Comparison of changes in jugular venous bulb oxygen saturation and cerebral oxygen saturation during variations of haemoglobin concentration under propofol and sevoflurane anaesthesia

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Background. A severe reduction in haemoglobin concentration can lead to a decrease in jugular venous bulb oxygen saturation (S_jO_2). However, recent evidences suggests that cerebral oxygen saturation (S_CO_2) measured by near infrared spectroscopy decreased during even mild haemodilution. We therefore tested the hypothesis that the changes in S_CO_2 may not be parallel to those in S_jO_2 during haemodilution. In addition, as cerebral oxygen balance during the operation can vary depending on the anaesthetics used, the changes in S_jO_2 and S_CO_2 during haemodilution were compared between patients under propofol and isoflurane/nitrous oxide anaesthesia.

Methods. Forty-two patients with pre-donated autologous blood were randomly assigned to receive propofol (Group P) or sevoflurane/nitrous oxide (Group S) anaesthesia. A fibreoptic catheter was placed in the jugular bulb to measure S_jO_2. A cerebral oximeter, INVOS 4100S was used to monitor S_CO_2. Arterial and jugular bulb blood samples were drawn simultaneously at: (i) 10 min after the start of operation, (ii) after 400 ml of blood loss, (iii) after 800 ml of blood loss, (iv) just before the transfusion of pre-donated autologous blood, and (v) after 400 ml transfusion.

Results. Mean (sd) control values of S_jO_2 in Group P were significantly lower than those in Group S (55 (8)% vs 71 (10)%), respectively; P<0.05), whereas there was no significant difference in control values of S_CO_2 between the two groups. During the operation, haemoglobin (Hb) concentrations significantly deceased in both groups compared with control values (from 9.8 to 7.6 g dl^-1 in Group P and from 9.9 to 8.0 g dl^-1 in Group S). During a reduction in Hb concentration, S_jO_2 values remained unchanged in both groups, whereas S_CO_2 values significantly decreased in both groups (from 57 to 51% in Group P and from 59 to 52% in Group S).

Conclusion. The results indicated that, although the changes in S_jO_2 and S_CO_2 during a reduction in haemoglobin concentration were similar under propofol and sevoflurane/nitrous oxide anaesthesia, the changes in S_CO_2 were not parallel to those in S_jO_2. The discrepancy of the results in S_jO_2 and S_CO_2 may make the interpretation of their values difficult during haemodilution.


Keywords: circulation, haemodilution; monitoring, jugular venous bulb oxygen saturation; monitoring, near infrared spectroscopy

Accepted for publication: October 22, 2004

Jugular venous bulb oxygen saturation (S_jO_2) has been used as an indirect assessment of global cerebral oxygen use to guide physiologic managements in a variety of clinical settings. During haemodilution, cerebral blood flow (CBF) and oxygen extraction are known to increase to compensate for the decreased oxygen transport in both human and experimental animals.1–3 CBF has been shown to change to keep oxygen transport to the brain tissue constant.4 When cerebral hyperaemic compensation cannot meet oxygen demand, significant increase in oxygen extraction and decrease in S_jO_2 can be observed. During mild to moderate haemodilution to a haematocrit of 20%, S_jO_2 values...
remained unchanged in patients undergoing orthopaedic surgery. During severe haemodilution, $S_jO_2$ began to decrease significantly at a mean haematocrit of 7.6% in a pig model. These suggested that a critical level of haematocrit and haemoglobin (Hb) concentration, in which $S_jO_2$ can decrease because of a failure to compensate a reduction in oxygen transport, is relatively low compared with those, which we encounter occasionally in clinical situations with mild to moderate haemodilution.

