Spatially resolved spectroscopy (NIRO-300) does not agree with jugular bulb oxygen saturation in patients undergoing warm bypass surgery

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Purpose: Near infrared spectroscopy (NIRS) is a promising non-invasive method for continuous monitoring of cerebral oxygenation during cardiac surgery with cardiopulmonary bypass (CPB). This study was designed to study the agreement between tissue oxygen index (TOI) measured by spatially resolved spectroscopy (NIRO-300) and jugular bulb oxygen saturation (SjO_2) in patients undergoing warm coronary bypass surgery.

Methods: Seventeen patients undergoing warm coronary artery bypass surgery were studied. NIRS was continuously monitored and was averaged before CPB, five, 20, 40, 60 min on CPB, five minutes before end of CPB and ten minutes after CPB to coincide with SjO_2 measurements. Bypass temperature was maintained at 34–37°C.

Results: Bland and Altman analysis showed a bias (TOI–SjO_2) of -6.7%, and wide limits of agreement (from 16% to -28%) between the two methods. In addition, mean TOI was lower than mean SjO_2 during and after CPB. We observed a statistically significant correlation between arterial carbon dioxide and SjO_2 measurements (r^2=0.33; P=0.0003), but the former did not correlate with TOI values (r^2=0.001; P=0.7).

Conclusion: Our results demonstrate a lack of agreement between SjO_2 and TOI for monitoring cerebral oxygenation during cardiac surgery. We conclude that the two methods are not interchangeable.

Objectif : *La spectroscopie proche infrarouge (SPIR) est une méthode non effractive et prometteuse de monitorage continu de l'oxygénation cérébrale utilisée en chirurgie cardiaque sous circulation extracorporelle (CEC). L'étude actuelle voulait tester la concordance entre l'index d'oxygène tissulaire (IOT) mesuré par spectroscopie à résolution spatiale (NIRO-300) et la saturation en oxygène du golfe de la jugulaire (SjO2) pendant une cardioplégie chaude.*

Méthode : *Dix sept patients subissant un pontage coronarien sous cardioplégie chaude ont été étudiés. La SPIR a été surveillée continûment et ajustée avant la CEC, à cinq, 20, 40, 60 min pendant la CEC, cinq minutes avant la fin de la CEC et dix minutes après pour coïncider avec les mesures moyennes de SjO2. La température a été maintenue à 34–37°C pendant la CEC.*

Résultats : *L'analyse de Bland et Altman a montré un biais (IOT–SjO2) de -6,7 % et de larges limites de concordance (de 16 % à -28 %) entre les deux méthodes. De plus, l'IOT moyen était plus bas que la SjO2 moyenne pendant et après la CEC. Il existait une corrélation statistiquement significative entre le gaz carbonique artériel et les mesures de SjO2(r2 = 0,33; P = 0,0003), mais non entre le CO2 et les valeurs de l'IOT (r2 = 0,001; P = 0,7).*

Conclusion : *Nos résultats démontrent un manque de concordance entre la SjO2 et l'IOT lors du monitorage de l'oxygénation cérébrale pendant une intervention cardiaque. Les deux méthodes ne sont donc pas interchangeables.*

CONTINUOUS or intermittent jugular bulb oxygen saturation (SjO_2) measurements have been used to assess cerebral oxygenation during cardiac surgery.[1] SjO_2 50% (desaturation) has been detected during rewarming from cold cardiopulmonary bypass (CPB),[2,3] and in the first 40 min of warm CPB (temperature 37°C).[4]

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In addition, SjO_2 50% during rewarming is associated with impaired cognitive function after CPB surgery.[2]

The unique ability of light in the near infrared range (700–1300 nm) to detect the oxygenation of living tissues was first described by Jobsis in 1977.[5] Since that time, NIRS has emerged as a promising *in vivo* technique and as a continuous cerebral oxygenation monitor during cardiac surgery.[6] NIRS has been used to study the changes in cerebral oxygenation in children and adults undergoing CPB surgery with or without deep hypothermic arrest[7–9] and to monitor cerebral hemodynamics.[10] In addition, it might be useful as a cerebral oxygenation monitor in patients undergoing carotid endarterectomy.[11]

