Effects of Beach-Chair Position and Induced Hypotension on Cerebral Oxygen Saturation in Patients Undergoing Arthroscopic Shoulder Surgery

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Purpose: We investigated the effects of the beach-chair position and induced hypotension on regional cerebral oxygen saturation (rSO_2) in patients undergoing arthroscopic shoulder surgery by using near-infrared spectroscopy. **Methods:** Twenty-eight patients scheduled for arthroscopic shoulder surgery were enrolled prospectively. After induction of anesthesia, mechanical ventilation was controlled to maintain Pa_{CO_2} at 35 to 40 mm Hg. Anesthesia was maintained with sevoflurane and remifentanil. After radial artery cannulation, mean arterial pressure (MAP) was measured at the external auditory meatus level and maintained between 60 and 65 mm Hg. The rSO_2 was measured by use of near-infrared spectroscopy. MAP and rSO_2 were recorded at the following times: before induction (T_0), immediately after induction (T_1 [baseline]), after beach-chair position (T_2), immediately after induced hypotension (T_3), 1 hour after induced hypotension (T_4), and after supine position at the end of surgery (T_5). Cerebral desaturation was defined as a reduction in rSO_2 to less than 80% of baseline value for 15 seconds or greater. **Results:** A total of 27 patients were evaluated until the end of this study. The MAP at T_2 was significantly lower than that at T_1. The MAP values at T_3 and T_4 were significantly lower than those at T_1 and T_2. The rSO_2 at T_2 was significantly lower than that at T_1. Unlike the pattern of change in the MAP, there was no additional decrease in rSO_2 at T_3 and T_4. There were 2 patients who had an episode of cerebral desaturation. **Conclusions:** The beach-chair position combined with induced hypotension significantly decreases rSO_2 in patients undergoing shoulder arthroscopic surgery under general anesthesia. **Level of Evidence:** Level IV, study of nonconsecutive patients without consistently applied reference gold standard.

The beach-chair position (a variation of the sitting position) for shoulder arthroscopy has been widely accepted among orthopaedic surgeons.[1] However, serious complications have been reported in relation to shoulder surgery with the patient in the sitting or upright position. Pohl and Cullen[2] reported 4 cases of shoulder surgery in the beach-chair position that resulted in death in 1 patient and severe brain damage in 3 patients. Stroke and brain death, loss of vision, and ophthalmoplegia have also been reported.[3] Possible causes of such complications were hypotension, reduction of blood flow of the vertebral artery due to hyperextension, and rotation or tilt of the head, which could decrease cerebral perfusion pressure and cerebral oxygenation, resulting in cerebral ischemia.[2,3] Furthermore, during shoulder arthroscopy, it is common to induce hypotension to achieve better visualization of the surgical field.[4] This combination of the beach-chair position and induced hypotension under general anesthesia has the potential to induce cerebral ischemia and increase related complications.

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Various techniques have been developed for central nervous system monitoring. Among these modalities of central nervous system monitoring, near-infrared spectroscopy (NIRS) provides continuous, noninvasive bedside monitoring of cerebral oxygenation, a marker of the balance between oxygen supply and demand.[5,6]

A recent case report suggested that NIRS may be useful in monitoring the adequacy of cerebral perfusion in the treatment of a patient undergoing shoulder surgery in the beach-chair position.[7] However, the relation between regional cerebral oxygen saturation (rSO_2) values and induced hypotension in the beach-chair position has not been established in patients undergoing arthroscopic shoulder surgery.

The goal of this study was to investigate the effects of the beach-chair position and induced hypotension on cerebral oxygen saturation in patients undergoing arthroscopic shoulder surgery. We hypothesized that the effect of placing a patient in the beach-chair position and inducing hypotension during arthroscopic shoulder surgery would reduce cerebral oxygen saturation by greater than 10%. The secondary endpoint of this study was to investigate the relation between the change in rSO_2 value and postoperative cognitive dysfunction.

