Netherlands). The finger plethymography measurements are automatically recalibrated with intermittent brachial cuff blood pressures taken as part of the same system. This blood pressure monitor recorded the arterial pressure waveform at a 40 Hz refresh rate. Noninvasive CBF autoregulation monitoring with the Finapres device has been validated previously in healthy volunteers.[20–22]

Arterial pressure was determined from the Finapres device, and NIRS digital signals were sampled with ICM+ software (Cambridge University; Cambridge, UK) at 60 Hz with a laptop computer.[23] The blood pressure and NIRS signals were time-integrated as non-overlapping 10-second mean values, which is equivalent to applying a moving average filter with a 10-second time window and resampling at 0.1 Hz. This operation eliminates high-frequency noise from the respiratory and pulse frequencies. Resampling at 10-second intervals allows detection of oscillations and transients that occur below 0.05 Hz. A continuous, moving Pearson correlation coefficient was then calculated between the mean arterial blood pressure (MAP) and NIRS data, rendering the variable COx. Consecutive, paired, 10-second averaged values from 300-second measurement periods were used for each calculation, incorporating 30 data points for each index. This methodology has been validated previously.[14] The LLA was defined as that MAP where COx increased from <0.3 to ≥0.3 as previously described.[14,18,19]

Neurologic Evaluation

Patients were evaluated at screening, on postoperative day 7 to 10, and 1 month after surgery with the National Institutes of Health Stroke Scale and with a battery of psychometric tests.[24] The battery consisted of the Rey Auditory Verbal Learning Test, a test of verbal learning and memory; Brief Visuospatial Memory Test-Revised, an assessment of visual memory; Controlled Oral Word Association Test, a test of executive functions; Symbol Digits Modalities Test, a test of psychomotor speed and attention control; Trail Making B, which tests visuomotor speed, attention, and executive functions; and the Grooved Pegboard Test, which measures fine motor dexterity and speed. After surgery, the Trail Making and Grooved Pegboard Test were performed only on the non-operative extremity.

Cognitive scores were combined into a composite cognitive outcome based on Z-score. For this, timed test scores were inverted so that higher values represent better performance for all tests. Next, Z-score for each test was calculated by subtracting the mean and dividing by the SD of the test score among patients who underwent surgery in the LDP (i.e., control group). The mean scores across all tests were calculated and renormalized by using the mean and SD of the LDP group.

Serum Biomarker Measurement

We collected venous blood into EDTA tubes before anesthesia induction, after surgery in the postanesthesia care unit, and on postoperative day 1 (when the patient remained in the hospital) to measure plasma levels of 3 biomarkers: neuron-specific enolase (NSE; R&D Systems, Minneapolis, MN), S100β (Sigma-Aldrich, St. Louis, MO, and Genway, San Diego, CA), and glial fibrillary acidic protein (GFAP; Covance, Vienna, VA, and Dako, Carpenteria, CA). Blood samples were processed within 2 hours of collection by centrifugation at 1500*g* for 8 minutes; serum was separated into aliquots and stored at −70°C in cryotubes. Assays were performed in duplicate serum samples with the electrochemiluminescent sandwich immunoassay platform (MesoScale Discovery, Gaithersburg, MD) and were analyzed on a Sector Imager 2400 (MesoScale Discovery) according to the manufacturer's protocol.[25,26] The lower limit of detection for the GFAP assay is 0.011 ng/mL, and the interassay variance is 2.4%.

Statistical Plan and Power Analysis

Our primary aim was to compare average COx as an indicator of diminished autoregulation obtained during shoulder surgery for patients placed in the BCP with that for patients placed in the LDP. Values of COx obtained throughout surgery were averaged for each patient. The sample size calculation was based on our experiences with patients undergoing cardiac surgery, for whom we found a COx of 0.15 ± 0.18 (mean ± SD) during the entire surgical procedure. Thus, we estimated that a sample size of 108 patients in each group would have at least 96% power to detect a difference of 0.1 in the mean COx between BCP and LDP. To evaluate the limits of autoregulation, we placed COx data from the entire surgical period into 5-mm Hg bins. The LLA was defined as the lowest blood pressure at which COx increased from <0.3 to ≥0.3, as previously described.[14,15,17–19,27] We obtained an estimate of cerebral blood pressure by subtracting 1.0 mm Hg for each 1.35 cm of head elevation (measured at the tragus) above an imaginary line drawn horizontally through the point where clinical blood pressure was measured (i.e., leg or arm).

