Cerebral tissue oxygen saturation values in volunteers and patients in the lateral decubitus and beach chair positions: a prospective observational study

Valeurs de saturation en oxygène cérébral tissulaire de volontaires sains et de patients en décubitus latéral et en position assise: une étude observationnelle prospective

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Abstract

Background The objective of this study was to describe changes in cerebral tissue oxygen saturation ($SctO_2$) due to changes in body position in healthy volunteers and in patients undergoing surgery under general anesthesia in the beach chair position (BCP) and lateral decubitus position (LDP).

Methods In this prospective observational study, $SctO_2$ was measured in 85 awake volunteers serially positioned every 15 min, beginning with the supine position (SP) and followed by the beach chair, supine, and lateral decubitus positions. Cerebral tissue oxygen saturation was also measured supine and in either the BCP or the LDP in 195

patients (according to surgical preference) undergoing elective arthroscopic shoulder surgery. We measured the lowest stable $SctO_2$ values in each position as well as changes in blood pressure and heart rate.

Results In healthy volunteers, the median (interquartile range [IQR]) lowest stable $SctO_2$ value in the SP was 69 [66–71] %. A change in position to the BCP caused a small but statistically significant decrease in the median [IQR] lowest $SctO_2$ value to 67 [65–70] % ($P = 0.028$ compared with baseline). This decrease was associated with an increase in median [IQR] arterial pressure from 83 [78–88] mmHg in the SP to 85 [81–93] mmHg in the BCP ($P < 0.001$ compared with baseline). In patients undergoing surgery in the BCP, the median [IQR] lowest stable $SctO_2$ value was 55 [51–59] %, which was significantly lower ($P < 0.001$) than the median [IQR] lowest $SctO_2$ value in patients in the LDP (66 [62–69] %). More patients in the BCP group (57%) showed $SctO_2$ values $\leq 55\%$ and/or a decrease of $\geq 20\%$ from baseline (57%) compared with the LDP group (5% and 6%, respectively; $P < 0.001$ for each comparison).

Conclusions More than 55% of patients undergoing arthroscopic shoulder surgery in the BCP experience cerebral desaturation events. In volunteers without anesthesia, no desaturation events were observed. The clinical importance of these findings needs further investigation.

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Résumé

Contexte L'objectif de cette étude était de décrire les changements de la saturation en oxygène cérébral tissulaire ($SctO_2$) provoqués par les changements de

position du corps chez des volontaires sains et des patients subissant une chirurgie sous anesthésie générale en position assise (PAs - beach chair position) et en décubitus latéral (DL).

Méthode Dans cette étude observationnelle prospective, on a mesuré la SctO₂ de 85 volontaires sains éveillés repositionnés en série toutes les 15 minutes, en commençant en position allongée (PAI) puis en position assise, puis allongée à nouveau, et finalement en décubitus latéral. La saturation en oxygène cérébral tissulaire a également été mesurée en position allongée et en PAs ou en DL chez 195 patients (selon la préférence chirurgicale) subissant une arthroscopie non urgente de l'épaule. Nous avons mesuré les valeurs stables de SctO₂ les plus basses dans chaque position ainsi que les changements de tension artérielle et de fréquence cardiaque.

Résultats Chez les volontaires sains, la valeur stable moyenne (écart interquartile [ÉIQ]) la plus basse de SctO₂ en PAI était 69 [66-71] %. Un changement en PAs a provoqué une réduction, faible mais significative d'un point de vue statistique, de la valeur médiane [ÉIQ] la plus basse de SctO₂ à 67 [65-70] % ($P = 0,028$ comparativement aux valeurs de base). Cette réduction a été associée à une augmentation de la tension artérielle médiane [ÉIQ] de 83 [78-88] mmHg en PAI à 85 [81-93] mmHg en PAs ($P < 0,001$ comparativement aux valeurs de base). Chez les patients subissant une chirurgie en PAs, la valeur médiane [ÉIQ] stable la plus basse de SctO₂ était de 55 [51-59], soit significativement plus basse ($P < 0,001$) que la valeur médiane [ÉIQ] stable la plus basse telle que mesurée chez les patients en DL (66 [62-69] %). La plupart des patients du groupe PAs (57 %) ont montré des valeurs de SctO₂ ≤ 55 % et/ou une réduction ≥ 20 % par rapport aux valeurs de base (57 %) comparativement au groupe DL (5 % et 6 %, respectivement; $P < 0,001$ pour chaque comparaison).