METHODS

After we obtained institutional review board approval and informed consent from each patient, 28 patients scheduled for elective shoulder arthroscopy in the beach-chair position were enrolled prospectively. Patients with diseases in which induced hypotension was contraindicated (severe pulmonary disease, anemia, cardiac disease, ischemic cerebrovascular disease, renal disease, hepatic disease, pregnancy, hypovolemia, severe systemic hypertension, and poorly controlled diabetes),[8] neurologic disease, and/or a preoperative Mini Mental State Examination (MMSE) score of 23 or less were excluded. The enrolled patients underwent the MMSE before surgery and 1 day after surgery. An anesthesiologist not involved in the trial assessed the MMSE. A decrease in the MMSE score by 2 points or more from baseline was considered a decline in cognitive function.[9,10]

Glycopyrrolate, 0.2 mg, was administered intravenously as the premedication. Standard monitoring with electrocardiography, radial arterial catheter, pulse oximetry, and esophageal temperature were used throughout surgery. According to the textbook recommendations[11] and practice guidelines of our institution on monitoring patients undergoing surgery in the sitting position, the pressure transducer of the radial arterial pressure measurement was zeroed at the level of the external auditory meatus throughout surgery, which made radial artery pressure directly reflect cerebral perfusion pressure. Sensors for NIRS (INVOS 5100; Somanetics, Troy, MI) were placed bilaterally at least 2 cm above the eyebrow on the right and left sides of the forehead according to the manufacturer's instructions before induction of general anesthesia. The rSO_2 value was continuously monitored by use of NIRS.

General anesthesia was administered by a standardized protocol. Anesthesia was induced with propofol (2 mg/kg) and remifentanil (1 μg/kg), and rocuronium (0.6 mg/kg) was given intravenously for neuromuscular blockade. After endotracheal intubation, ventilation was mechanically controlled by use of 50% oxygen in an air mixture to maintain the end-tidal carbon dioxide tension at 35 to 40 mm Hg. Anesthesia was maintained with 1 minimum alveolar concentration of sevoflurane and remifentanil.

After the induction of anesthesia, patients were put into the beach-chair position using a beach-chair table (T-MAX beach chair; TENET Medical Engineering, Calgary, Alberta, Canada). After positioning, hypotension was induced and maintained at a target mean arterial pressure (MAP) of 60 to 65 mm Hg with continuous infusion of remifentanil. If remifentanil over 0.5 $\mu g \cdot kg^{-1} \cdot min^{-1}$ could not induce target MAP, infusion of nitroglycerin was added. When incidental hypotension below the target MAP occurred, infusion of phenylephrine was used to restore MAP to the target level. MAP and rSO_2 were recorded at the following times: before the induction of anesthesia (T_0), 5 minutes after the induction of anesthesia and establishment of mechanical ventilation (T_1 [baseline]), 5 minutes after the beach-chair position (T_2), 5 minutes after the establishment of induced hypotension (T_3), 1 hour after the establishment of induced hypotension (T_4), and 5 minutes after the supine position at the end of surgery (T_5). Arterial blood gas analysis was performed at the time points of T_1, T_3, T_4, and T_5. The mean values from left and right rSO_2 at each time point were used for analysis. Cerebral desaturation was defined as a reduction in rSO_2 by less than 80% of the baseline value for 15 seconds or greater.[9,12,13] When cerebral desaturation occurred, a 2-step treatment was planned: the first step was to check and correct the anesthetic circuit, hemoglobin, fraction of inspired O_2, end-tidal carbon dioxide tension, and MAP. If the first step failed to restore an acceptable rSO_2 value, MAP was increased with intravascular fluid administration and phenylephrine.

Statistical Methods

In a previous study Fuchs et al.[14] reported that the rSO_2 value decreased from 78.5% in the supine position to 73.8% in the sitting position with the patient under general anesthesia. Another study described that induced hypotension reduced the rSO_2 value by more than 10% in 4% of the total measured points.[15] Therefore we presumed that the rSO_2 value would be reduced by more than 10% from that at baseline in patients placed into the sitting position combined with induced hypotension under general anesthesia. A power analysis indicated that a sample size of 28 patients would be required to detect a difference of 10% in rSO_2 between T_1 (baseline) and T_3 (induced hypotension in beach-chair position) with $\alpha = .05$ and a power of 90%. SPSS software (version 15.0; SPSS, Chicago, IL) was used for the statistical analysis. Changes in MAP, rSO_2, and values of arterial blood gas analysis with time were compared with the baseline values by use of repeated-measures analysis of variance with Bonferroni correction to determine which time point had values significantly different from the baseline values. Differences in MMSE and hemoglobin between T_1 and T_5 were examined with the Wilcoxon signed rank test and paired *t* test, respectively. $P < .05$ was considered significant.

RESULTS

Among the 28 patients enrolled in this study, 1 patient was removed from this study because the procedure changed from arthroscopic surgery to open surgery during the operation. Data analysis of the remaining 27 patients showed that the reduction in rSO_2 value was greater than we had expected and the achieved power of this result was 0.99 despite the removal of 1 patient from our study. Therefore we did not include 1 more patient in this study.