We assessed the relationship between surgical position and continuous outcomes (and 95% confidence interval [CI]) at each time point (baseline, 7–10 days, and 4–6 weeks postoperatively) using *t*-tests and a generalized linear model after adjusting for confounding factors, such as age and baseline cognitive score. Analysis of residuals was used to assess the validity of model assumptions. For each time point, logistic regression was used to estimate the effect of head position on the logit of probability of having a low Z-score, defined as a score of −1 or lower, which is 1 SD below the mean for the LDP group at baseline.

We used generalized linear mixed effects models with random intercept for patients to model time-related change of cognitive outcomes and biomarkers. The random intercept for each patient denotes influence of unobserved individual-level factors that are common to all responses for that person and represent individual propensity for certain level cognitive functioning for each patient.[28] The models included fixed effects for surgery group, age, and time after surgery (modeled as 2 indicator variables: for 7–10 days after surgery versus baseline and 4–6 weeks after surgery versus baseline).

To assess the effect of missing data on these relationships, we imputed missing cognitive data by using a random draw from the lowest range (between worst performance and lower 5th percentile) of each domain assuming that patients with missing data had the worst outcomes. We compared the models with and without imputation to assess robustness of the findings.

RESULTS

Two hundred forty-seven patients were enrolled from June 29, 2010, until December 19, 2012. Twenty-nine patients withdrew because they did not wish to comply with postoperative psychometric testing. Patient characteristics based on surgical position are listed in Table 1. Patients undergoing surgery in the BCP were older and were more likely to have hypertension than were patients in the LDP group. Surgical procedures differed between the groups. The BCP and LDP groups did not differ in regard to the percentage of

Table 1. Medical and Surgical Characteristics of Patients Undergoing Shoulder Surgery in the Lateral Decubitus or Beach Chair Position

Characteristic	Lateral decubitus (n = 109)	Beach chair (n = 109)	P value
Age (y)	50 ± 15	66 ± 12	<0.0001
Male/Female	57%/43%	52%/48%	0.497
Height (cm)	171 ± 11	170 ± 11	0.386
Weight (kg)	85 ± 22	88 ± 27	0.417
Body mass index (kg/m^2)	29 ± 6	30 ± 8	0.118
Preoperative systolic blood pressure (mm Hg)[a]	137 ± 17	141 ± 15	0.038
Preoperative diastolic blood pressure (mm Hg)[a]	74 ± 8	74 ± 8	0.765
Diabetes mellitus	7.3%	11.0%	0.482
Hypertension	33%	61%	<0.0001
Coronary artery disease	1.8%	4.6%	0.445
Stroke	0	0	
Congestive heart failure	0.9%	1.8%	1.000
Transient ischemic attack	0.9%	3.7%	0.369
Peripheral vascular disease	0.9%	2.8%	0.622
Chronic obstructive lung disease	0.9%	5.5%	0.119
Current tobacco use	10%	13%	0.671
Obstructive sleep apnea	2.8%	6.4%	0.332
Family history of Alzheimer disease	0	0	
Procedure			
Repair torn rotator cuff	57.8%	4.6%	<0.0001
Total shoulder arthroplasty	1.8%	28.4%	<0.0001
Reverse shoulder arthroplasty	2.8%	63.3%	<0.0001
Biceps tenodesis	2.8%	0	<0.0001
Capsular shift	14.7%	0	<0.0001
Superior labrum anterior-posterior repair	4.6%	0	<0.0001
Distal clavicle excision	7.3%	0	<0.0001
Diagnostic arthroscopy	3.7%	0	<0.0001
Other	4.6%	3.7%	<0.0001

Data are presented as mean ± SD or percent.

[a]Preoperative blood pressure is the average of the blood pressure values obtained during the preoperative clinic visit, in the anesthesia preparation room, and before anesthesia induction in the operating room.