Near infrared spectroscopy (NIRS) provides a non-invasive optical monitoring technique assessing regional cerebral oxygen saturation ($S_Co_2$). Several studies have proven the efficacy of NIRS during neurosurgical and cardiac surgical areas. Recent evidences have indicated that $S_Co_2$ can decrease as haemoglobin concentration decreased during haemodilution. Torella and colleagues have demonstrated that $S_Co_2$ values decreased significantly during normovolemic haemodilution to a target Hb concentration of 11 g dl$^{-1}$ and had a significant positive correlation with Hb concentrations. Lassnig and colleagues also reported that a decrease in Hb concentration (from 11.7 to 8.5 g dl$^{-1}$) during the onset of cardiopulmonary bypass (CPB) induced a significant reduction in oxyhemoglobin (O$_2$Hb) measured by NIRS. These data suggested that $S_Co_2$ can decrease even during mild haemodilution and changes in $S_Co_2$ may differ from those in $S_jO_2$ during haemodilution. In the present study we therefore tested the hypothesis that the changes in $S_Co_2$ may not be parallel to those in $S_jO_2$ during haemodilution. In addition, recent data suggested that cerebral oxygen balance during the operation could vary depending on the anaesthetics used. $S_jO_2$ values have been shown to be lower under propofol compared with isoflurane or sevoflurane anaesthesia. Therefore we compared the changes in $S_jO_2$ and $S_Co_2$ during changes in haemoglobin concentration between patients under propofol and isoflurane/nitrous oxide anaesthesia.

**Methods**

After institutional approval and informed consent, 42 patients scheduled for elective total hip arthroplasty with pre-deposited autologous blood were enrolled in this study. Autologous blood donation of two units (800 ml) was performed 2 weeks before the day of the surgery. The donation volume was replaced simultaneously with 6% hydroxyethylated starch in a 1:1 ratio. The patients were randomly allocated into two groups: Group P ($n=21$) receiving propofol/fentanyl and Group S ($n=21$) receiving sevoflurane/nitrous oxide/fentanyl. No drug was given for preanaesthetic medication. Anaesthesia was induced with fentanyl (4 $\mu g$ kg$^{-1}$) and propofol (2 $mg$ kg$^{-1}$) and tracheal intubation was facilitated with vecuronium 0.2 $mg$ kg$^{-1}$. In Group P, anaesthesia was maintained with propofol 5 $mg$ kg$^{-1}$ h$^{-1}$ and the lungs were mechanically ventilated with an air/oxygen mixture ($F_{O_2}=0.4$). In Group S, anaesthesia was maintained with sevoflurane (1%, end-tidal concentration) and the lungs were mechanically ventilated with an oxygen nitrous oxide mixture ($F_{O_2}=0.4$). Additional fentanyl was administered if necessary. Pre-donated autologous blood was returned when Hb concentration decreased to <7 g dl$^{-1}$ or the femoral prosthesis was inserted into the femoral canal.

Routine monitoring equipment included a radial artery catheter for direct arterial blood pressure measurement, a pulse oximeter, and an electrocardiograph. End-tidal carbon dioxide (E$_{CO_2}$) tension and end-tidal concentration of sevoflurane were measured using a CAPNOMAC multi-gas analyser (Hewlett-Packard, Andover, MA, USA). The tympanic membrane temperature was also continuously monitored by Mon-a-Therm (Mallinckrodt Co., St Louis, MO, USA) and maintained between 35.5°C and 36.5°C using a warming blanket.

Cerebral oximeter, INVOS 4100S (Somanetics, Troy, MI, USA) was used to monitor cerebral oxygen saturation. For the measurements, the cerebral oximeter probe was placed on the right forehead, with the caudal border ~1 cm above the eyebrow with the medial edge at the midline. This position places the light source and sensors away from the frontal sinus. To measure $S_jO_2$ for the assessment of the ratio of cerebral oxygen delivery to demand, a fibreoptic catheter (U 440, Oximetrix, Abbott Critical Care System, Abbott Laboratory, North Chicago, IL, USA) was placed in the right jugular venous bulb. Catheter position was verified by radiography in the anterior–posterior projection. Measurements were performed at the following 5 points: (i) 10 min after the start of operation, (ii) after 400 ml of blood loss, (iii) after 800 ml of blood loss, (iv) just before the transfusion of pre-donated autologous blood, and (v) after 400 ml transfusion.