TABLE 1. *Demographic Data*

	Data
Age (yr)	57.5 ± 7.4
Sex (M/F)	11/16
Height (cm)	160.9 ± 6.4
Weight (kg)	61.5 ± 7.7

NOTE. Values are mean ± SD or number of patients.

TABLE 2. *Clinical Characteristics*

	Data
Duration of anesthesia (min)	201.1 ± 59.5
Duration of surgery (min)	136.0 ± 57.9
Duration of beach-chair position (min)	152.6 ± 57.2
Duration of induced hypotension (min)	117.9 ± 53.5
Fluid intake (mL)	1,108.9 ± 473.0
Urine output (mL)	314.5 ± 157.5
Infused phenylephrine dose (μg)	2,194.8 ± 1,925.6
Infused remifentanil dose (μg)	946.6 ± 564.8
MAP at T_0 (mm Hg)	104.2 ± 12.0
The value of rSO_2 at T_0 (%)	66.3 ± 5.9

NOTE. All values are given as mean ± SD.
Abbreviation: T_0, before induction of anesthesia.

The demographic data of the patients are shown in Table 1. The clinical characteristics related to surgery and anesthesia are summarized in Table 2. Serial blood gas analysis is shown in Table 3. There were no cases of acidosis, hypoxia, or hypercapnia/hypocapnia on serial blood gas analysis. In addition, there was no difference among the time points in Pa_{O_2} and Pa_{CO_2}. Although the lactate level at T_5 was higher than that at T_2 (1.45 ± 0.84 mmol/L *v* 1.09 ± 0.57 mmol/L, $P <$ .05), there was no further increase from baseline in the lactate level. The postoperative hemoglobin level was statistically lower than the preoperative level (12.3 ± 0.8 g/dL *v* 12.5 ± 0.8 g/dL, $P = .021$). However, the difference has no clinical significance.

The changes in rSO_2 and MAP are shown in Figs 1 and 2. The MAP values at T_2, T_3, and T_4 (74.8 ± 14.8 mm Hg, 63.6 ± 5.2 mm Hg, and 64.3 ± 4.9 mm Hg, respectively) were lower compared with that at T_1 (85.0 ± 16.1 mm Hg) ($P < .05$). In addition, the MAP values at T_3 and T_4 (63.6 ± 5.2 mm Hg and 64.3 ± 4.9 mm Hg, respectively) were significantly lower than that at T_2 (74.8 ± 14.8 mm Hg, $P < .05$). The rSO_2 values at T_2, T_3, and T_4 (67.4% ± 4.9%, 66.0% ± 6.3%, and 66.7% ± 6.9%, respectively) were significantly lower than that at T_1 (74.0% ± 5.6%) ($P <$ .05). Unlike the pattern of MAP values, there was no additional decrease in rSO_2 values at T_3 and T_4 compared with T_2.

There were 2 episodes of cerebral desaturation in this study period. The first episode occurred in a 41-year-old woman who had no coexisting disease. After her MAP decreased below 55 mm Hg for about 5 minutes during induced hypotension, the rSO_2 value decreased to less than 80% of her baseline value for about 1 minute. The rSO_2 was restored after the MAP increased above 60 mm Hg by reducing the infusion

TABLE 3. *Changes in Arterial Blood Gas Analysis During Shoulder Arthroscopic Surgery*

	T_1	T_3	T_4	T_5
pH	7.43 ± 0.03	7.43 ± 0.04	7.43 ± 0.04	7.42 ± 0.05
Pa_{O_2} (mm Hg)	229.3 ± 48.2	219.1 ± 29.7	228.2 ± 29.6	215.1 ± 46.4
Pa_{CO_2} (mm Hg)	35.4 ± 2.6	34.9 ± 3.5	35.5 ± 4.3	35.7 ± 3.4
Lactate (mmol/L)	1.12 ± 0.51	1.09 ± 0.57	1.17 ± 0.61	1.45 ± 0.84*
Hemoglobin (g/dL)	12.5 ± 0.8			12.3 ± 0.8†

NOTE. All values are given as mean ± SD.
*$P < .05$ versus T3.
†$P < .05$.

rate of remifentanil. The second episode occurred in a 63-year-old man who had hypertension. Immediately after he was put into the beach-chair position, his MAP was reduced to less than 60 mm Hg for about 3 minutes and cerebral desaturation occurred for about 5 minutes. After the MAP was increased to more 60 mm Hg by reducing the infusion rate of remifentanil and administering intravenous phenylephrine, the rSO_2 was restored to above 80% of his baseline value.

A decline in cognitive function measured by MMSE was not observed in any of the patients (Table 4).