Table 2. Percentage of Patients and Dose (Mean ± SD) of Vasoactive Medication Used for Patients Undergoing Surgery in the Lateral Decubitus or Beach Chair Position

	Lateral decubitus (n = 109)		Beach chair (n = 109)			
Medication	Received medication	Dose	Received medication	Dose	P value frequency	P value dose
Phenylephrine (μg)	36.7%	182 ± 364	58.7%	341 ± 525	0.001[a]	0.010[b]
Esmolol (mg)	11.9%	4.4 ± 18	12.8%	4 ± 13	0.837[a]	0.877[b]
Metoprolol (mg)	1.8%	0.1 ± 0.4	8.3%	0.3 ± 1.2	0.059[c]	0.062[b]
Ephedrine (mg)	32.1%	5 ± 9	56.9%	16 ± 24	<0.0001[a]	<0.0001[b]

[a]χ^2 test.

[b]Independent group t-test.

[c]Fisher exact test.

patients receiving anesthesia with isoflurane or sevoflurane (BCP, 70% and 11% versus LDP, 79% and 11%; P = 0.121 and P = 1.0, respectively). Some patients in each group received desflurane toward the end of surgery (BCP, 29%; LDP, 38%; P = 0.196). The height of the head (measured at the tragus) above the horizontal for patients in the BCP was 46 ± 14 cm, and estimated average blood pressure during surgery at the head was 63.2 ± 14.3 mm Hg. Of note, blood pressure was measured clinically in the arm in 11 patients and in the leg in the remainder. Patients in the BCP group were more likely to receive phenylephrine, ephedrine, and/or metoprolol than were patients in the LDP group, and the cumulative doses were higher in the BCP group (Table 2).

Blood pressure, BIS, cerebral autoregulation, and $rSco_2$ results are listed in Table 3. Average blood pressure obtained while monitoring during anesthesia and surgery was higher (P = 0.003), but estimated blood pressure at the tragus was lower (P < 0.0001) in the BCP group compared with the LDP group. Average $rSco_2$ was lower in the BCP group than in the LDP group (P < 0.0001). Patients undergoing surgery in the BCP had higher average COx (P = 0.035) after adjustment for age and hypertension status at baseline, indicating diminished autoregulation compared with patients undergoing surgery in the LDP. The average of preoperative blood pressures obtained in the clinic before surgery, in the preoperative preparation room, and before induction of anesthesia was not predictive of the lower LLA (Fig. 1, A–C).

No patient had a postoperative stroke. The psychometric testing results are listed in Table 4. Baseline cognitive tests showed differences between patients in the BCP and the

Table 3. Comparison of Mean Arterial Blood Pressure (MAP), Bispectral Index (BIS), and Cerebral Oximetry Index (Cox Autoregulation Data for Patients Who Underwent Surgery in the Lateral Decubitus and Beach Chair Position)

Characteristic	Lateral decubitus (n = 109)	Beach chair (n = 109)	β coefficient (95% confidence interval)	P value[a]
MAP (mm Hg)	73 ± 14	79 ± 13	6.6 (2.2, 11.0)	0.003
Estimated average MAP (mm Hg) at tragus	76 ± 13	50 ± 16	−28.0 (−32.7, −23.3)	<0.0001
BIS	41 ± 11	46 ± 10	1.6 (−1.3, 4.5)	0.276
Mean left $rSco_2$ (%)	75 ± 13	64 ± 14	−7.7 (−11.8, −3.5)	<0.0001
Mean right $rSco_2$ (%)	74 ± 14	63 ± 14	−8.3 (−12.4, −4.2)	<0.0001
Mean Cox (left and right)	0.09 ± 0.12	0.15 ± 0.13	0.04 (0.00, 0.08)	0.035
Patients achieving LLA	65%	75%	−0.3 (−1.0, 0.4)	0.367
MAP at LLA (mm Hg)[b]	65 (55–75)	70 (55–80)	1.3 (−3.9, 6.5)	0. 620

Data are given as mean ± SD unless otherwise indicated. The P values were adjusted for age and hypertension status at baseline.
$rSco_2$ = regional cerebral O_2 saturation; LLA = lower limit of autoregulation.
[a]Wald test from the generalized linear regression model with robust variance. The model is fitted using fractional polynomial approach in Stata (Reference: Royston and Altman.[29]
[b]Median (25th–75th percentile).

