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The effect of acute normovolemic haemodilution on cerebral oxygenation

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SUMMARY

Acute normovolemic haemodilution (ANH) may cause an imbalance in cerebral oxygen metabolism because it decreases the arterial oxygen content. This study was designed to investigate the effect of ANH on cerebral oxygenation. By using cerebral oximetry, the regional cerebral oxygen saturation (rSO_2) was monitored during ANH in 26 patients without systemic illness (initial haematocrit = 42 ± 1%). The rSO_2 did not show a significant change until the Hct reached >30%. However, it decreased significantly thereafter to reach 88% of the baseline value when the ANH was completed with a Hct value of 24 ± 1% (before ANH; 71 ± 6% vs. after ANH; 62 ± 4%, $p < 0.01$). In conclusion, an ANH can lead to a reduction in cerebral oxygenation when a patient's Hct goes below 30%.

Keywords: Acute normovolemic haemodilution; cerebral oxygenation; cerebral oximetry

INTRODUCTION

Acute normovolemic haemodilution (ANH) is one of the most widely adopted blood conservation methods during anaesthesia. ANH has some benefits in respect of anaesthetic management. It can be easily performed in the operating room, it is cost-beneficial, and it can conserve the platelets and coagulation factors.

In terms of the brain, ANH increases the cerebral blood flow in an inverse relationship with Hct (1–3). However, this increase in cerebral blood flow does not necessarily improve the level of cerebral oxygenation because the cerebral oxygen transport may decrease (1,4,5) as a result of the reduced arterial oxygen content (CaO_2).

To our knowledge, there is as yet no report on the effects of ANH on cerebral oxygenation in patients undergoing general anaesthesia. Therefore, we designed a prospective study to examine the effects of ANH on cerebral oxygenation by using cerebral oximetry.

A cerebral oximetry, based on the principle of near-infrared spectroscopy as first described by Jobsis (6), is a monitoring device for non-invasively assessing the level of cerebral tissue oxygenation. This optical technique is based on the relative transparency of biological tissue to near-infrared light, where oxygenated and deoxygenated haemoglobin have a distinct absorption spectrum (7). The cerebral oximetry measures the ratio of oxyhaemoglobin to total haemoglobin in the field beneath the sensor, which is represented as the percentage regional cerebral oxygen saturation (rSO_2). It is used widely in patients undergoing various procedures including neurosurgery and cardiac surgery because it provides real-time information non-invasively (8–12).

METHODS

After obtaining approval from the Committee on Human Research of our institution and written informed consents from the patients, 26 patients scheduled for major orthopedic surgery were enrolled. The exclusion criteria were as follows: older than 65 years, pre-operative haemoglobin concentration < 13 g/dl and a history or laboratory data suggesting a bleeding tendency. Those who have any systemic diseases, such as hypertension, diabetes mellitus, hepatic disease, renal disease, or neurological disease and who were allergic to hydroxyethylstarch were also excluded.

Anaesthesia was induced with thiopental sodium (4–5 mg/kg). Vecuronium (0.1–0.15 mg/kg) was given to facilitate the tracheal intubation. Lungs were ventilated with oxygen/nitrous oxide (FiO_2 0.5) to obtain an arterial carbon dioxide partial pressure of 35–40 mmHg. Anaesthesia was maintained with isoflurane 0.7–1.2 vol%. A radial arterial and a central venous cannulation were done after induction of anaesthesia,

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after which ANH was started. Blood was withdrawn to reach a target Hct of 24%. The volume of blood to be removed (V) was calculated using the following formula:

$$V = EBV \times (H_i - H_f)/H_{av}$$

where EBV is the patient's estimated blood volume (male 70 ml/kg, female 65 ml/kg), H_i is the patient's initial haematocrit (Hct), H_f is the final Hct after ANH and H_{av} is the average Hct (average of H_i and H_f). The H_f was set to 24%. To maintain the normovolemia during ANH, the first 500 ml of blood that was withdrawn was simultaneously replaced with the same volume of 6% hydroxyethylstarch, and the remaining volume was replaced with three times the volume of a lactated Ringer's solution. The blood was collected in standard citrate-phosphate-dextrose storage bags.