Conclusion Plus de 55 % des patients subissant une arthroscopie de l'épaule dans le groupe PAs ont subi des épisodes de désaturation cérébrale. Chez les volontaires sains n'ayant pas subi d'anesthésie, aucun épisode de désaturation n'a été observé. L'importance clinique de ces résultats nécessite des recherches plus approfondies.

Surgery in the beach chair position (BCP) has repeatedly been associated with significant hemodynamic changes that have the potential to compromise the cerebral circulation and place a patient at risk for cerebral ischemia.^{1,2} Moreover, for many surgical procedures (such as endoscopic shoulder surgery), optimal surgical visualization may require the use of controlled hypotension. Combining the BCP with controlled hypotension could increase the threat of inadequate cerebral perfusion. These assumptions are supported by case reports on

adverse neurological sequelae after shoulder surgery in the BCP.^{3,4}

Cerebral oximetry near-infrared spectroscopy (NIRS) permits the detection of changes in cerebral tissue oxygen saturation (SctO₂). This technology has been extensively used to provide a noninvasive real-time indicator of cerebral hypoperfusion⁵ - mainly during cardiac surgery. Not surprisingly, several groups have reported their experience on the use of cerebral oximetry during shoulder surgery in the BCP, and every group revealed significant decreases in SctO₂ during the procedure.⁶⁻¹³ Nevertheless, many questions remain about what constitutes a "normal" SctO₂ value and what SctO₂ values are acceptable during general anesthesia.

The first objective of this study was to measure the changes in SctO₂ values in healthy volunteers after positioning in the supine, BCP, and lateral decubitus positions (LDP). Our second objective was to measure the changes in SctO₂ values in patients after position changes during shoulder surgery under general anesthesia.

Methods

Cerebral tissue oxygen saturation monitoring

Bilateral SctO₂ was measured using the FORE-SIGHT™ technology (CAS medical systems Inc, Branford, CT, USA) in both volunteers and patients. The FORE-SIGHT cerebral oximeter is a noninvasive device that uses four wavelengths of laser light to determine absolute cerebral oxygen saturation. Cerebral tissue oxygen saturation represents the oxygen saturation level in the microvasculature of brain tissue, which contains a mixture of arterial and venous blood (estimated to be 30/70%). Sensors were applied to each frontotemporal area and covered to prevent external light interference. For each body position, the lowest stable (i.e., displayed for at least ten seconds) SctO₂ value (right or left side) was recorded and used for statistical analysis. In the case of shoulder surgery, the attending anesthesiologist was blinded to the SctO₂ data, and therefore, any changes in SctO₂ could not have resulted in any changes in therapy such as blood pressure management.

Volunteers

The study protocol was approved by the local committee (Ziekenhuis Oost-Limburg, Genk, Belgium) for medical ethics, and written informed consent was obtained from all participants (patients and volunteers).

Volunteers were healthy (American Society of Anesthesiologists physical status I) males and females 18-30 yr of age. Monitoring of baseline bilateral SctO₂

values was started in the supine position. The position was then changed to the beach chair, supine, and the lateral decubitus positions for 15 min each. Apart from the bilateral SctO₂ monitoring, heart rate (HR), pulse oximetry, and noninvasive blood pressure measurements were taken every five minutes.

Patients

Patients scheduled to undergo elective arthroscopic shoulder surgery under general anesthesia in the BCP or LDP were enrolled in the study. Exclusion criteria were pre-existing cerebrovascular disease, peripheral vascular disease, and age < 18 yr. Monitoring of baseline bilateral SctO₂ values was started in the supine position and monitoring continued with the change to either the BCP or LDP. Allocation to either the BCP or the LDP group was determined by surgical preference.

