Transcranial Monitoring of Cerebral Oxygen Saturation under Different Anesthetic Drugs and Ventilation Patterns: Observations in an Animal Model

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Citation

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Abstract

Background: Transcranial regional cerebral oxygen saturation (rSO2) is based on specific algorithms of near infrared spectroscopy (NIRS). In an animal model we measured the reactivity of rSO2 trends under basal total intravenous anesthesia (TIVA) with propofol and remifentanil during different experimental interventions. These maneuvers included the additional application of desflurane and halothane as well as hypo- and hyperventilation in two pigs.Results: Induced hypercapnia during administration of desflurane and halothane led to increased rSO2 values. Administration of thiopental (5mg/kg bolus followed by 3mg/kg/h continuously) under normocapnia also led to increased rSO2 values. In contrast, thiopental administration during hypocapnia led to moderately decreased rSO2 readings.Conclusion: Monitoring of cerebral oxygenation metabolism seems to be a control tool in an interventional setting using the combination of thiopental and hyperventilation. Further studies in this context using NIRS monitoring and cerebral tissue oxygenation appear warranted.

INTRODUCTION

Transcranial near infrared spectroscopy (NIRS) is assigned to estimate the balance of cerebral oxygen supply and cerebral oxygen consumption [$_{12345678910111213141516}$]. In our animal model, we recorded cerebral regional oxygen saturation (rSO_2) during various anesthesiologic conditions and maneuvers (different ventilation settings, use of volatile anesthetic agents and thiopental). The aim of this study was to detect if and how these different conditions may be reflected by changes of rSO_2 values.

METHODS

We recorded rSO_2 during different maneuvers in two pigs during standardized anesthesia. The study design is shown in Fig. 1. Appropriate approval for animal experimentation was obtained (BM/BWK-66.010/36-BrgT/2006).

ANESTHESIA

Two pigs (sus domesticus; 30 and 34 kg, respectively) were studied. The animals were premedicated intramuscularly with diazepam (7/9 mg), azaperone (80/100 mg) and ketamine (250/450 mg) 15 minutes before placement of an intravenous line at an ear. Orotracheal intubation was performed after administration of fentanyl (2-3 mg/kg) and propofol 1% (3 mg/kg). Total intravenous anesthesia (TIVA) with 1% propofol (6 mg/kg) and remifentanil (0.08-0.1 mg/kg) and paralysis with rocuronium (0.6 mg/kg) were maintained until the end of the experiment.

In addition to standardized anesthesia animal A was insufflated desflurane under hypercapnia during measurement phase I (MAC II) and animal B halothane (MAC II). During measurement phase II both animals were administered thiopental.

After an initial dosage of thiopental (5 mg/kg) as bolus a continuous rate of 3 mg/kg/h was maintained (Fig. 1).

RESPIRATORY AND CIRCULATORY MANAGEMENT

The animals were ventilated with a Julian Plus® machine (Dräger, Lübeck, Germany) (Table 1).

Figure 1

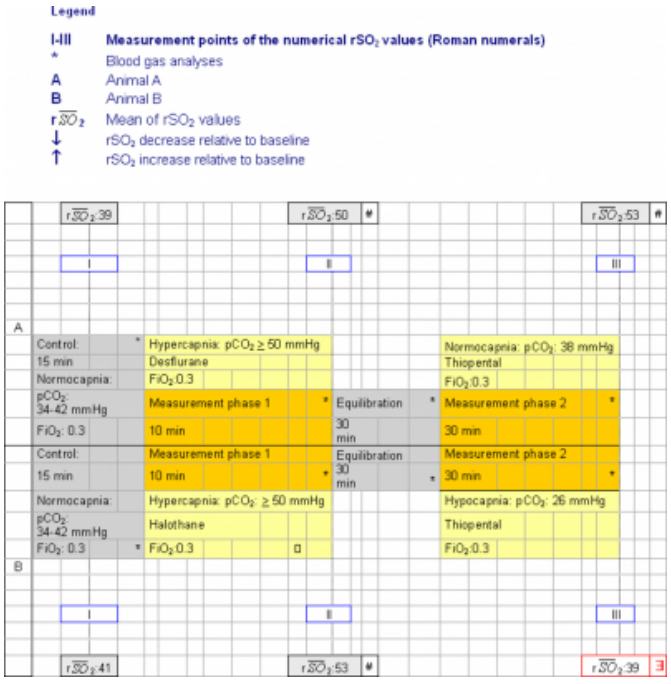
Table 1: Respiratory and ventilatory settings.