For estimation, cerebral oxygenation state and cerebral oxygen extraction ratio (COER) were calculated using the following equations:

$$Ca_o_2=(Sa_o_2-xHb\times1.39) + 0.0031\timesPa_o_2$$

$$Cjv_o_2=(Sjv_o_2-xHb\times1.39) + 0.0031\timesPjv_o_2$$

$$Ca_j_o_2=Ca_o_2-Cjv_o_2$$

$$COER=100\timesCa_j_o_2/Ca_o_2$$

where $Ca_o_2$ and $Cjv_o_2$ are the arterial and jugular venous bulb oxygen contents.

**Statistics**

Data are expressed as mean (SD). Demographic variables between the groups were compared using unpaired $t$-test or $\chi^2$-test. Haemodynamic variables and cerebral oxygen
parameters were analysed using two-way ANOVA with repeated measurement (intergroup comparison) and one-way ANOVA with repeated measurement (intrgroup comparison). Post-hoc analysis using multiple independent sample t-tests with Bonferroni correction was performed where significant differences occurred. A preliminary estimate of sample size was based on an expected 10% reduction in $S_{jO_2}$. With a type I error of 0.05 and a type II error of 0.2, the required sample size was 17–19 patients in each group. We estimated dropout rate as 10%. Therefore we assigned 21 patients randomly to Groups P and S, respectively. During measurements, patients who required vasodilator drugs were excluded from the study. Sample size was determined by ‘G power’ (the software is freely available from the website: http://www.psycho.uni-duesseldorf.de/aap/projects/gpower/index.html). Data were analysed using the SPSS-PC statistical software program (Version 11.0.1: SPSS, Inc., Chicago, IL, USA).

**Results**

Of the 42 patients who were enrolled into the study, five patients were excluded because of unsuccessful cannulation of internal jugular vein or treatment with vasodilator. Patient characteristics are shown in Table 1. There were no significant differences in patient characteristics between the two groups. Physiological data are shown in Table 2. There was no significant difference in physiological variables between the two groups.

Changes in Hb concentrations and cerebral hemodynamic values are shown in Figure 1. There was no significant difference in Hb concentrations of control values between the two groups (Group P, 9.8 (1.0) g dl$^{-1}$; Group S, 9.9 (1.3) g dl$^{-1}$). During the operation, Hb concentrations gradually decreased and Hb concentrations just before transfusion of pre-donated blood were significantly lower than control values in both groups (Group P, 7.6 (1.0) g dl$^{-1}$; Group S, 8.0 (1.2) g dl$^{-1}$).

Changes in cerebral haemodynamic values are shown in Figure 1. Control $S_{jO_2}$ values in Group P were significantly lower than those in Group S (55 (8)% vs 71 (10)% respectively; $P<0.05$). Control values of COER in Group P were significantly higher compared with those in Group S (32 (8)% vs 21 (10)% respectively; $P<0.05$). During a reduction in Hb concentration, $S_{jO_2}$ values did not change significantly in both groups. After the transfusion of pre-donated blood, $S_{jO_2}$ values were significantly increased compared with those just before the transfusion in Group P (from 55 (8) to 60 (5)%; $P<0.05$), but not in S. After the transfusion of pre-donated blood, COER values were significantly decreased compared with those just before transfusion in Group P (from 45 (8) to 43 (9)%; $P<0.05$), but not in Group S.

In contrast to the results of $S_{jO_2}$, there was no significant difference in control values of $S_{CO_2}$ between the two groups (Group P, 57 (10)%; Group S, 59 (9)%). During a reduction in Hb concentration, $S_{CO_2}$ values were gradually decreased in both groups. $S_{CO_2}$ values just before the transfusion of pre-donated blood (Group P, 51 (8)%; Group S, 52 (10)%) were significantly lower compared with control values in both groups ($P<0.05$).