Anesthesia

Anesthetic management was performed in both patient groups by the same team of anesthesiologists. Thirty minutes prior to surgery, all patients received an interscalene plexus block with a single injection of a maximum of 30 mL of 0.5% bupivacaine. All surgical procedures were performed under general anesthesia (propofol/rocuronium/remifentanyl; F_IO₂ 30%). Standard monitoring (noninvasive blood pressure measurement on the contralateral arm, electrocardiography, peripheral oxygen saturation, and end-tidal capnography) was applied. The management of anesthesia and, when requested by the surgeon, controlled hypotension was left to the discretion of the attending anesthesiologist who was blinded to the cerebral oximetry values. In all patients, severe arterial hypotension [i.e., mean arterial pressure (MAP) < 60 mmHg] was countered by reducing the remifentanyl or propofol infusions or by administering boluses of colloids, phenylephrine, or ephedrine.

Statistical analysis

Statistical analysis was performed using SPSS® V19.0 (SPSS Inc, Chicago, IL, USA). Discrete data were compared using the χ^2 test. The normality of variable distributions was tested using the Kolmogorov-Smirnov test. Normally distributed continuous data were compared using the unpaired Student's *t* test. Hemodynamic and cerebral oxygen saturation values were compared between groups using the Mann-Whitney U test. To compare values within the same group, the paired Wilcoxon test was used. Possible correlations between SctO₂ and MAP were analyzed using the Pearson correlation test. The results are represented as median (interquartile range [IQR]),

mean [standard deviation (SD)], or percent (%) as indicated. All reported *P* values are two sided.

Results

Healthy volunteers

Ninety-one healthy volunteers with a mean (SD) age of 23 (3) yr were recruited from October 2008 to May 2010. Due to missing SctO₂ data, six volunteers were excluded from further analysis. Characteristics of the 85 healthy volunteers are presented in Table 1.

In volunteers, changing the body position from supine to beach chair caused the median [IQR] lowest stable SctO₂ value to decrease from 69% [66-71] to 67% [65-70] (*P* = 0.028). This decrease was associated with an increase in median MAP from 83 to 85 mmHg (*P* < 0.001 compared with baseline), while HR and arterial oxygen saturation (SpO₂) remained stable. When the body position was changed again from beach chair to supine, the median [IQR] lowest stable SctO₂ value was 68 [65-70] % (*P* = 0.47). Median [IQR] MAP decreased to 80 [74-87] mmHg (*P* < 0.001 compared with the BCP), while HR and SpO₂ remained stable. When turned from supine to the right lateral decubitus position, the median [IQR] lowest stable SctO₂ value remained at 68 [65-71] %. Median [IQR] MAP further decreased to 75 [69-83] mmHg (*P* < 0.001 compared with supine). Detailed results obtained in the healthy volunteers are presented in Table 2.

Patients

There were 236 patients recruited for the study; however, 41 of the participants were excluded from further analyses because SctO₂ and/or hemodynamic data were incompletely recorded or stored. Of the 195 remaining patients, 101 and 94 patients underwent surgery in the BCP and LDP, respectively. The two patient groups were comparable regarding sex, American Society of Anesthesiologists status, pre-existing hypertension, and preoperative hemoglobin levels. The age of patients in the BCP was significantly higher than the age of patients in the LDP (Table 1).

Table 1 Characteristics

	Volunteers	Patients	P value
Number, n	85	195	-
Age, yr (SD)	23 (3)	53 (13)	< 0.001
ASA status, n (I/II/III)	85/0/0	124/67/4	< 0.001
Hypertension, n (%)	0 (0%)	26 (13%)	< 0.001

ASA = American Society of Anesthesiologists; SD = standard deviation

Table 2 Results of healthy volunteers

	SP	BCP	SP	LDP
Lowest SctO ₂ (%)	69 [66-71] *	67 [65-70]	68 [65-70]	69 [65-71]
HR (beats·min ⁻¹)	68 [61-76]	68 [63-76]	67 [61-75]	68 [61-73]
MAP (mmHg)	83 [78-88] *	85 [81-93] *	80 [74-87] *	75 [69-83]
SpO ₂ (%)	98 [97-99]	98 [97-99]	98 [97-99]	98 [97-99]
% decrease in SctO ₂	1 [0-2]	-1 [-1-0]		0 [-1-1]

Volunteers were serially moved from the supine position to the beach chair position, followed by a return to the supine position and a final change to the lateral decubitus position. Each position was held for 15 min

Results are shown as median [interquartile range]. *Significant difference compared with previous position ($P < 0.05$). BCP = beach chair position; HR = heart rate; LDP = lateral decubitus position; MAP = mean arterial pressure; SctO₂ = regional cerebral tissue oxygen saturation; SpO₂ = peripheral capillary oxygen saturation; SP = supine position

In patients undergoing elective arthroscopic shoulder surgery, the median [IQR] lowest stable SctO₂ value in the supine position before induction of anesthesia (during pre-oxygenation) was used as baseline (72 [70-75] % and 73 [71-76] % for the BCP and LDP groups, respectively; $P = 0.18$).

