

Measurements of oxygen saturation of brain, liver and heart areas in the supine and sitting position using near infrared spectrophotometry

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Abstract

Background and aims: Regional oxygen saturation (rSO₂) monitoring of the brain by near-infrared spectroscopy (NIRS) has been mainly used during carotid endarterectomy. The present study was conducted in volunteers and investigates the rSO₂ values of the brain, heart and liver tissue as assessed by NIRS in the supine and the sitting position.

Methods: After obtaining written informed consent from forty-nine healthy volunteers, rSO₂ values were recorded in the heart and liver areas in the supine and the sitting position, while simultaneously the rSO₂ values of the brain.

Results: The rSO₂ brain values in the supine and the sitting position were 69 ± 6.0 and 66 ± 6.1 respectively (p = 0.0001). The rSO₂ values in the supine and the sitting position were 76 ± 10.5 and 79 ± 6.7 for the heart (p > 0.05) and 85 ± 6.8 and 82 ± 7.2 for the liver, (p = 0.007). Heart rSO₂ values were higher than the brain rSO₂ values in both the supine (76 ± 10.4 versus 69 ± 6.6; p = 0.0001) and the sitting position (79 ± 6.7 versus 66 ± 6.1; p = 0.0001). The liver rSO₂ values were also higher than the brain rSO₂ values in the supine (85 ± 6.8 versus 69 ± 6.0; p = 0.0001) and in the sitting position (82 ± 7.2 versus 66 ± 5.7; p = 0.0001). Arterial blood pressure and arterial oxygen saturation (SpO₂) did not differ between the two positions but the heart rate was higher in the sitting position (p = 0.030).

Conclusions: We conclude that brain and liver (but not heart) rSO₂ values are higher in the supine than sitting position. Additionally, NIRS may be used to assess oxygenation of the heart and liver.

Keywords: tissue oxygenation, near infrared spectroscopy (NIRS), brain oxygenation, heart oxygenation, liver oxygenation

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Introduction

Cerebral oximetry by near-infrared spectroscopy (NIRS) measures intracerebral oxygen saturation (rSO₂) continuously and non-invasively [1]. The method has been validated and used extensively during carotid endarterectomy to monitor the rSO₂ values during carotid clamping [2, 3]. It has also been used in stroke and cardiac arrest patients to detect desaturation of

the metabolically active brain but may exhibit normal values in the absence of cerebral perfusion [4]. Cerebral oximetry is useful during coronary artery bypass surgery as its use is associated with a shorter length of stay in the ICU, lower incidence of stroke, renal failure, deep sternal infection, prolonged ventilation, reoperation and death [5].

In elderly patients undergoing major abdominal surgery, monitoring of cerebral oxygen saturation revealed that cerebral desaturation is common, and it is associated with early postoperative cognitive dysfunction that can be corrected by blood transfusion [6, 7]. The rSO₂ values depend on blood flow and on the perfusion pressures and oxygen extraction by the different tissues. Our hypothesis was that regional

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hemoglobin saturation is posture dependent, thus rSO_2 values will change from supine to sitting position and vice versa. We also hypothesized that cerebral oximetry may be used to assess the oxygenation of other vital organs like heart and liver.

The aim of this prospective observational study was to evaluate changes in the rSO_2 in volunteers due to changes in position (from sitting to supine or the other way around) using the INVOS 4100 cerebral oximeter (Somanetics, Troy, MI, USA). A secondary aim was to investigate the potential of monitoring the regional oxygenations of other organs such as the liver and heart by means of NIRS in both the supine and sitting positions.

Methods

After obtaining approval from the Institutional Review Board (IRB), 36 women and 13 men gave written informed consent to participate in the study. All volunteers were ASA I physical status with a mean age of 30 (min-max: 20-61) years. Exclusion criteria included intake of drugs with effect on the nervous system (such as benzodiazepines and opioids), obesity, smoking and alcoholism. The study was performed between June 2006 and November 2009.

Measurements included simultaneous rSO_2 recordings of the brain and heart in the supine and sitting positions. Similarly, rSO_2 recordings of the liver in both supine and sitting position were performed simultaneously with rSO_2 recordings of the brain, as NIRS is primarily the method used to measure the regional hemoglobin saturation in the brain. All measurements for heart and liver along with the brain measurements as a standard comparator were performed on the same day. The rSO_2 of each organ was measured with the INVOS 4100 cerebral oximeter (Somanetics, Troy, MI, USA) and the Somanetics disposable sensor.