Figure 2 shows the relationship between $S_{jO_2}$ values and Hb concentrations, and between $S_{CO_2}$ values and Hb concentrations. There is a significant positive correlation between $S_{CO_2}$ values and Hb concentrations (Group P, $r=0.37$, $P<0.001$; Group S, $r=0.46$, $P<0.001$), whereas there are no significant correlation between $S_{jO_2}$ values and Hb concentrations (Group P, $r=0.12$, $P=0.26$; Group S, $r=0.19$, $P=0.07$).

**Discussion**

The results in the present study showed that $S_{jO_2}$ values remained unchanged during mild to moderate haemodilution, whereas $S_{CO_2}$ values significantly decreased as Hb concentration decreased. This suggests that the changes in $S_{CO_2}$ were not parallel to those in $S_{jO_2}$ during haemodilution. The changes in $S_{jO_2}$ and $S_{CO_2}$ values were not modified by the background anaesthetics used, although $S_{jO_2}$ values, but not $S_{CO_2}$ values, were significantly lower under propofol anaesthesia compared with those under sevoflurane/nitrous oxide anaesthesia.

Although available data on changes in $S_{jO_2}$ and $S_{CO_2}$ during mild to moderate haemodilution are limited in humans, previous data are consistent with the results obtained in the present study, in which the reduction in mean Hb concentrations from 9.8 to 7.6 g dl$^{-1}$ in Group P and from 9.9 to 8.0 g dl$^{-1}$ in Group S did not affect $S_{jO_2}$ values, but significantly reduced $S_{CO_2}$ values. Shapira and colleagues$^{7}$ evaluated the safety of haemodilution combined with induced hypotension with $S_{jO_2}$ in patients under isoflurane anaesthesia and demonstrated that $S_{jO_2}$ values remained unchanged during mild to moderate haemodilution with a haematocrit: from 35.6 to 20%. In contrast, Torella and colleagues$^{14}$ have demonstrated that $S_{CO_2}$ values decreased significantly during acute normovolaemic haemodilution to a target haemoglobin of 11 g dl$^{-1}$ in aortic surgery and a significant positive correlation between Hb concentrations and $S_{CO_2}$ values were noted. Lassnigg and colleagues$^{15}$ also reported that $O_2$Hb measured by NIRS

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**Table 1** Patient characteristics ($n=37$). Data are presented as mean (sd) unless indicated. There were no statistically significant differences between the two groups.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group P ($n=18$)</th>
<th>Group S ($n=19$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr) (range)</td>
<td>57 (49–73)</td>
<td>60 (41–77)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>56 (12)</td>
<td>56 (10)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>153 (9)</td>
<td>152 (7)</td>
</tr>
<tr>
<td>Sex (M/F)</td>
<td>2/16</td>
<td>2/17</td>
</tr>
<tr>
<td>Anaesthetic time (min)</td>
<td>240 (47)</td>
<td>242 (54)</td>
</tr>
<tr>
<td>Operation time (min)</td>
<td>178 (50)</td>
<td>174 (49)</td>
</tr>
<tr>
<td>Blood loss (ml)</td>
<td>981 (410)</td>
<td>1137 (594)</td>
</tr>
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</table>
significantly decreased during the onset of CPB, in which Hb concentrations were decreased from 11.7 to 8.5 g dl⁻¹.

The reasons of discrepancy in changes of $S_{jO_2}$ and $S_{CO_2}$ during haemodilution are unknown. However, possible explanations are as follows. First, $S_{jO_2}$ is an indirect indicator of global cerebral oxygen use and has high specificity and low sensitivity of cerebral ischaemia. Normal $S_{jO_2}$ values may not reflect focal areas of ischaemia, although low $S_{jO_2}$ values were indicative of low flow.²⁰

Table 2 Physiological data (n=37). Data are presented as mean (SD). Measurements were performed at: (i) 10 min after the start of operation, (ii) at 400 ml of blood loss, (iii) at 800 ml of blood loss, (iv) just before the transfusion of pre-donated autologous blood, and (v) after 400 ml transfusion. There were no significant differences between groups. MAP=mean arterial pressure; Temp=tympanic body temperature