In patients positioned in BCP, the median [IQR] lowest stable SctO₂ value during surgery was 55 [51-59] %, which was significantly lower ($P < 0.001$) than the median [IQR] lowest stable SctO₂ value in patients undergoing surgery in the LDP (66 [62-69] %). In 57% of the patients in the BCP group, a drop of $\geq 20\%$ in SctO₂ compared with baseline was observed, whereas this happened in only 6% of the patients in the LDP group. Detailed SctO₂ data are presented in Table 3. The time course of the median SctO₂ values during surgery in the BCP and LDP groups is shown in Figure.

After induction of anesthesia and change in position, MAP (measured at the level of the heart) decreased in each patient group, but this decrease was not significantly different between the two groups ($P = 0.097$). Nevertheless, assuming a decrease of 0.77 mmHg for every centimetre gradient¹⁴ and an approximate gradient of 22 cm (30° angle) between the external auditory meatus and the site of the blood pressure cuff, the median [IQR] decrease in MAP measured at the level of the brain was significantly more important in the BCP group than in the LDP group (61 [57-68] mmHg vs 43 [31-46] mmHg, respectively; $P < 0.001$).

For the patients in the BCP group, a correlation ($R^2 = 0.4$) was observed between the decrease in MAP (measured at the level of the brain) and the decrease in SctO₂.

The median [IQR] end-tidal CO₂ (EtCO₂) at the moment of the lowest stable SctO₂ value was 31 [29-34] mmHg in the BCP group and 31 [28-34] mmHg in the LDP group ($P = 0.34$).

Discussion

In this study, a very small decrease in SctO₂ was observed in healthy volunteers when body position changed from the supine to the BCP. Only a very limited number of studies have been published on the impact of body positioning on SctO₂ in healthy volunteers.¹⁵⁻¹⁸ Moreover, in these studies, the numbers of healthy volunteers studied were rather small (minimum, $n = 5$; maximum, $n = 28$) and different types of cerebral oximeters were used (NIROTM,¹⁵ OxyMonTM,¹⁶ INVOSTM).^{17,18} Generally, a decrease (although not significant in all studies) in SctO₂ was reported when changing from the supine to the upright position, which is confirmed by the results from our current study.

In awake subjects, upright positioning activates the sympathetic nervous system, resulting in an increase in blood pressure.¹ In our group of healthy volunteers, MAP increased from 83-85 mmHg when changing from the supine to the upright position (Table 2). This small increase in MAP was accompanied by a small decrease in SctO₂.

In patients under general anesthesia, activation of the sympathetic nervous system to maintain cerebral perfusion in the sitting position is often blunted or absent.¹⁹ With 57% of our patients under general anesthesia revealing SctO₂ values $< 55\%$ and a decrease of $\geq 20\%$ from baseline in the BCP, we confirm previous results on the frequent occurrence of cerebral tissue oxygen desaturation in patients undergoing arthroscopic shoulder surgery in the BCP.⁶⁻¹¹

The combination of general anesthesia and controlled hypotension resulted in a median decrease in blood pressure of 45 mmHg in both of our patient groups. Brachial noninvasive blood pressure monitoring, as in our

Table 3 Results of patients in beach chair and lateral decubitus position

	SP	BCP	SP	LDP
Lowest SctO ₂ (%)	72 [70-75] *	55 [51-59]	73 [71-76] *	66 [62-69]
HR (beats·min ⁻¹)	79 [71-92] *	59 [54-66]	84 [66-91] *	54 [49-64]
MAP (mmHg)	106 [98-121] *	59 [51-66]	110 [98-122] *	63 [57-74]
cMAP (mmHg)	106 [98-121] *	42 [34-49]	110 [98-122] *	63 [57-74]
SpO ₂ (%)	99 [98-100]	97 [96-98]	99 [98-99]	98 [97-99]
SctO ₂ ≤ 60%, n (%)	86 (85)		16 (17)	
SctO ₂ ≤ 55%, n (%)	57 (56)		5 (5)	
Time ≤ 55% (min)†	16 (15-73)		14 (3-34)	
% decrease in SctO ₂	21 [15-28]*		10 [3-15]	
≥ 20% decrease in SctO ₂ , n (%)	57 (56)		6 (6)	

