Association between temporal mean arterial pressure and brachial noninvasive blood pressure during shoulder surgery in the beach chair position during general anesthesia

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Background: Estimation of cerebral perfusion pressure during elective shoulder surgery in the beach chair position is regularly performed by noninvasive brachial blood pressure (NIBP) measurements. The relationship between brachial mean arterial pressure and estimated temporal mean arterial pressure (eTMAP) is not well established and may vary with patient positioning. Establishing a ratio between eTMAP and NIBP at varying positions may provide a more accurate estimation of cerebral perfusion using noninvasive measurements.

Methods: This prospective study included 57 patients undergoing elective shoulder surgery in the beach chair position. All patients received an interscalene block and general anesthesia. After the induction of general anesthesia, values for eTMAP and NIBP were recorded at 0°, 30°, and 70° of incline.

Results: A statistically significant, strong, and direct correlation between NIBP and eTMAP was found at 0° ($r = 0.909, P \leq .001$), 30° ($r = 0.874, P < .001$), and 70° ($r = 0.819, P < .001$) of incline. The mean ratios of eTMAP to NIBP at 0°, 30°, and 70° of incline were 0.939 (95% confidence interval [CI], 0.915-0.964), 0.738 (95% CI, 0.704-0.771), and 0.629 (95% CI, 0.584-0.673), respectively. There was a statistically significant decrease in the eTMAP/NIBP ratio as patient incline increased from 0° to 30° ($P < .001$) and from 30° to 70° ($P < .001$).

Conclusion: The eTMAP-to-NIBP ratio decreases as an anesthetized patient is placed into the beach chair position. Awareness of this phenomenon is important to ensure adequate cerebral perfusion and prevent hypoxic-related injuries.

Level of evidence: Basic Science, Physiology.
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Keywords: Mean arterial pressure; beach chair position; shoulder surgery; cerebral perfusion pressure; noninvasive blood pressure; cerebral hypoxic injury.
The beach chair, or seated, position is the most commonly used position for patients undergoing arthroscopic and open shoulder procedures in the United States, and its safety has been well established. Although extremely rare, cerebral ischemic events have been observed after surgery in the beach chair position. These reports have identified upright positioning as an independent risk factor for cerebral ischemia during surgery. Ischemic brain and spinal cord injuries have been described, resulting in blindness, pituitary apoplexy, and death. In a survey of the American Shoulder and Elbow Surgeons Society, the reported incidence of intraoperative cerebrovascular events during beach chair positioning was 0.00291% (8 of 274,225). It is believed that transitioning from supine to the beach chair position, in an anesthetized patient, results in a decrease in blood pressure, increasing the risk for cerebral hypoperfusion and ischemic brain injury. Significant decreases in cardiac output, mean arterial pressure (MAP), and cerebral perfusion pressure (CPP) have been observed with this position change. Nonanesthetized patients are able to compensate for this decrease in blood pressure by increasing systemic vascular resistance to maintain MAP and cardiac output, a response that is blocked in anesthetized patients due to vasodilating intravenous and volatile anesthetics.

Historically, it was believed that cerebral autoregulation was able to preserve constant cerebral blood flow when MAP was maintained between 50 and 150 mm Hg. However, the lower limit of autoregulation (LLA) has recently been challenged. Many believe that higher values, up to 80 ± 8 mm Hg, for the LLA are necessary to prevent potential hypoxic ischemic encephalopathy. Koh et al have stated that cerebral blood flow may be underestimated by as much as 40 mm Hg with the use of brachial cuff readings due to hydrostatic pressure differences between the arm and head in the beach chair position. Numerous other studies have also shown the beach chair position results in a decrease in blood pressure.

These recent findings suggest that brachial measurements may not accurately represent cerebral arterial pressures. However, no study, to our knowledge, has determined the ratio between these 2 variables at varying positions in an anesthetized patient. The purpose of this study is to determine if a direct correlation exists between brachial and temporal arterial pressures and to calculate the ratio of the estimated temporal MAP (eTMAP) to the noninvasive brachial mean arterial blood pressure (NIBP) at 0°, 30°, and 70° of inclination. Establishing these ratios may provide a more accurate assessment of cerebral blood pressure during procedures performed in the beach chair position without the need for invasive monitoring. We hypothesize that there is a strong direct correlation between eTMAP and NIBP and that a ratio between these 2 variables exists, regardless of position.

Materials and methods

This was a prospective cohort study of 57 patients (32 men, 25 women) undergoing elective shoulder surgery (56 shoulder arthroplasty and 1 humeral fracture fixation), from July 2012 to July 2013, using noninvasive arterial monitoring of blood pressure in the beach chair position. Patients were included if they were having an elective open shoulder procedure and were at least 18 years old. Excluded were minors, pregnant patients, prisoners, and patients with impaired decision-making abilities.