DISCUSSION

We found that the beach-chair position itself reduced both cerebral oxygenation and MAP with the patient under general anesthesia. In addition, induced hypotension did not result in a further decrease in cerebral oxygenation during the beach-chair position in our study. However, there were 2 cases of cerebral desaturation during a temporary decline in MAP under 60 mm Hg. Despite the 2 cases of cerebral desaturation, cognitive dysfunction or other neurologic complications did not occur in any of the patients during the study period.

At present, brain oxygenation can be measured by jugular bulb oximetry or brain tissue oxygen tension sensors. However, these methods are invasive and difficult to apply.[7] NIRS is a noninvasive monitor that continuously provides cerebral oxygenation values. NIRS measures the ratio of oxyhemoglobin to total hemoglobin in a field beneath the sensor, and this ratio is expressed as a percentage of rSO_2. NIRS has been used to detect cerebral hypoxia and ischemia in patients undergoing procedures at high risk for adverse neurologic outcomes such as cardiovascular surgery.[16]

There are reports regarding the relation of body position and rSO_2. In a study in which the subjects were non-anesthetized healthy volunteers, the rSO_2

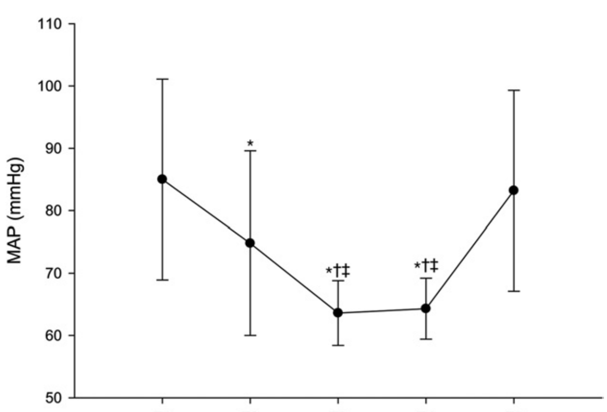

FIGURE 1. Change in MAP during shoulder arthroscopic surgery. The beach-chair position and the induced hypotension each decreased MAP. A filled circle with error bars represents the mean and standard deviation. Asterisk, $P < .05$ versus T1; dagger, $P < .05$ versus T2; double dagger, $P < .05$ versus T5.

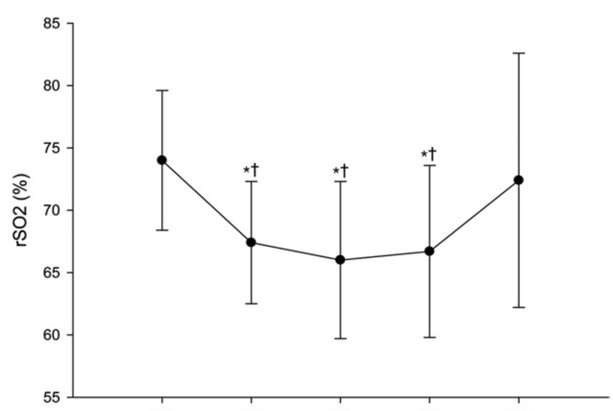

FIGURE 2. Change in regional cerebral oxygenation saturation during shoulder arthroscopic surgery. The beach-chair position reduced rSO_2. However, there was no further decrease in rSO_2 after induced hypotension. A filled circle with error bars represents the mean and standard deviation. Asterisk, $P < .05$ versus T_1; dagger, $P < .05$ versus T_5.

TABLE 4. *Comparison Between Preoperative and Postoperative Measurement of MMSE Score*

	Preoperative	Postoperative	*P* Value
MMSE score [median (range)]	28 (26-30)	29 (26-30)	.117

value in the 20° reverse Trendelenburg position was not different from that in the supine position under normocapnia.[17] In addition, Fuchs et al.[14] reported that rSO_2 values in the sitting position were not different from those in the supine position in non-anesthetized volunteers. However, rSO_2 values in the sitting position were significantly lower than those in the supine position in anesthetized patients, although their MAP was increased or maintained at baseline values. This phenomenon seems to occur because general anesthesia impairs the compensatory mechanism that includes the regulation of peripheral circulation and cerebral autoregulation and thus indicates that changes in rSO_2 related to positioning cannot be entirely explained only by changes in hemodynamic parameters such as MAP.