The NIRO-300 is a new NIRS monitor introduced recently by Hamamatsu Photonics, Japan, which uses spatially-resolved spectroscopy (SRS) to provide not only the usual measurements of change in hemoglobin concentration, but also an absolute signal of the tissue oxygenation index (TOI) which is related to the averaged regional hemoglobin saturation.[12,13] The SRS technique incorporates several detectors housed in a single probe placed over an area of 8 x 8 mm, and 4–5 cm from the light source fibre. A combination of these multi-distance measurements of optical attenuation with the usual multi-wavelength spectroscopy data allows calculation of the relative concentrations of deoxyhemoglobin and oxyhemoglobin in the illuminated tissue and therefore an index of the mean tissue hemoglobin saturation.[13]

The aim of this study was to evaluate the intra-operative use of the NIRO-300 for monitoring of TOI which may provide a non-invasive alternative to SjO_2 monitoring in patients undergoing warm CABG, and to determine if the two methods are interchangeable.

Methods

The Local Research Ethics Committee approved the study and individual informed- patient consent was obtained. We studied 17 patients undergoing CABG. Patients with a pre-operative history of cerebral injury or with a past history of open-heart surgery were not studied. All patients were premedicated with temazepam 30–40 mg given orally 60 to 90 min before operation. Anesthesia was induced with etomidate 0.2– 0.3 $mg \cdot kg^{-1}$ and fentanyl 10–20 $\mu g \cdot kg^{-1}$. Pancuronium 0.1 $mg \cdot kg^{-1}$ was administered to facilitate tracheal intubation. The lungs were ventilated mechanically with oxygen-enriched air adjusted to keep the end-tidal carbon dioxide tension around 35 mmHg. Anesthesia was maintained with boluses of fentanyl up to a total dose of 50 $\mu g \cdot kg^{-1}$ and isoflurane in oxygen/air at a concentration of (0.5–1.0 %).

CPB was established using a membrane oxygenator and a roller pump with an arterial line filter. Perfusion was non-pulsatile with a flow rate of 2.4 $L \cdot min^{-1} \cdot m^{-2}$ body surface area. A pH-stat carbon dioxide management strategy (blood gas measurements corrected to body temperature) was employed. Nasopharyngeal temperature was maintained at 34–37°C and intermittent, antegrade warm blood cardioplegia (temperature 37°C) was administered to all patients. During CPB, anesthesia was maintained by isoflurane 0.5–1%.

The jugular bulb catheter (Hydrocath 16 G, 15–20 cm) was placed by retrograde cannulation of the right internal jugular vein and its position was checked radiologically. SjO_2 samples were measured by a co-oximeter (Radiometer ABL 520, Radiometer, Ltd, Copenhagen, Denmark).

NIRO-300 probes were applied over the right supra-orbital region with an inter-optode distance of 5 cm. Continuous monitoring of TOI was averaged to synchronize with the SjO_2 measurements at the following time points: before CPB, five, 20, 40, 60 min on CPB, five minutes before end of CPB and ten minutes after CPB. Jugular bulb samples were taken at a rate of 0.5 $ml \cdot min^{-1}$ to avoid extracranial contamination.[14]

Statistical analysis

All results were analysed with SPSS version 7.5 for Windows. The Bland and Altman analysis with limits of agreement[15] was used to study the agreement between the TOI and SjO_2. We decided that ± 5% would be a clinically acceptable difference between the two methods (SjO_2 and TOI) while still supporting the conclusion that the two methods are interchangeable.

Differences from baseline for SjO_2, TOI were assessed by Wilcoxon signed rank test.

Results

Seventeen patients were studied with a mean age of 63.2 yr (range 45–73). The mean aortic cross-clamping time was 52.3 min (range 24–80) and mean CPB time was 99.8 min (range 44–140).