LDP groups. After adjustment for age, patients in the BCP group had poorer cognitive function before surgery than did patients in the LDP group. Patients from the LDP group showed improvement from baseline on some of the tests 7 to 10 days and 4 to 6 weeks after surgery. Patients whose surgery was in the BCP had improvements from baseline on 1 test 7–10 days after surgery and on 2 tests 4–6 weeks after surgery. The composite cognitive outcome results for each group are shown in Figure 2. The lower scores observed before surgery in the BCP group compared with the LDP group persisted at each postoperative testing session. A linear mixed effect model was used to estimate the difference between the BCP and the LDP groups after adjusting for age and the specific postoperative visit. This analysis showed that the composite cognitive Z-score was on average lower by 0.50 for an individual in the BCP group compared to that for an individual of the same age at any particular visit who had surgery in the LDP (95% CI, 0.21–0.78 lower; P = 0.001) as shown in Table 5. There was no difference in the composite cognitive Z-score outcome between baseline and 7 to 10 days after surgery, but it was lower by 0.14 at 4 to 6 weeks after surgery compared to baseline after adjusting for position and age (95% CI, 0.04–0.24 lower; P = 0.007). There was no significant interaction between postoperative visit and surgical position. That is, individuals in both surgical groups had similar changes in Z-score after accounting for unobserved individual characteristics. Importantly, after adjusting for baseline composite cognitive outcome, there was no difference in Z-score at 7 to 10 days (P = 0.530) or 4 to 6 weeks (P = 0.202) between the BCP and the LDP groups. We repeated similar analyses after imputation of results to account for missing cognitive data. These analyses again showed that patients who underwent surgery in the BCP had lower composite cognitive outcomes 4 to 6 weeks after surgery than did patients who underwent surgery in the LDP.

We found no differences in serum concentrations of GFAP, S100β, or NSE between surgical groups at the specified time points (Table 6). The patient biomarker data were further classified based on whether the individual had a value higher than the upper bound of 95% CI for the true value of the measurement obtained at baseline. The number of patients who had a high biomarker level in the postanesthesia care unit or on the first postoperative day did not differ between the BCP and the LDP groups.

DISCUSSION

Our results show that patients undergoing shoulder surgery in the BCP are more likely to have diminished autoregulation (or more pressure-passive CBF) as demonstrated by a higher COx as well as lower $rSco_2$ than are patients undergoing surgery in the LDP. We observed differences in the composite cognitive outcome between patients in the BCP and the LDP groups before surgery after adjusting by patient age. After surgery these differences persisted at both testing sessions. After adjusting for baseline Z-score, however, there was no difference in the composite cognitive outcome between the BCP and the LDP groups. Finally, there were no differences in serum concentration of brain injury biomarkers between the 2 surgical groups.

The exact frequency of neurologic complications among patients who undergo shoulder surgery in the BCP is not known, but a survey of the American Shoulder and Elbow Surgeons (32% responders) indicated that major stroke occurs in 0.0004% of such patients.[1] Most of the available data on these complications are derived from case reports or case series. The latter have included reports of stroke from paradoxical air embolism in the presence of a patent foramen ovale.[30,31] In a retrospective analysis from a single institution, there were no strokes in 5177 patients undergoing either orthopedic or neurological surgery in the BCP.[32] Researchers have speculated that hemodynamic changes associated with head elevation and anesthesia may result in inadvertent cerebral hypotension when anesthesiologists fail to consider the gravitational effects of head elevation