Ventilation parameters	Normoventilation	Hypoventilation	Hyperventilation
Tidal volumes	350 cm^3	280 cm^3	330 cm^3
Inspiration : Expiration	1 : 2	1 : 2	1 : 1
Inspiratory peak pressure	18 mmHg	13 mmHg	23 mmHg
Mean inspiratory pressure	7 mmHg	5 mmHg	10 mmHg
Respiration rate	20/min	7/min	33/min

The inspiratory gas concentration was 30% O_2 in air and peripheral O_2-saturation was maintained at 97-100%. Fluid volume (e.g., Ringer´s solution, electrolyte-glucose solution 2.5%) was administered at 10 ml/kg/h during the first hour and 3 ml/kg/h thereafter. Invasive blood pressure (right or left femoral artery), temperature (esophagus), heart rate (pulse oxymetry) were recorded with a Cardiocap Datex Ohmeda monitor (Helsinki, Finland). Blood gas analysis was performed at predetermined points. The mean arterial blood pressure was kept between 50 and 80 mmHg ; etilefrin (1 mg/10 ml 0.9% NaCl) was applicated as needed.

Figure 2

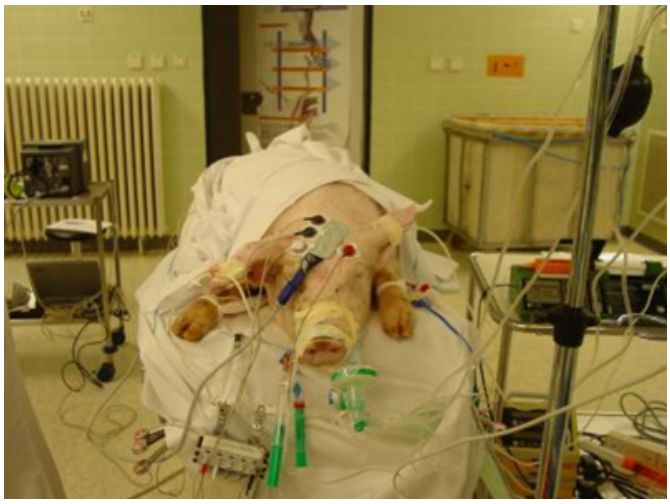
Figure 1: Study design. Numeric rSO values were registered at the beginning and end of measurement phases 1 and 2 as well as during the initial observation phase.



Values of rSO_2 were measured with a cerebral oximeter INVOS R 4100 (Somanetics, Troy, USA). Positioning of the optodes is shown in Fig. 2. The EEG bispectral index (BIS) was recorded with an Aspect A1000 monitor (Aspect Medical Systems, Natick, MA, USA) with modified positioning of the electrodes (Fig. 2).

Figure 3

Figure 2: Positioning of the rSO optodes for NIRS and electrodes for BIS monitoring.



RESULTS

During the baseline/control phase (Fig. 1) the mean rSO_2 values were stable (38 (38-41) and 41 (40-42) in animals A and B, respectively). The sampling frequency was 1/min. The rSO_2 values immediately before reduction of the anesthetic agent concentrations at points II and III in measurement phases 1 and 2 are shown in Fig. 1.

In measurement phase 1 (hypercapnia ($pCO_2 \geq 50$ mmHg), the administration of a volatile anesthetic agent (desflurane in animal A and halothane in animal B) increasing incrementally to MAC II resulted in different patterns in the increase of rSO_2 trends (Figs. 3 and 4).

During the return to normoventilation and after cessation of insufflation of volatile agents rSO_2 decreased toward the initial range.

Figure 4

Figure 3: rSO trend curve during hypercapnia and desflurane (MAC II) and return to baseline.