A total of 118-paired measurements of TOI and SjO_2 were analysed. The mean difference (bias) between measurements was -6.7% (TOI - SjO_2) with wide limits of agreement (15 to -28%), more than the chosen tolerable clinical difference (± 5%). Correlation between the two methods was poor (r^2=0.166; Table and Figure 1). When this variation was split into between-and within-patient measurements, Bland and Altman analysis for the means of the 17 cases also showed a bias of -6.74%, with limits of agreement that were closer, but still wider than acceptable (8 to -21%). Correlation between the two methods

TABLE The correlation and limits of agreement between TOI% and SjO_2

	Sample size	r^2	*P*	*Mean difference (bias)*	*SD of the difference (precision)*	*Limits of agreement upper*	*lower*
1) Mean for each patient	17	0.237	<0.05	-6.74	± 7.27	7.9	-21.3
2) All individual values	118	0.166	<0.01	-6.74	± 10.7	14.7	-28.1
3) Differences from the mean	118	0.132	<0.01	0.0	±8.08	16.16	-16.16

TOI: tissue oxygen index; SjO_2: jugular bulb oxygen saturation.

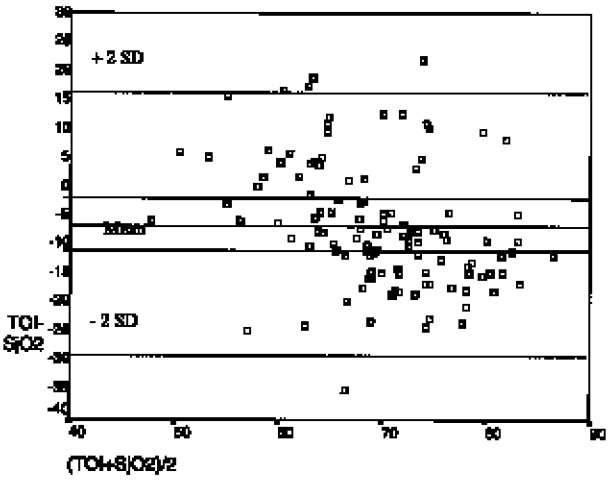

FIGURE 1 Bland and Altman plot of the mean differences and limits of agreement between all individual measurements of SjO_2% and TOI%. TOI, tissue oxygen index; SjO_2, jugular bulb oxygenation. Solid lines represent the suggested tolerable clinical difference (± 5%) between TOI and SjO_2.

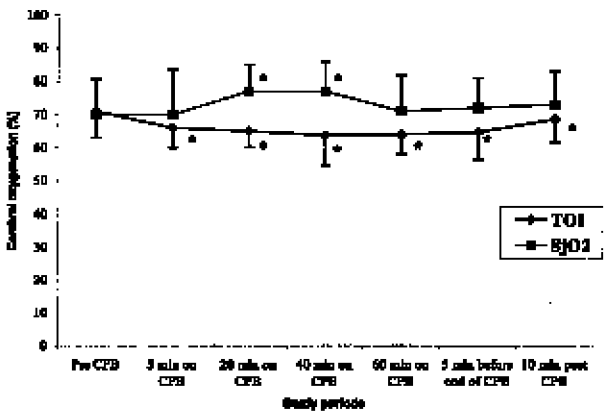

FIGURE 2 Mean ± SD of SjO_2% and TOI% before, during and after CPB TOI%, tissue oxygen index; SjO_2, jugular bulb oxygen saturation. **P* <0.05 by Wilcoxon signed ranks test (bypass and post-bypass measurements compared with pre-bypass values).

improved somewhat (r^2=0.237; Table).

In terms of within-patient variation (differences of individual measurements from the mean of each variable in each patient; Table), the bias between TOI and SjO_2 was zero, with intermediate limits of agreement (± 16%). The correlation between the two methods was a little better than for all individual measurements (r^2=0.132).

We observed a statistically significant correlation between individual measurements of SjO_2 and arterial carbon dioxide tension ($PaCO_2$) (r^2=0.333, *P*=0.0003). However, TOI did not correlate with $PaCO_2$ (r^2=0.001, *P*=0.7).

A few patients had one or two episodes of cerebral desaturation (50%), but no measurement was less than 44% and never were SjO_2 and TOI both below 50%.

At each time point during and after CPB, the mean TOI is lower than the corresponding mean SjO_2 (Figure 2). Mean TOI was significantly decreased during and after CPB, and mean SjO_2 increased significantly at 20 and 40 min on CPB compared to pre-bypass levels (Figure 2). All patients made an uneventful recovery on the first post-operative day.

Discussion

This study examined the possible agreement between two methods for assessing cerebral oxygenation during cardiac surgery with warm CPB. The study demonstrated lack of agreement between SjO_2 measured by co-oximetry and TOI measured by NIRO-300, despite a statistically significant correlation between TOI and SjO_2.