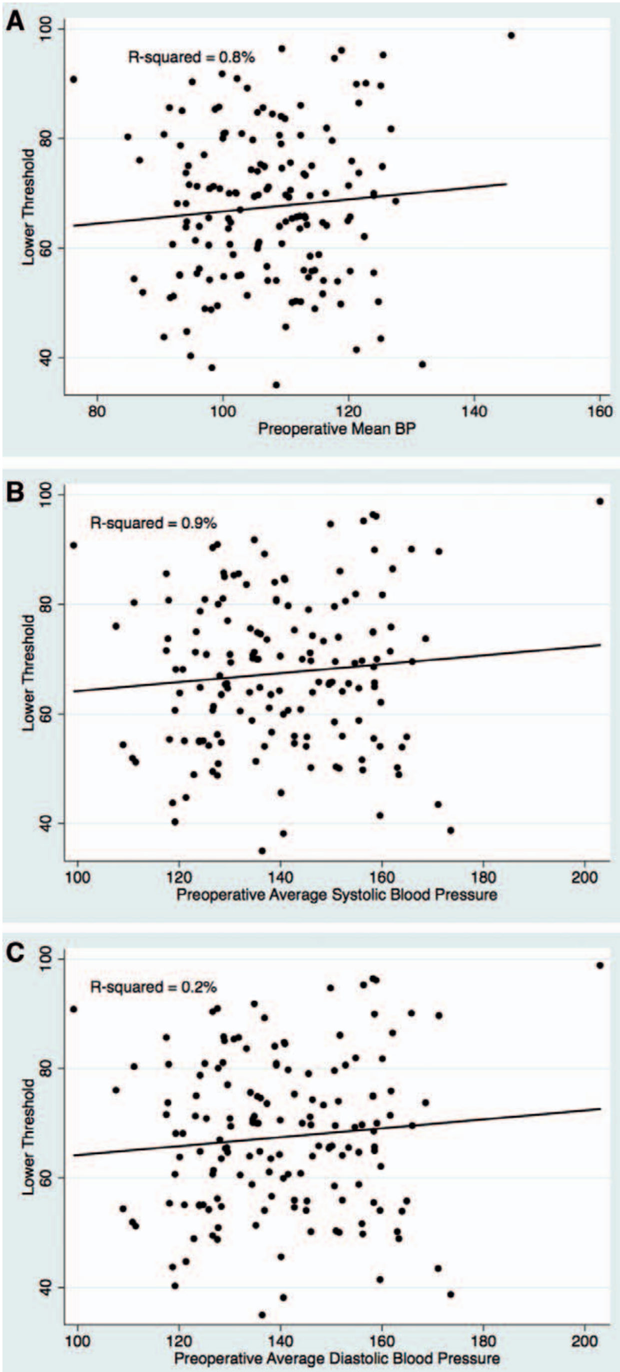

Figure 1. Relationship between preoperative systolic, diastolic, and mean arterial blood pressure (BP) and the lower limit of autoregulation. Preoperative BP was the average of that measured during the clinic visit before surgery, in the anesthesia patient preparation area, and before anesthesia induction. All BPs before surgery were measured in the arm. The measurements were made in the sitting position in the clinic but in the recumbent position in the preoperative preparation area, and supine in the operating room. These data show that only 0.2% to 0.9% of the variability in the lower limit of autoregulation can be explained by its linear relationship with preoperative BP. After dichotomizing the lower threshold as <60 and >60, mean arterial BP as a predictor is associated with area under the receiver operating characteristic curve = 0.53 (95% confidence interval, 0.44–0.63), indicating no predictive ability of mean preoperative arterial BP.

on cerebral perfusion.[12,13] That is, when blood flows vertically, blood pressure decreases proportionally to the weight of the column of blood.[8,10,14] Subtracting 1.35 mm Hg from blood pressure measured in the arm or leg for each 1 cm of head elevation height has been recommended as a means for avoiding cerebral hypoperfusion.[7,8,10] Others have argued that venous pressure decreases proportionately with decreases in arterial blood pressure when the head is upright, resulting in no net change in cerebral perfusion ("venous siphon").[12]

Our findings that autoregulation was more diminished in patients undergoing surgery in the BCP than the LDP support the hypothesis that failing to consider the effects of head elevation on blood pressure measurement from the arm or leg may result in inadvertent cerebral hypotension. Indeed, while MAP measured clinically from the arm or leg was higher, estimated blood pressure at the tragus was lower in the BCP group versus the LDP group. More importantly, our results show that some patients undergoing shoulder surgery have periods during which blood pressure is below the LLA regardless of position. These results extend the finding of our prior studies in patients undergoing cardiac surgery with cardiopulmonary bypass of a wide range of MAP at the LLA (40–90 mm Hg).[15,17–19] Thus, accounting for head elevation with blood pressure measurement will not completely eliminate the potential for patients to experience pressure-passive CBF because some patients may have an LLA that is above what is traditionally viewed as an acceptable blood pressure. Our findings illustrate that the lower limit of blood pressure is difficult to predict based on preoperative blood pressure measurements (Fig. 1, A–C) and suggest that CBF autoregulation monitoring may be more accurate than empirical methods for determining individual perioperative blood pressure targets. Consistent with the reports of others,[9,10] we observed lower $rSco_2$ in the BCP group than in the LDP group. Blood pressure below the LLA, however, may not necessarily predispose patients to cerebral ischemia if the compensatory increases in oxygen extraction by tissue are adequate. This assumption may not apply though for patients with poor cerebral collateral blood flow caused by cerebral vascular disease or an underdeveloped circle of Willis.[8,33–35]