Results are shown as median [interquartile range] unless otherwise indicated

† Mean (min-max)

* Significant difference compared with previous position (P < 0.05)

BCP = beach chair position; cMAP = estimated mean arterial pressure at the level of the brain; LDP = lateral decubitus position; HR = heart rate; MAP = mean arterial pressure; SctO₂ = regional cerebral tissue oxygen saturation; SpO₂ = peripheral capillary oxygen saturation; SP = supine position

Figure Cerebral oxygen saturation (SctO₂) during arthroscopic shoulder surgery in the beach chair position (grey line) or lateral decubitus position (black line). Results are presented as median with interquartile range

study, overestimates the pressure in the elevated brain.^{13,14} When we apply the hydrostatic gradient¹⁴ to the blood pressure values of our patients, MAP would be approximately 42 mmHg in the brain of patients in the BCP compared with 59 mmHg measured at the level of the heart. The MAP at the top of the cortex could add another 6-9 mmHg to this gradient.²⁰ This low cerebral MAP could help explain the lower SctO₂ values in patients in the BCP compared with patients in the LDP. Nevertheless, the calculated R² of 0.4 between a decrease in MAP and a decrease in SctO₂ suggests that some patients with higher

MAPs may have lower SctO₂ values and vice versa, so factors other than MAP must contribute to SctO₂.

To maintain arterial pressure in patients undergoing shoulder surgery in the BCP, phenylephrine and/or ephedrine are most commonly used. Meng *et al.* observed that SctO₂ did not change when ephedrine was used but decreased (together with cardiac output) after the use of phenylephrine.²¹ Ogoh *et al.* recently showed that vasoconstriction in the extracranial vasculature could be responsible for this decrease in SctO₂.²² To monitor the effect of vasopressor treatment on cerebral oxygenation, NIRS monitoring could be of further value.

In addition to the effects of the sitting position and hypotension in patients, ventilator strategies, such as hyperventilation, can influence cerebral blood flow and thus cerebral oxygenation. Recently, Murphy *et al.* observed a lower incidence of desaturation events and higher cerebral oxygenation values in a patient group with an EtCO₂ of 40-42 mmHg compared with a group with an EtCO₂ of 30-32 mmHg.⁷ We report EtCO₂ values of 31 mmHg in both of our patient groups, which corresponds with the standard practice group of Murphy *et al.* with lower SctO₂ values.

Finally, NIRS technology measures saturation in the arterial, venous, and capillary compartments. Change in body position may alter the ratio of these compartments in the cerebral circulation, and therefore, reductions in SctO₂ may not necessarily reflect an actual change in brain oxygenation.

There are several limitations to the present investigation. Near-infrared spectroscopy measurements are limited to the prefrontal cortex; therefore, we were not able to measure oxygenation in other parts of the brain. Near-infrared spectroscopy monitors are provided with an algorithm to remove the signal of extracerebral tissues from the actual value. Nevertheless, this could still contribute significantly to the signal.²³ Patients were not randomized but allocated to either the BCP or the LDP according to surgical preference, and this preference may introduce bias. Finally, cerebral tissue oxygenation is a surrogate marker for clinically important outcomes such as adverse neurological events. We have not attempted to associate SctO₂ values with clinically important outcomes. It is still unknown whether low SctO₂ values presage worse postoperative neurological outcomes.

Conclusion

More than 55% of the patients undergoing arthroscopic shoulder surgery in the BCP experienced cerebral desaturation events. In contrast, SctO₂ in awake volunteers decreased only minimally. Further research should be performed to elucidate the clinical importance of cerebral desaturation events in patients undergoing shoulder surgery under general anesthesia in the beach chair position.

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Conflicts of interest None to declare.

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