<table>
<thead>
<tr>
<th>Time points</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
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<tbody>
<tr>
<td>MAP (mm Hg)</td>
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<td></td>
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</tr>
<tr>
<td>Group P</td>
<td>77 (9)</td>
<td>77 (9)</td>
<td>82 (11)</td>
<td>80 (10)</td>
<td>81 (7)</td>
</tr>
<tr>
<td>Group S</td>
<td>75 (10)</td>
<td>77 (8)</td>
<td>79 (9)</td>
<td>75 (9)</td>
<td>77 (8)</td>
</tr>
<tr>
<td>$S_{aO_2}$ (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group P</td>
<td>99 (0.8)</td>
<td>99 (0.5)</td>
<td>99 (0.4)</td>
<td>99 (0.4)</td>
<td>99 (0.3)</td>
</tr>
<tr>
<td>Group S</td>
<td>99 (0.4)</td>
<td>99 (0.3)</td>
<td>100 (0.2)</td>
<td>99 (0.4)</td>
<td>99 (0.6)</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group P</td>
<td>7.41 (0.04)</td>
<td>7.40 (0.04)</td>
<td>7.40 (0.04)</td>
<td>7.41 (0.04)</td>
<td>7.39 (0.04)</td>
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<tr>
<td>Group S</td>
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<td>7.40 (0.04)</td>
<td>7.39 (0.04)</td>
<td>7.40 (0.04)</td>
<td>7.39 (0.03)</td>
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<tr>
<td>$P_{aO_2}$ (mm Hg)</td>
<td></td>
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<tr>
<td>Group P</td>
<td>167 (43)</td>
<td>181 (43)</td>
<td>188 (42)</td>
<td>184 (39)</td>
<td>202 (53)</td>
</tr>
<tr>
<td>Group S</td>
<td>192 (37)</td>
<td>187 (28)</td>
<td>183 (16)</td>
<td>191 (29)</td>
<td>192 (38)</td>
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<tr>
<td>$P_{aCO_2}$ (mm Hg)</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Group P</td>
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<td>39 (3)</td>
<td>39 (4)</td>
<td>41 (4)</td>
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<td>Group S</td>
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<td>39 (3)</td>
<td>39 (3)</td>
<td>39 (3)</td>
<td>41 (3)</td>
</tr>
<tr>
<td>Temp (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group P</td>
<td>36.0 (0.5)</td>
<td>36.0 (0.6)</td>
<td>35.8 (0.5)</td>
<td>36.1 (0.7)</td>
<td>36.1 (0.7)</td>
</tr>
<tr>
<td>Group S</td>
<td>36.0 (0.5)</td>
<td>36.0 (0.7)</td>
<td>35.7 (0.4)</td>
<td>36.0 (0.8)</td>
<td>35.8 (0.7)</td>
</tr>
</tbody>
</table>

Fig 1 The time course of changes in (A) Hb concentrations, (B) jugular venous bulb oxygen saturation ($S_{jO_2}$), (C) cerebral oxygen saturation ($S_{CO_2}$), and (D) cerebral oxygen extraction ratio (COER) in the two experimental groups. Patients in Group P received propofol/fentanyl anaesthesia and those in Group S received nitrous oxide/sevoflurane/fentanyl anaesthesia. Measurements were performed at: (i) 10 min after the start of operation (control values), (ii) at 400 ml of blood loss, (iii) at 800 ml of blood loss, (iv) just before the transfusion of pre-donated autologous blood, and (v) after 400 ml transfusion. Data are expressed as mean (SD). *P<0.05 vs control values; †P<0.05 vs time (iv); ‡P<0.05 vs Group P.
In contrast, monitoring $S_{C_{O_{2}}}$ to detect cerebral ischaemia had high sensitivity and specificity. Therefore, it seems likely that $S_{C_{O_{2}}}$ changes might reflect regional oxygen imbalance during mild to moderate haemodilution, although $S_{jO_{2}}$ did not detect any changes in global cerebral oxygen balance. In fact, Hino and colleagues demonstrated that regional cerebral oxygen extraction fraction (OEF) of cortical grey matter significantly increased (41.7 to 43.3%) during a mild reduction in Hb concentration (14.3 to 12.6 g dl$^{-1}$) using positron emission tomography in human volunteers. Mori-moto and colleagues also reported that brain tissue oxygen tension gradually decreased as Hb concentration decreased, as the increases in CBF and oxygen extraction could only partially compensate for the decreased oxygen transport during haemodilution.