Systolic and diastolic arterial pressure as well as arterial oxygen saturation by means of pulse oximeter (SpO_2) was also measured along with the rSO_2 measurements. The order of the position for measurements, supine versus sitting, was determined by a coin toss. Regarding liver versus heart rSO_2 measurements, the order was determined with opaque sealed envelopes containing the code for the relevant tissue. Systolic and diastolic arterial blood pressure, heart rate and SpO_2 were recorded before and after rSO_2 measurements in each position.

The left disposable INVOS sensor was applied on the ipsilateral temporal area of the brain, specifically on the left forehead with the caudal border about 1 cm above the eyebrow and the medial edge on the midline, between the two eyebrows. The right sensor was

attached over the sternum area, or over the liver area according to the order of randomization (Fig. 1). The volunteer was allowed to relax in the predetermined position at least 5 minutes and subsequently remained in this position to accomplish the series of measurements, thus rSO_2 values of the brain and the predetermined organ. Subsequently the right sensor was applied over the next tissue while the left sensor remained on the temporal area. The rSO_2 values of the brain and the next tissue, liver or heart were recorded. When measurements were completed at the supine or the sitting position the volunteer was asked to change position and to remain relaxed for more than 5 minutes. Then the whole series of measurements was repeated in the new position.



Fig. 1. Sensor placement over the brain and heart areas

The primary endpoint of the study was determination of the rSO_2 values in each organ in the supine versus the sitting position. The secondary end point was to compare the rSO_2 values obtained from the sensor applied on the sternum area representing the heart and the right sub costal area representing the liver with the values recorded simultaneously from the brain.

A priori power analysis (GPower 3.0.8, Universität Düsseldorf, Germany) showed that in order to find a medium size (0.25) of effect according to d Cohen's

coefficient, between the brain rSO₂ in the supine and sitting positions, which corresponds to 6% variance, with a power of 0.90 and an error $\alpha = 0.5$, a sample of 45 subjects was needed.

Statistical analysis was performed with SPSS, IBM statistical package (version 17.0). According to Kolmogorov Smirnov test all rSO₂ values followed normal distribution.

The heart rate and the rSO₂ values in the supine versus the sitting position obtained from each individual organ were analyzed with paired t-test. Similarly, paired t-test was used to compare the rSO₂ values between the brain and the heart and between the brain and the liver in both supine and sitting position. Systolic and diastolic arterial pressure and arterial oxygen saturation (SpO₂) values in the supine versus the sitting position did not follow normal distribution and were analyzed with Wilcoxon Signed Ranks test. A value of $p < 0.05$ was considered statistically significant.

Results

Measurements were performed in all volunteers and their characteristics are shown in Table 1. Incomplete measurements were one rSO₂ value in the heart recordings with the volunteer in the supine position, and six and four rSO₂ values during measurements with the sensor over the liver at the supine and sitting position, respectively. These values were not obtained due to technical reasons.

Table 1. Age, body weight and height in the 49 volunteers recruited for the study

Age (years)	30 (20-61)
Body Weight (kg)	65 (47-100)
Height (cm)	169 (150-180)

Values are mean (range)

The rSO₂ comparisons for the same organ between the supine and the sitting position are shown in table 2 and figure 2. The rSO₂ values obtained for the brain and the liver were lower in the sitting when compared

to the supine position ($p = 0.0001$ and $p = 0.007$, respectively). However, we found no significant differences in the rSO₂ values between the supine and sitting position in the heart ($p = 0.212$).

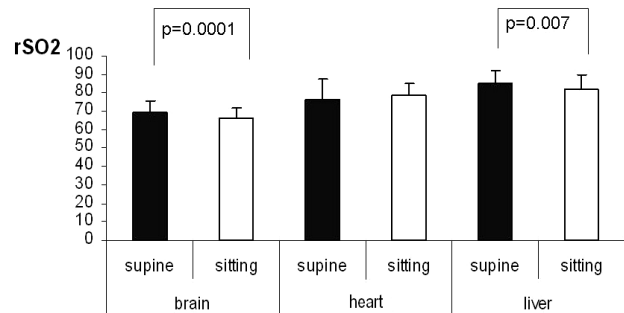


Fig. 2. The rSO₂ values of the brain, heart and liver in the supine versus the sitting position