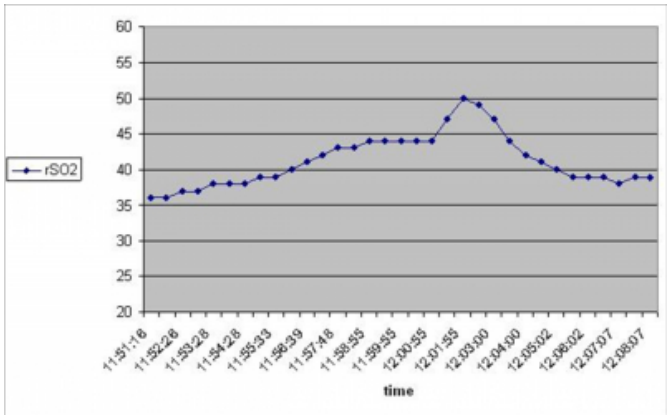
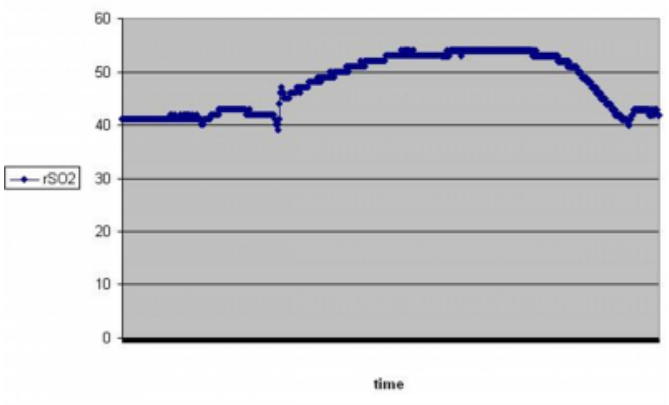


Figure 5

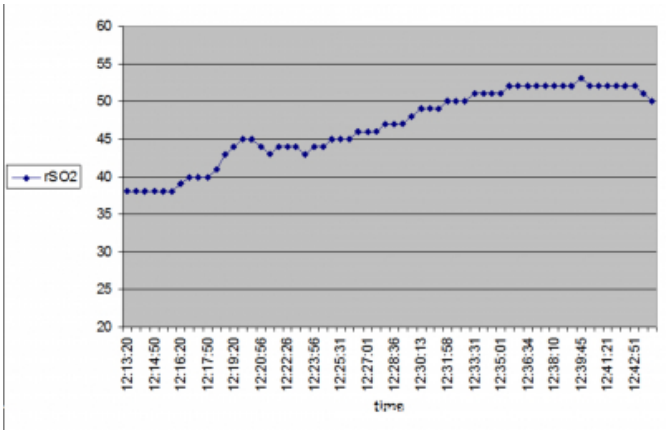
Figure 4: rSO trend curve during hypercapnia and halothane (MAC II) and return to baseline



In measurement phase 2 in animal A administration of thiopental during normocapnia (pCO_2, 38 mmHg) led to an increase of the rSO_2 trend curve compared to baseline (Fig. 5).

Figure 6

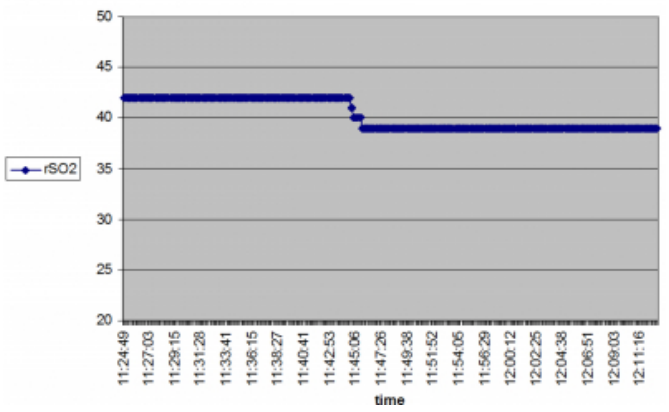
Figure 5: Increased rSO trend curve during normocapnia after thiopental administration (animal A).