Second, the algorithm to estimate $S_{C_{O_{2}}}$ might lead to an overestimated reduction in $S_{C_{O_{2}}}$ values during haemodilution. A modified Beer–Lambert law has been used to estimate $S_{C_{O_{2}}}$ and $O_{2}Hb$ in NIRS and contains a factor of pathlength. Lassnigg and colleagues suggested that low arterial Hb concentration leads to an increase in optical pathlength and an overestimation of the decrease in cerebral $O_{2}Hb$. In fact, Kurth and colleagues demonstrated that optical pathlength increased linearly with decreasing Hb concentration in the perfusate to the brain. As pathlength factors are assumed to be constant in the Beer–Lambert law, the increase in pathlength factors may lead overestimation of changes in $S_{C_{O_{2}}}$.

Although the control values of $S_{jO_{2}}$ were significantly lower under propofol than sevoflurane anaesthesia, $S_{jO_{2}}$ values did not change significantly in either group during haemodilution in the present study. Previous studies have reported that $S_{jO_{2}}$ values were lower under propofol anaesthesia compared with isoflurane or sevoflurane anaesthesia. Our results were compatible with those in previous studies. Different effects of these anaesthetics on cerebral blood flow might have caused the differences of $S_{jO_{2}}$ values between the two groups. However, any differences in absolute $S_{C_{O_{2}}}$ values between the two groups were not observed. Previous studies showed that there was a significant correlation between percentage changes in $S_{C_{O_{2}}}$ and $S_{jO_{2}}$ values, but there was a wide limit of agreement between absolute $S_{C_{O_{2}}}$ and $S_{jO_{2}}$ values. These were consistent with the result of our study. However, we previously reported that tissue oxygen index (TOI), one of $S_{C_{O_{2}}}$, that use the algorithm independent of pathlength factors, were significantly lower under propofol anaesthesia than under isoflurane anesthesia. Although exact mechanisms are
unknown, pathlength factors might affect the absolute values of $\Delta_{CO}_2$.

There are several limitations in the present study to merit comments. First, we did not measure CBF and CMRO$_2$, which may limit the interpretation of the results because we could not differentiate between the changes of flow and oxygen consumption. Second, although we tried to maintain normovolaemia, we did not have haemodynamic parameters including pulmonary artery pressure and central venous pressure proving that we achieved this goal. In fact, inaccuracy of calculating blood loss may have prevented us to achieve this goal. Third, all patients in this study were free from cerebral pathology. It remains therefore unknown how $S_{J_0}$ and $S_{CO}_2$ would have responded during haemodilution in patients with a cerebral pathology. Fourth, only mild haemodilution was assessed in the present study. During severe haemodilution, the changes in $S_{J_0}$ and $S_{CO}_2$ may be different from those obtained in the present study. To clarify these points, further studies will be necessary.

In summary, we compared the changes in $S_{J_0}$ and $S_{CO}_2$ values during a mild changes in Hb concentration under propofol and sevoflurane/nitrous oxide anaesthesia. Although $S_{J_0}$ values remained unchanged, $S_{CO}_2$ values significantly decreased as Hb concentration decreased and positive correlation between $S_{CO}_2$ values and Hb concentrations was observed. These results suggest that the changes in $S_{CO}_2$ were not parallel to those in $S_{J_0}$ during haemodilution and transfusion. In clinical situations, the discrepancy between the results of $S_{J_0}$ and $S_{CO}_2$ makes their interpretation difficult. Further studies will be necessary to clarify this point.

References

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