In our study rSO_2 values were influenced by body position and MAP under the conditions where Pa_{CO_2} and Pa_{O_2} were constantly controlled. When patients were put into the beach-chair position (T_2), there was a significant decrease in MAP and rSO_2 values compared with those at T_1. When induced hypotension was established at T_3 and T_4, MAP values at T_3 and T_4 were significantly lower than that at T_2. However, rSO_2 values at T_3 and T_4 did not decrease significantly from that at T_2. Although there was a great decrease in the MAP value from T_2 to T_3, the rSO_2 value was maintained after the beach-chair position. Our data showed that the rSO_2 value was not directly correlated with MAP when other major factors that affect rSO_2 were controlled. As such, our findings are consistent with the report by Fuchs et al.[14] However, our study also showed the relation between the rSO_2 value and MAP. In 2 episodes of cerebral desaturation, the events occurred after MAP fell below 60 mm Hg and resolved after MAP increased to over 60 mm Hg. Because other major factors that affect rSO_2 were controlled, the reduction of MAP below 55 to 60 mm Hg could have been a cause of cerebral desaturation.

We continuously measured blood pressure at the level of the external auditory meatus, which is located at the level of the circle of Willis, to reflect cerebral perfusion pressure. When the patient is in the beach-chair position, the MAP measured with the cuff on the arm, which is located at the heart level, may overestimate the MAP at the level of the external auditory meatus because the circle of Willis will be positioned above the brachial artery. Assuming a 0.77-mm Hg decrease for every centimeter gradient[18,19] and an approximate vertical distance of 30 cm between the external auditory meatus level and the brachial artery level, 60 mm Hg of MAP at the external auditory meatus level corresponds to 83 mm Hg of MAP at the brachial artery level. According to this study, MAP less than 83 mm Hg at the brachial artery level may compromise cerebral perfusion in some patients during the sitting position.

The outcomes of our study would be helpful in developing guidelines for intraoperative management of shoulder surgery in the sitting position. To prevent the occurrence of cerebral ischemia, it would be desirable for patients undergoing shoulder arthroscopic surgery in the beach-chair position combined with hypotensive anesthesia to undergo continuous blood pressure monitoring at the external auditory meatus level or cerebral oxygenation by use of NIRS. However, these monitoring devices further require more preoperative preparation and add to the total cost of the surgical procedure. In addition, radial artery cannulation is reported to be associated with complications including severe hand ischemia (0.09%), pseudoaneurysm (0.09%), and hematoma (14.4%).[20] Therefore we recommend that only patients at high risk for cerebral ischemia, such as those with previous cerebral ischemic disease or cardiovascular disease, should be monitored with these monitoring devices. In particular, NIRS may be of more use in patients with dysfunction of cerebral autoregulation such as uncontrolled hypertension. In patients having no risk factors for cerebral ischemia, blood pressure could be measured with the cuff on the arm, and it may be ideal to maintain MAP at more than 80 mm Hg to guarantee sufficient cerebral perfusion pressure, according to our results. The measurement of blood pressure on the leg is undesirable because the vertical distance between the brain and the leg is so great that it is difficult to estimate cerebral perfusion pressure.[21] It has been suggested that decreased rSO_2 values during surgery were significantly related to postoperative neurologic dysfunction.[9,22,23] On the other hand, there is no consensus on the degree of rSO_2 reduction from baseline that should be considered as cerebral desaturation because previous studies were carried out under different conditions, including type of anesthesia and surgery. In our study there was no postoperative neurologic dysfunction, although a 20% decrease in rSO_2 from the baseline value occurred.

This study has some limitations. First, the measurement of cerebral oxygenation with NIRS reflects regional cerebral oxygenation rather than a global measure. Pollard et al.[5] tried to validate the use of NIRS for monitoring cerebral oxygenation. In their report, when Pa_{CO_2} and body position changed, the rSO_2 value and calculated global brain hemoglobin saturation were not as well correlated.[17] However, because jugular venous bulb oxygen saturation, which was used to calculate global brain hemoglobin oxygen saturation, was influenced by the change in Pa_{CO_2} and body position, it may not be the correct method of validation for rSO_2. The assessment of cognitive function with the MMSE is the second limitation of our study because this test does not completely evaluate cognitive function.[24] There are other cognitive screening tests that cover a broad range of cognitive functions. However, they have major disadvantages of lengthy administration time and complex administration guidelines. Therefore the MMSE, which combines high validity and reliability with brevity and ease of application, was used for evaluating cognitive function.[25] Third, our study was confined to patients who underwent surgery under general anesthesia. Because regional anesthesia is also used for patients undergoing shoulder arthroscopic surgery in the beach-chair position,[1] further study on this issue with patients under regional anesthesia is required.

CONCLUSIONS

The beach-chair position combined with induced hypotension significantly decreases rSO_2 in patients undergoing shoulder arthroscopic surgery under general anesthesia.

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