American Society of Anesthesiologists Physical Status Classification scores of 1, 2, and 3 were assigned to 1, 35, and 21 patients, respectively. The patients were an average age of 71 years (range, 32-87 years). All patients had a preoperative interscalene block and peripheral arterial catheterization. Anesthesia was induced with propofol and maintained with inhaled sevoflurane.

An arterial transducer was leveled at the temporal artery to represent the arterial pressure at the level of the brain. The eTMAP was recorded from the reading of this transducer. The NIBP was measured from an automated sphygmomanometer placed on the upper arm. Baseline values for eTMAP and NIBP were recorded with the patient supine after the induction of general anesthesia. Values were again recorded in the beach chair position at 30° and 70° of inclination. Any postoperative neurologic sequelae were reported.

Statistical analysis

Data were checked for normality, and descriptive statistics were calculated for each of the examined variables. Repeated-measures analysis of variance with least significant difference pairwise comparisons were conducted to assess differences in NIBP, eTMAP, and the eTMAP/NIBP ratio at 0°, 30°, and 70° of inclination. The relation between NIBP and eTMAP at the 3 different positions (0°, 30°, and 70° of inclination) was assessed using Pearson correlation coefficients (r). Data were analyzed using PASW Statistics 18.0 software (SPSS Inc, Chicago, IL, USA). A P value of <.05 was considered statistically significant.

Results

Our results demonstrate a statistically significant effect of inclination on NIBP (P < .001) and eTMAP (P < .001). Mean NIBP was highest at 0° of inclination (110 ± 24 mm Hg), with statistically significant decreases seen at inclines of 30° (94 ± 20 mm Hg) and at 70° (81 ± 19 mm Hg; P < .001 for all pairwise comparisons). Increasing the degree of inclination also elicited significant reductions in eTMAP. The highest mean values of eTMAP were recorded at 0° of inclination (104 ± 24 mm Hg), with statistically significant decreases in eTMAP occurring at inclinations of 30° (71 ± 22 mm Hg) and 70° (52 ± 21 mm Hg; P < .001 for all pairwise comparisons; Table I). Statistically significant, strong, and direct correlations between eTMAP and
Likewise, care should be taken to ensure that the head is in a proper neutral position to prevent obstruction or compression of vascular perfusion.4 A number of autoregulatory events help to maintain CPP during surgery. The generally accepted range of CPP is 50 to 150 mm Hg based on the expected limits of autoregulation.4,10 Although the true CPP can be calculated by invasive monitoring, this requires the placement of a temporal arterial catheter and intracranial devices, such as an intraventricular catheter, subarachnoid bolt, or an epidural sensor, to obtain a direct measurement of intracranial pressure. This form of invasive measurement is not a reasonable option for elective shoulder procedures.

Owing to the difficulty in measuring true CPP for routine procedures, alternative methods have been described to estimate CPP. Estimation of a LLA has been described as a method of defining the minimum MAP necessary to maintain a constant, adequate cerebral blood flow.10 A LLA value of 50 mm Hg, as determined with brachial measurement, has recently been claimed to inadequately represent CPP.4,6,12 In addition, numerous anesthesia texts support the idea that leveling an arterial pressure transducer at the midbrain level approximates the MAP at the level of the circle of Willis (eTMAP).2 A common practice by neuroanesthesiologists is to manage

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Comparisons between noninvasive blood pressure (NIBP), estimated temporal mean arterial pressure (eTMAP), and the eTMAP/NIBP ratio at 0°, 30°, and 70° of incline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variables</td>
<td>0° incline</td>
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<tr>
<td>----------</td>
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</tr>
<tr>
<td>NIBP, mm Hg</td>
<td>110.6 ± 23.5</td>
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<tr>
<td>eTMAP, mm Hg</td>
<td>103.9 ± 23.7</td>
</tr>
<tr>
<td>eTMAP/NIBP ratio</td>
<td>0.939 ± 0.09</td>
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</table>

SD, standard deviation.

* Repeated-measures analysis of variance with least significant differences was used to compare variables.

1 Significant at P < .001 with 0° incline as the reference category.

1 Significant at P < .001 with 30° incline as the reference category.

NIBP were found at inclinations of 0° (r = 0.909, P < .001; Fig. 1), 30° (r = 0.874, P < .001; Fig. 2), and 70° (r = 0.819, P < .001; Fig. 3). The mean ratio of eTMAP to NIBP was 0.939 (95% confidence interval [CI], 0.915-0.964) at 0° of incline, 0.738 (95% CI, 0.704-0.771) at 30° of incline, and 0.629 (95% CI, 0.584-0.673) at 70° of incline. A statistically significant decline occurred in the eTMAP/NIBP ratio as patient incline increased from 0° to 30° (P < .001) and from 30° to 70° (P < .001; Table I). No clinical cerebral vascular accidents or neurologic sequelae were observed postoperatively.