In prior investigations of neurologic complications among patients undergoing shoulder surgery in the BCP, researchers did not perform systematic neurologic examinations, particularly evaluations for subtle neurologic abnormalities.[1,4–8] In this study, we performed exploratory analysis for any relationship between surgery in the BCP and neurologic complications by assessing for postoperative cognitive dysfunction. At baseline, we observed differences in cognitive test results between patients who would subsequently undergo surgery in the BCP or LDP even after adjusting for patient age. After surgery we observed differences in the composite cognitive outcome score between groups which showed that an individual in the BCP group was on average more likely to have a lower Z-score than was an individual in the LDP group of the same age and the same unobserved characteristics (i.e., random effect) at both postoperative testing sessions. However, after accounting for the baseline score, there was no difference in the Z-score at any of the

Table 4. Psychometric Testing Results from Baseline, 7 to 10 Days, and 4 to 6 Weeks After Surgery

	Baseline			7 to 10 days after surgery			4 to 6 weeks after surgery		
	Lateral decubitus	Beach chair	*P* value[a]	Lateral decubitus	Beach chair	*P* value[b]	Lateral decubitus	Beach chair	*P* value[b]
RAVLT trial V correct	11.0 ± 2.4	9.1 ± 2.9	0.007	12.0 ± 2.3*	10.0 ± 2.9†	0.364	12.0 ± 2.4*	10.6 ± 3.0*	0.853
RAVLT trial IX correct	13.4 ± 1.8	13.0 ± 2.5	0.083	14.0 ± 1.7	13.0 ± 2.4	0.183	13.9 ± 1.6†	13.1 ± 2.1†	0.318
Rey complex figure	34.0 ± 3.4	32.0 ± 4.9	0.013	35.0 ± 1.8	31.0 ± 6.6	0.057	34.8 ± 2.0†	32.3 ± 4.1	0.059
Correct, letter F	14.0 ± 4.6	12.0 ± 4.7	0.464	15.0 ± 5.0	13.0 ± 4.6	0.367	15.3 ± 4.7†	14.0 ± 4.5†	0.368
Correct, letter A	11.0 ± 4.1	11.0 ± 4.4	0.916	12.0 ± 4.4†	11.0 ± 4.7	0.077	13.3 ± 5.0*	11.3 ± 4.4	0.004
Correct, letter S	15.0 ± 4.8	13.0 ± 4.6	0.610	15.0 ± 4.3	13.0 ± 4.9	0.262	15.3 ± 5.4	14.3 ± 5.0	0.783
Digit symbol correct	49.0 ± 10.0	41.0 ± 12	0.289	49.0 ± 9.9	41.0 ± 14	0.417	52.3 ± 10.8*	43.4 ± 13.0	0.493
Trail making B time (s)	68.0 ± 31.0	90 ± 37	0.232	58 ± 24†	80 ± 42	0.457	54 ± 18*	81 ± 41	0.075
Grooved peg board dominant hand (s)	67 ± 15	87 ± 26	<0.0001	67 ± 18	94 ± 35	0.685	62 ± 13†	86 ± 33	0.846
Grooved peg board non-dominant hand (s)	75 ± 16	96 ± 35	0.003	78 ± 22	102 ± 31	0.679	70 ± 12*	94 ± 36	0.237

Data are presented as mean ± SD. Note that lower scores represent worse performance, except for the timed test, where longer time represents worse results. RAVLT = Rey Auditory Verbal Learning Test.
[a]*P* value for the age-adjusted difference between positions using linear regression with each cognitive variable at baseline as the outcome and position and age as the predictors.
[b]*P* value for age- and baseline score-adjusted *P* values using linear regression with each cognitive variable as the outcome and position, age, and baseline cognitive score as the predictors.
**P* ≤ 0.001 versus baseline; †*P* ≤ 0.05 versus baseline.