Measurements

During ANH, the rSO_2 was monitored using a cerebral oximetry (INVOS 3100, Somanetics, Troy, MI, USA) and the ANH was stopped if either its absolute value decreased below 50% or the relative value decreased below 80% of the baseline. The heart rate, the mean arterial pressure, the central venous pressure, the cardiac output (CO) and the nasopharyngeal temperature were also monitored. The CO was measured with esophageal Doppler (Cardio Q, Deltex, UK). The above parameters were recorded at the following time points: immediately before commencing haemodilution (baseline), when 25%, 50%, 75% and 100% of the target volume was withdrawn (V_{25}, V_{50}, V_{75}, V_{100}). The arterial blood gases were also analysed at each time point. The arterial oxygen content (CaO_2) and the systemic oxygen delivery (DaO_2) were calculated using the following equation:

$$CaO_2(vol\%) = 1.34 \times Hb \times SaO_2 + 0.0031 \times PaO_2$$
$$DaO_2(ml/min) = CO \times CaO_2 \times 10$$

Table 1 Patients' clinical characteristics

Sex (M/F)	15/11
Age (years)	59 ± 12
Weight (kg)	63 ± 7
Height (cm)	164 ± 14
Initial Hct (%)	42 ± 1

Data are mean ± SD or number of patients.

Statistics

The data obtained at each time point was compared to the baseline value using a Kruskal–Wallis test. A p-value <0.05 was considered significant. The results are presented as mean ± SD.

RESULTS

The patients' clinical characteristics are shown in Table 1. A total of 1497 ± 437 ml of autologous blood was collected during the 36 ± 9-min period of ANH to achieve a Hct of 24 ± 1%. The changes in the physiologic variables are shown in Table 2. Despite the increased CO, the DaO_2 was reduced gradually. The nasopharyngeal temperature decreased significantly as ANH proceeded (from 36.1 ± 0.3 °C to 35.2 ± 0.2 °C, $p < 0.05$).

At the baseline, the rSO_2 was 71 ± 6%. The rSO_2 did not change significantly through V_{50} (69 ± 6%, $p > 0.05$ vs. baseline). At V_{75}, the Hct decreased to 30 ± 1% and the rSO_2 showed a significant reduction (64 ± 4%, $p < 0.05$ vs. baseline). After completing ANH, the rSO_2 was reduced down to 88% of the baseline value (62 ± 4%, in absolute value). In any of the patients, the absolute value of rSO_2 did not decrease below 50%, nor did the relative ratio decrease below 80% of the baseline value (Figure 1). From the serial arterial blood gas profile, acidosis (arterial pH < 7.35) or an increased base deficit (>3 mmol/l) was not found throughout the study period.

Table 2 Physiologic values during the study

	Baseline	V_{25}	V_{50}	V_{75}	V_{100}
HR (rate/min)	69.9 ± 10.4	69.5 ± 9.3	67.3 ± 12.3	70.1 ± 7.5	70.8 ± 6.6
MAP (mmHg)	88.4 ± 8.4	87.7 ± 6.4	84.9 ± 5.8*	82.5 ± 7.0*	81.8 ± 6.8†
CVP (mmHg)	5.6 ± 1.2	5.6 ± 1.2	5.9 ± 1.7	5.4 ± 1.0	5.6 ± 1.3
CO (l/min)	4.7 ± 0.6	4.8 ± 0.7	5.0 ± 0.5*	5.2 ± 0.7*	5.5 ± 0.8†
CaO_2 (vol%)	19.5 ± 1.0	18.4 ± 1.2*	15.4 ± 3.2†	14.1 ± 1.2†	12.0 ± 0.4‡
DaO_2 (ml/min)	927 ± 141	863 ± 150*	761 ± 100†	728 ± 64†	649 ± 86‡

Data are mean ± SD.

HR, heart rate; MAP, mean arterial pressure; CVP, central venous pressure; CO, cardiac output; CaO_2, arterial oxygen content; DaO_2, systemic oxygen delivery; V_{25}, when 25% of target volume of blood was withdrawn; V_{50}, when 50% of target volume of blood was withdrawn; V_{75}, when 75% of target volume of blood was withdrawn; V_{100}, when 100% of target volume of blood was withdrawn.

*$p < 0.05$ vs. baseline value.