**Discussion**

As hypothesized, a statistically significant, strong, and direct correlation exists between NIBP and eTMAP at 0°, 30°, and 70° of inclination. However, contrary to our hypothesis, we found that as the inclination angle increased, a significant decline occurred in the eTMAP-to-NIBP ratio. These results permit a calculated adjustment in NIBP to better reflect expected eTMAP at 0°, 30°, and 70° of inclination. With these ratios accounted for, a change in NIBP at varying positions will provide a more accurate assessment of the corresponding change in eTMAP. This allows the use of mean arterial brachial pressures to estimate cerebral perfusion more accurately at varying degrees of beach chair positioning, ultimately helping to prevent overestimation of cerebral perfusion and consequently decreasing the risk of hypotensive ischemic events.

Many factors must be considered as potential causes of cerebral hypoperfusion in the beach chair position. Possible contributors include intraluminal atherosclerosis, external compression of carotid and vertebral vessels by osteophytes, and anomalies in vessel configuration, which may be prevalent in more than 50% of the population.13,36,37 Likewise, care should be taken to ensure that the head is in a proper neutral position to prevent obstruction or compression of vascular perfusion.4

A number of autoregulatory events help to maintain CPP during surgery. The generally accepted range of CPP is 50
blood pressure with inferences from this noninvasive estimate, obtained by raising the arterial transducer to the level of brain. This is particularly important to our study due to the ongoing debate about which theory, the open “waterfall” or closed “siphon,” is more applicable to true cerebral perfusion in the beach chair position.10

NIBP measurements may also be affected by the method of delivering anesthesia. We induced all patients with propofol and maintained anesthesia with sevoflurane. Although there is a debate regarding the effects of sevoflurane on cerebral autoregulation, this has not yet been definitively established. Recent literature has shown that sevoflurane, like other volatile anesthetics, has a dose-dependent cerebral vasodilatory action that needs to be considered by the anesthesia provider.16,20,26,31 Our consistent approach to anesthesia limits variability in our measurements; however, we are unable to determine if sevoflurane, and its influence on cerebral autoregulation, has an effect on the magnitude of the relationship between eTMAP and NIBP.

The results of this study emphasize the importance of correcting measurements of brachial NIBP to estimate cerebral perfusion in the beach chair position. Brachial NIBP measurements, without consideration of the eTMAP/NIBP ratio at varying upright positions, would lead to an overestimation of CPP. This is especially important in patients with poorly controlled hypertension, who have been shown to require a higher LLA to ensure adequate cerebral perfusion.4,12 In a retrospective review of 384 patients in the beach chair position, Trentman et al38 found an increased incidence of hypotensive episodes and vasopressor use in patients receiving preoperative antihypertensive medication.

Recent literature has argued that a reduction in blood pressure may be better tolerated in the beach chair position than previously thought. In a prospective study of 52 patients who underwent general anesthesia with controlled hypotension in the beach chair position, Gillespie et al19 used electroencephalography (EEG) to monitor cerebral perfusion.9 Three patients experienced ischemic changes on EEG that resolved with an increase in blood pressure, with no postoperative complications. A mean systolic blood pressure and MAP decrease of 36% and 42%, respectively, from baseline yielded no EEG changes.7

Despite a lack of consensus regarding the ideal blood pressure required during elective shoulder surgery in the beach chair position, being able to infer changes at the cerebral level using brachial measurements is important. Results of this study show that with increasing inclination, the eTMAP/NIBP ratio lessens. If this decrease is not taken into consideration, the use of brachial NIBP in a patient in the upright position may lead to overestimation of eTMAP and cerebral perfusion. Proper adjustment for these differences will help to ensure adequate cerebral perfusion and prevention of hypoxic-related sequelae.

This study has several limitations. Only 3 points of reference (0°, 30°, and 70° of incline) were used. Additional points of reference would provide a more accurate insight to the gradual progression to the upright position and its effects on the measured variables. Also, repeated measures at each position may limit the variability in the data by allowing adequate time for equilibration and reconfirming the obtained values. In addition, the mean age of the patients in this study, 71 years, does not adequately represent the overall population undergoing shoulder surgery. Owing to age-related changes, such as decrease in arterial compliance and cardiac response, these findings may more accurately represent the elderly population undergoing shoulder surgery in the beach chair position. Lastly, a single surgeon at a single institution performed the operation on all patients in this study. Variability of
References


Conclusion

The ratio of eTMAP to NIBP decreases as an anesthetized patient is placed into the beach chair position. Estimated MAP at the level of the brain can be calculated from NIBP measurements by using defined ratios. These ratios are important in ensuring adequate cerebral perfusion and preventing hypoxic-related injury reported with this position. Proper adjustment in pressure control should be made based on patient position.

Disclaimer

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anesthesia protocol, surgeon technique, and operating time may influence cerebral perfusion and data values.