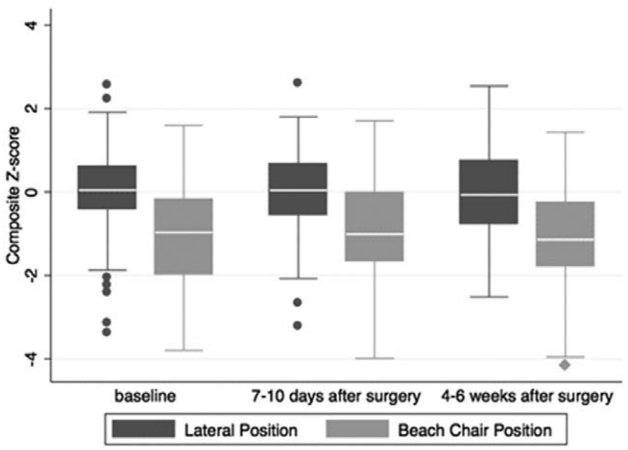

Figure 2. Box and whisker plot of the composite cognitive outcome Z-score for the 2 surgical groups at baseline and at 7 to 10 days and 4 to 6 weeks after surgery. The horizontal line in each box represents the median value for each group, and the bottom and top bars represent the 25th and 75th percentiles. The length of the box is the interquartile range (IQR). The dots represent "outliers" that are larger than the highest value within 1.5 IQR of the 75th percentile or less than the lower value within 1.5 IQR of the 25th percentile.

Table 5. Results of the Linear Mixed Effects Model Looking at Longitudinal Change in the Composite Cognitive Z-Score

	Linear mixed effects model	
	β coefficient (95% confidence interval)	*P* value
Z-score 7–10 days after surgery versus baseline score	0.01 (−0.08, 0.11)	0.769
Z-score 4–6 weeks after surgery versus baseline score	−0.14 (−0.24, −0.04)	0.007
Z-score between BCP and LDP	−0.50 (−0.78, −0.21)	0.001
Age at baseline (per 1 year)	−0.03 (−0.04, −0.03)	<0.0001

LDP = lateral decubitus position; BCP = beach chair position.

2 postoperative testing sessions between the BCP and the LDP groups. Nonetheless, our study was not powered to accurately assess the effects of surgical position on cognitive end points, and the sample size was insufficient to statistically adjust for all factors that might influence cognitive end points. Thus, we cannot firmly exclude the possibility that differences in baseline characteristics between the 2 surgical groups can explain our cognitive findings.

We tested serum levels of biomarkers that have been associated with brain injury. S100β, a protein found in brain astrocytes and microglial cells, has been reported to be increased in patients after cardiac arrest, head trauma, and stroke and in those with cognitive dysfunction after cardiac surgery.[36–41] NSE is a neuronal protein released into the serum of patients who have experienced ischemic stroke or traumatic brain injury or who have undergone cardiopulmonary bypass.[42] Substantial extracerebral contamination by S100β or NSE limits their specificity for detecting brain injury.[42–44] GFAP is a cytoskeletal protein in astrocytes that has been shown to be increased in the serum of patients after ischemic stroke and head trauma.[45,46] It has higher specificity for brain injury than does S100β or NSE.[44] However, none of these biomarkers differed depending on surgical position. A challenge to assessing changes in brain injury biomarkers in patients undergoing shoulder surgery is that some patients are discharged from the hospital on the day of surgery or the next day, limiting the availability of postoperative blood specimens. Hence, it is possible that the usual pattern of elevation in the biomarkers was not adequately assessed.

In this study, we used NIRS-based COx as a monitor of CBF autoregulation. In pilot studies of patients undergoing shoulder surgery, we were unable to obtain bilateral continuous transcranial Doppler CBF velocity measurements with which to monitor autoregulation owing to head rotation for the surgery and motion artifact caused by the close proximity of the Doppler probes to the surgical field. There is precedent for using monitors of brain oxygenation as surrogates of CBF for measuring autoregulation including direct tissue

Table 6. Comparison of Serum Injury Biomarker Concentrations at Baseline, in the Postanesthesia Care Unit, and on the Morning of Postoperative Day 1 for Patients Undergoing Surgery in the Lateral Decubitus Position and Beach Chair Position