†$p < 0.01$ vs. baseline value.

‡$p < 0.001$ vs. baseline value.

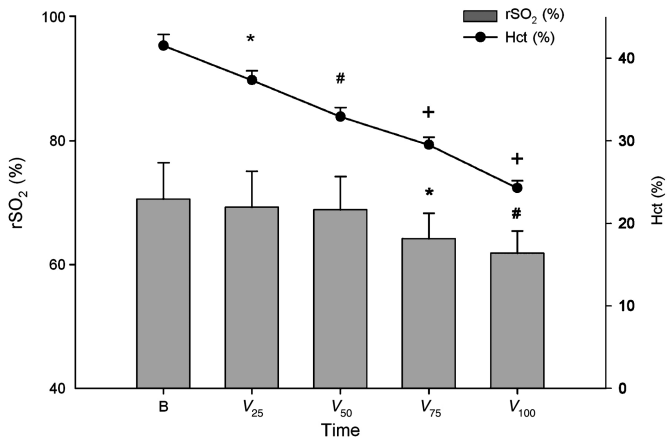

Figure 1 Changes in the regional cerebral oxygen saturation and haematocrit during the study. rSO_2, regional cerebral oxygen saturation;*, $p < 0.05$ vs. baseline value; #, $p < 0.01$ vs. baseline value; +, $p < 0.001$ vs. baseline value

DISCUSSION

This study showed that the rSO_2 decreased significantly as the ANH proceeded.

The rSO_2 began to fall significantly from V_{75}, when the Hct value was 30%, while maintained in the baseline value until V_{50} despite the decrease in DaO_2. This discrepancy in the extent of the reduction between the systemic DaO_2 and rSO_2 may be partially accounted for by the redistribution of the CO. During ANH, the augmented CO is redistributed resulting in more flow to the brain or heart to preserve the cerebral or coronary oxygen supply (13). Although our results did not include the cerebral oxygen transport, cerebral oxygen transport is reported to be maintained until the Hct value of 31% or 32% in dogs with or without cerebral ischemia (5,14). The study by Shinozuka et al. performed in rats is also in line with this study (15). Shinozka et al. measured the change in the cerebral cortical tissue oxygen tension during haemodilution. The cerebral tissue oxygen tension began to fall significantly when the Hct was reduced to below 30%. Similarly, these results suggest that cerebral oxygenation could not be fully compensated for when the ANH proceeded below 30% of Hct.

While the systemic DaO_2 decreased as much as 30% from the baseline during ANH, the rSO_2 decreased by only 12%. Along with the redistribution of the augmented CO, the decreased body temperature and cerebral metabolic effects of the general anaesthetic agents could partially explain this discrepancy. This study was performed under general anaesthesia. It has been suggested that some intravenous and inhalational agents used in general anaesthesia, including thiopental and isoflurane, lead to a reduction in the cerebral metabolic rate for oxygen and thereby a decrease in the cerebral oxygen demand (16–18). In addition, the nasopharyngeal temperature reduced by as much as 0.9 °C during the ANH, probably because of the rapid infusion of unwarmed fluid. Hypothermia, even slight, can also provide a cerebral protective effect (19,20). Both the anaesthetics and hypothermia may partially contribute to the cerebral metabolic oxygen balance during ANH.

A reduction in the rSO_2 below 50% of the absolute value (11), or below 80% of the relative ratio of the baseline value (10) is associated with postoperative neurological problem. Although this study showed that there was an actual reduction in the rSO_2 during ANH, the absolute value of the rSO_2 or the relative ratio of rSO_2 after ANH was well above the clinically dangerous level from this standpoint.

Despite concerns regarding the clinical validity of cerebral oximetry, such as the discordance between rSO_2 and the jugular venous oxygen saturation (21) or potential extracranial contamination (22), many studies have shown that it can be used to detect cerebral hypoxia with a sensitivity comparable to jugular venous oxygen saturation (8,9,12,23) or electroencephalography (23). Accordingly, a cerebral oximetry, a non-invasive monitoring device for cerebral tissue oxygenation was chosen in this study.

In conclusion, ANH below Hct 30% can result in reduction in cerebral oxygenation. Monitoring cerebral oxygenation will be helpful when ANH is performed below this level of Hct.

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