In contrast to animal A, the combination of marked hypocapnia (pCO_2, 26 mmHg) led to a decrease of the rSO_2 trend in animal B. In both animals BIS values were between 30 and 40.

Figure 7

Figure 6: rSO trend during hypocapnia and thiopental administration (see the slightly reduced rSO values).



DISCUSSION

For the rSO_2 trends in measurement phase 1 of this study we hypothesized that the cerebral vasodilatative effects of the combination of hypercapnia and volatile anesthetic agents appeared to increase cerebral blood volume (CBV) and therefore the oxygen supply. With this study design we are unable to say whether this effect is mainly or equally induced by hypercapnia [17] and/or the volatile anesthetics [18]. In this context it is to keep in mind that halothane has the greatest vasodilatory effect of all volatile anesthetics. Lesser effects are expected in desflurane, isoflurane, and particularly in sevoflurane.

Similarly, we are unable to say which role the reduced cerebral oxygen metabolism ($CMRO_2$) caused by the anesthetics plays for the rSO_2 readings. There was no analysis of raw EEG. But, from the pharmacodynamic viewpoint the inhibitory effect on the bioelectric cortical activity seems to be greater under desflurane than under halothane. Thus, it could be expected that desflurane exerts a greater concentration-dependent effect on $CMRO_2$ than halothane.

Barbiturates are used for prophylactic or therapeutic neuroprotection [19 20]. A goal is to reduce $CMRO_2$ by inhibiting bioelectrical synaptic activity and thereby decreasing oxygen extraction from arterial blood. Algorithms for cerebral NIRS monitoring are designed to detect changes in the ratio of intravasal oxygenated/deoxygenated hemoglobin. It is assumed that about 75% of the cerebral vasculature are contributed to the venous compartment. According to this concept, cerebral oxygen saturation should increase with barbiturate administration by reduced $CMRO_2$.

However, barbiturates can also increase the cerebrovascular resistance / cerebral vasoconstriction.

The results in measurement phase II of our study suggest that the barbiturate effects may depend on the initial vascular diameter, caused by diverging effects of ventilation: CBF-correlated diameter of the cerebral vessels under normocapnia (animal A) versus hypocapnic vasoconstriction and increased cerebrovascular resistance (CVR, animal B). We hypothesize that under normocapnia in animal A the $CMRO_2$-decreasing effect of the barbiturate (via the reduction of the neuronal energy requirements) overall favored an rSO_2 increase.

Alternatively, an inhibitory effect of the barbiturate on cerebral oxygen metabolism could be too small to compensate vasoconstriction induced by hypocapnia, and thus leave rSO_2 measurements unchanged. The CVR-increasing effect of the barbiturate may even increase hypocapnic vasoconstriction, with a further reduction in CBF.

From this we conclude that in animal B the arterial oxygen supply to the brain was decreased somewhat so that rSO_2 readings decreased slightly.

These results, in two animals, have to be interpreted with caution. We have no alternative assessment of overall and regional cerebral oxygen metabolism and no assessment of actual vascular diameters or definitive CBF as well as cerebral tissue oxygenation. Also, the BIS-monitor we used did not permit precise quantitative analysis of cerebral electrical activity, in particular burst suppression activity (later models of the monitor provide more of this information).

Nonetheless the course of the readings in animal B is noteworthy. In clinical practice in patients with marked increase of intracranial pressure hyperventilation is part of the traditional bridging management, and barbiturate coma is a supplementary option to control life-threatening intracranial pressure episodes.

NIRS–monitoring is a helpful tool for estimating the cerebral oxygen metabolism status in a various number of clinical indications [1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16]. But, using NIRS monitoring it is to keep in mind that in some specific constellations the method fails to reflect dramatic intracranial dynamics adequately [21 22 23 24 25].

Despite the methodologic limitations of our study design and the pathophysiologic interactions, our singular observation in an interventional setting using the combination of thiopental and hyperventilation in an experimental animal model suggest that noninvasive monitoring of the regional cerebral oxygen saturation could be a useful modality to control treatment under the described conditions and to detect cerebral oxygen desaturation events. Further studies in this context using NIRS monitoring and cerebral tissue oxygenation appear warranted.

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