The rSO₂ comparisons between brain and heart and brain and liver in the supine and the sitting position are shown in table 3 and figure 3. The heart area exhibited higher rSO₂ values when compared to the brain in both the supine and the sitting position ($p = 0.0001$ and $p = 0.0001$, respectively). This might be due to the venous blood return to the heart, which is increased in the supine position, while in the same position the brain receives more arterial blood. With regard to the brain

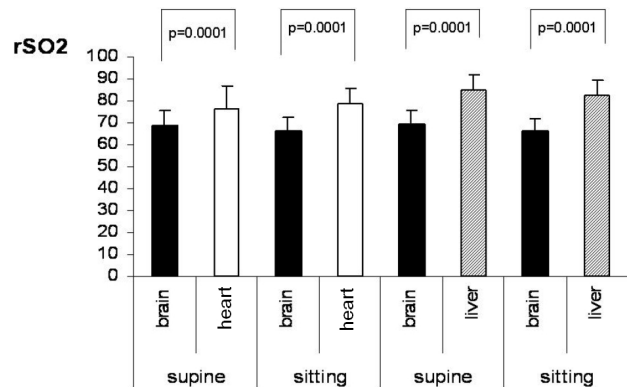


Fig. 3. The rSO₂ values of the brain versus heart and of the brain versus liver in the sitting and in the supine position

Table 2. The rSO₂ values in the supine and sitting position for the brain, heart and liver tissue

Brain		Heart		Liver	
Supine (N = 49)	Sitting (N = 49)	Supine (N = 48)	Sitting (N = 49)	Supine (N = 43)	Sitting (N = 45)
69 ± 6.0	66 ± 5.7	76 ± 10.5	79 ± 6.7	85 ± 6.8	82 ± 7.2
67.7-71.1	64.6-67.9	73.5-79.6	76.7-80.6	82.9-87.1	80.1-84.4
t = -5.837, p = 0.0001		t = 1.26, p = 0.212		t = -2825, p = 0.007	

Values are mean ± SD, 95% confidence interval and t score

Table 3. The rSO₂ values of the brain compared to the rSO₂ values obtained from heart and to the rSO₂ values obtained from the liver in the supine and sitting position

Supine		Sitting		Supine		Sitting	
Brain (N = 49)	Heart (N = 48)	Brain (N = 49)	Heart (N = 49)	Brain (N = 49)	Liver (N = 43)	Brain (N = 49)	Liver (N = 45)
69 ± 6.6	76 ± 10.4	66 ± 6.1	79 ± 6.7	69 ± 6.0	85 ± 6.8	66 ± 5.7	82 ± 7.2
67.1 - 70.9	73.5 - 79.6	64.3 - 67.8	76.7 - 80.6	67.7 - 71.1	82.9 - 87.1	64 - 67.9	80 - 84.4
t = -5.079, p = 0.0001		t = -10.114, p = 0.0001		t = -10.542, p = 0.0001		t = -11.576, p = 0.0001	

Values are mean ± SD and 95% confidence interval

and liver comparisons, the liver rSO₂ values are higher in both the supine (p = 0.0001) and sitting position (p = 0.0001). The rSO₂ difference between brain and liver in both positions is the same (16%) considering that both organs receive more arterial blood in the supine position.

We found no difference in the SpO₂ values recorded during the rSO₂ measurements of the heart and the liver between the supine and the sitting position (p = 0.738 and p = 0.434 respectively). Similarly systolic and diastolic blood pressures did not differ significantly (p = 0.311 and p = 0.73 respectively). Heart rate was higher in the sitting versus the supine position (p = 0.030).

Discussion

The results of the present study demonstrate that rSO₂ values for the brain and for other areas of the body measured by NIRS vary with the patient's posture. The data also showed that rSO₂ measured in the brain and heart area in the sitting position differ. The rSO₂ values between brain and liver differ and this difference is the same in both positions (16%).

Several factors may interfere and influence the rSO₂ measurements by NIRS. Kishi et al. investigated the rSO₂ values in the brain obtained after a sensor position at different sites on the forehead and also the impact of factors such as patient characteristics and hemoglobin concentration [8]. The sensor location, age and hemoglobin all are determinants of the rSO₂ values. An inverse relationship was found between age and rSO₂ values and a direct relationship between hemoglobin and rSO₂ values [8]. In fact in elderly patients undergoing prolonged major abdominal surgery the significant decreases observed in rSO₂ during major hemorrhage, despite maintenance of blood pressure responded only to blood transfusion [7]. We did not include elderly volunteers so we do not expect age to have an impact to the rSO₂ values we measured. We did not measure the hemoglobin of our volunteers with free history for disease as our interest was focused on possible changes in the rSO₂ with changes in posture and not on absolute rSO₂ values.