Comparison of SjO_2 and regional cerebral oxygen saturation measured by another NIRS machine (INVOS 3100®, Somanetics Inc., Troy, MI) has been performed.[16–20] The design of the Somanetics device differs considerably from others. It has two receivers at different distances from the light emitter to correct for surface tissue overlying the brain. A single absolute

value of regional cerebral oxygen saturation is calculated by an algorithm which is thought to be independent of path length.[16–20]

Daubeney *et al.*[16] studied 29 children undergoing cardiac catheterization and 11 children during cardiac surgery. They found a significant correlation between the individual measurements (n=147) of the two methods (r^2=0.476, P <0.0001) but the authors did not perform a Bland and Altman analysis. Although, Brown *et al.*[17] reported a minimal bias of -0.46%, the limits of agreement between the two methods were considerable (~ ± 25%) during adult cardiac surgery, a finding consistent with our results. Furthermore, poor agreement between the two methods of cerebral oxygenation were detected in head injury patients[18,19] as well as in patients resuscitated from cardiac arrest.[20]

Sapire *et al.*[21] found a good correlation (r^2=0.63, P <0.001) between the changes from baseline of SjO_2 and regional oxygenation monitored by another NIRS (RunMan, NIM, Philadelphia, PA) device. Yet, correlation was poor in some patients, and in others, there was a delay between the two measurements.[21] The authors also suggested that this time difference might be a result of the difference between regional oxygenation in the area of the brain monitored by NIRS and the global oxygen saturation measured by jugular bulb catheter.

Several factors may contribute to the observed lack of agreement. First, NIRS cerebral monitoring measures TOI in a small region of the cranial microvasculature, whereas SjO_2 reflects a more global measurement. Thus, any inhomogeneous distribution of blood or metabolic activity will reduce the agreement between the two methods.[17] Second, the actual TOI signal is the average of arterial (25%), capillary (5%) and venous blood (70%). In addition, contamination from the extracranial tissues may be a contributing factor.

TOI, which includes arteriolar blood, would normally be expected to be higher than SjO_2. However, mean TOI was less than SjO_2 both during and after CPB (Figure 2). This could be explained by higher SjO_2 compared with TOI because jugular bulb saturation incorporates blood from deeper brain structures that extract less oxygen than the neocortex monitored by NIRS,[22] or it could be due to the impact of extracranial tissue on NIRS signals.[18–22]

The suggestion that extracranial tissue makes a major contribution to NIRS signals has been extensively documented in theoretical and laboratory studies of light transport in a multi-layer media.[23] These have been supported by clinical experimental data, which indicate that cerebral blood flow measured by NIRS is three times greater when the probe is placed on the dura than when it is measured through the scalp.[24] More recently, Young *et al.*[25] found that removal of skull bone and dura from the NIRS light path caused a significant reduction in detected intensity (up to 14-fold decrease). These authors suggested that the skull and/or its interface with other layers might act as an optical channel distorting the behaviour of NIRS light in the human head.

If the disagreement between TOI and SjO_2 is due to regional desaturations, it could be assumed that SjO_2 is less sensitive for detection of regional cerebral ischemia: whereas a normal SjO_2 does not guarantee that there is no regional cerebral ischemia, a low SjO_2 may be indicative of global or focal ischemia, or both.[26]

The lack of correlation between TOI and $PaCO_2$ is consistent with the studies of Germon *et al.*[22,27] Using another NIRS machine (INVOS 3100®) device, they were not able to detect changes in cerebral oxygenation as a result of cerebral hyperemia due to hypercapnia. By contrast, Tateishi *et al.*[28] studied nine patients with head trauma and found that the direction and magnitude of changes in cerebral oxyhemoglobin concentration measured by NIRS and SjO_2 in response to changes in $PaCO_2$ were similar in eight of the patients. However, in one patient, despite an increase in SjO_2 by 20% in response to increased $PaCO_2$, the response of oxyhemoglobin was negligible. This might indicate a local difference in CO_2 responsiveness.

Our results show that the two methods are not interchangeable. Which one is "right"remains a subject of controversy, since both methods probably measure different entities.

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