	Baseline			Postanesthesia care unit			Postoperative day 1		
	Lateral decubitus (*n* = 85)	Beach chair (*n* = 86)	*P* value	Lateral decubitus (*n* = 87)	Beach chair (*n* = 84)	*P* value[a]	Lateral decubitus (*n* = 31)	Beach chair (*n* = 67)	*P* value[a]
GFAP (ng/ml)	0.02 ± 0.04 (0.001)	0.02 ± 0.062 (0.001)	0.480	0.018 ± 0.05 (0.001)	0.03 ± 0.6	0.358	0.03 ± 0.06 (0.001)	0.02 ± 0.06 (0.001)	0.119
S100β (ng/mL)	33.8 ± 119.7 (0.3)	21.7 ± 87.3 (0.001)	0.456	43 ± 131 (0.9)	20 ± 83 (0.05)	0.287	7.4 ± 24 (0.001)	8.2 ± 49 (0.001)	0.349
NSE (ng/mL)	60.0 ± 65.5 (33)	84.5 ± 110.0 (43)	0.880	81 ± 169 (34)	84 ± 134 (45)	0.354	122 ± 443 (26)	53 ± 54 (64)	0.554

Data are presented as mean ± SD.
GFAP = glial fibrillatory acidic protein; NSE = neuron-specific enolase.
[a]Comparison between positions adjusted for age and baseline value.

O_2 tension measurement, jugular bulb O_2 saturation, and NIRS.[47,48] The use of COx for this purpose has been validated in laboratory and clinical investigations by our group and others.[14,15,27,49,50] Adjustments to the ventilator were based on capnographic monitoring with a goal of normocapnia and not direct arterial blood gas measurement since arterial catheters are not routinely inserted for shoulder surgery at our institution. Insofar as these methods may not necessarily ensure normal $Paco_2$ depending on individual dead-space ventilation, mild hyper- or hypocarbia cannot be excluded in some patients. The latter might alter CBF autoregulation. Patients in the BCP group were more likely to receive phenylephrine and to receive higher cumulative doses than those in the LDP group. Some data suggest that this drug and other vasoconstrictors may reduce $rSco_2$ measured with NIRS.[51,52] Since scalp blood flow is not autoregulated and because COx measures the relationship between low-frequency changes in $rSco_2$ and blood pressure, the effects of phenylephrine on NIRS measurements, if any, seem minimal.

Our report has some limitations including the observational study design. However, we believe that randomization would be difficult, if not unethical, because the decision regarding which position to use should be based on optimizing surgical conditions for particular diseases and patient factors. As noted, there were differences in demographics between patients undergoing surgery in the BCP versus the LDP including a higher frequency of risk factors for cerebral vascular disease such as age, history of hypertension, and transient ischemic attacks. Furthermore, the types of surgery were more complex in the BCP group versus the LDP group. Together, these observations may imply that patients undergoing surgery for conditions that may require the BCP are at higher risk for diminished autoregulation than those whose surgery can be conducted in the LDP regardless of position during surgery. Consequently, such patients may require higher blood pressure during surgery. Head elevation for patients undergoing surgery in the BCP was approximately 30°. Although we did not include patients with more marked head elevation as used for BCP in some centers (i.e., 60°–90°), we expect that in such instances our autoregulation findings would be at least similar if not worse. Additionally, we were unable to obtain psychometric data for some tests in the postoperative testing period because of patient noncompliance. We attempted to account for missing data by using imputation, which showed no impact on the basic cognitive findings.

In conclusion, compared with patients in the LDP, patients undergoing shoulder surgery in the BCP are more likely to have higher COx indicating diminished cerebral autoregulation and lower $rSco_2$. There were no differences in the composite cognitive outcome between the BCP and the LDP groups after accounting for baseline Z-score despite the fact that patients in the former group were older and were at higher risk for cerebral vascular disease.

RECUSE NOTE

Dr. Charles Hogue is the Associate Editor-in-Chief for Cardiovascular Anesthesiology for *Anesthesia & Analgesia*. This manuscript was handled by Dr. Gregory Crosby, Section Editor for Neuroscience in Anesthesiology and Perioperative Medicine and Pediatric Neuroscience, and Dr. Hogue was not involved in any way with the editorial process or decision.

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