Yoshitani et al. evaluated clinically the skull thickness, the area of the cerebrospinal fluid layer, the mean arterial pressure and the hemoglobin concentration, and found that all are determinants of the NIRS values [9]. These parameters had no effect on the tissue oxygen index, which is the ratio of oxyhemoglobin to total hemoglobin.

Nonetheless, these factors are dependent upon the technique of measurement and not upon the patient's factors as in the rSO₂ measurements the calculations include the optical path length, while in the tissue oxygen index algorithm the optical path length is not included in the formula [10]. For this reason the same parameters had no effect on the tissue oxygen index.

In our study the impact of the different factors that may influence the rSO₂ measurements, such as hemoglobin and patients' characteristics are constant and do not change during the measurements obtained in the different positions or in the different body areas. Therefore, these variables are not expected to affect the measurements in different ways.

The rSO₂ was found to increase significantly when NIRS assessments were made with the subjects placed from the supine to the 20° Trendelenburg position, but not in the 20° reverse Trendelenburg position [11]. Similarly, in our study the supine position is associated with increased rSO₂ values in both the brain and liver compared to the sitting position. This change, which may not be clinically significant, is likely related to increased cardiac output due to increased venous return in the supine position. In contrast, in the heart we found higher rSO₂ values in the sitting position. This could be explained by the fact that in the supine position the increased return of venous blood goes directly to the heart decreasing so the rSO₂ value. The finding that rSO₂ values in the heart are higher in the sitting than in the supine position suggests that the sternum area may be appropriate location for the sensor to monitor the heart rSO₂. Additionally other locations for placement of the sensor to monitor the rSO₂ of the heart (such as the apical area of the chest) are not always feasible particularly in women due to the breasts.

Arterial blood pressure and SpO₂ may also influence the NIRS measurements. Yoshitani et al. found that mean arterial pressure was a significant factor that determines the SpO₂ [9]. In a retrospective study Paquet et al. reported that rSO₂ brain values correlated significantly to the central venous pressure, the pulmonary capillary wedge pressure, the mean pulmonary artery pressure, the mean arterial pressure/mean pulmonary artery pressure ratio, the left fractional area change and the regional and motion score index and the diastolic function [12]. The authors conclude that NIRS may have a place in cardiac function assessment.

Although we found changes in the rSO₂ between the supine and the sitting position systolic and diastolic arterial pressure did not change. This finding may be explained by the fact that the volunteers were young subjects and compensated by the increase in heart rate. Sitting position is rarely used today during surgery, aside from neurological (sitting craniotomy) and orthopedic (shoulder surgery) procedures. However the changes in the rSO₂ values we observed imply possible changes of this variable when positions other than the supine are adopted intraoperatively.

Regarding the rSO₂ in areas other than the brain, to our knowledge no previous studies used INVOS to investigate the feasibility of monitoring the rSO₂ in other organs such as heart or liver. The rSO₂ values we recorded in the sternum area are consistent with those close to the SvO₂ values in healthy subjects. Considering the rSO₂ of the brain as the gold standard we found higher rSO₂ values primarily in the liver and secondarily in the heart areas. Nonetheless, each tissue exhibits its own rSO₂ values and the importance may be the changes in rSO₂, particularly in critical situations like multiple organ failure.

The consistent difference between the rSO₂ values in the brain and liver in both positions suggests that the method and the medical device may be useful to monitor oxygenation of the liver but the rSO₂ baseline values should be higher. Also the fact that the rSO₂ values obtained in the heart do not differ between the two positions, evidently due to the increased return of venous blood to the heart in the supine position suggests that the method may be useful to monitor the global oxygenation of the heart.

Conclusion

The position of the patient influences the rSO₂ values measured by NIRS in the brain and liver but not in the heart. However, our results are limited to healthy young subjects not undergoing surgery. More studies are required to validate and expand these data to patients undergoing major surgery as well as to older, sicker surgical patients. The method and the apparatus

may be useful to monitor the global oxygenation of the heart and the liver as well.

Conflict of interest

Nothing to declare

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