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Relation between mixed venous oxygen saturation and cerebral oxygen saturation measured by absolute and relative near-infrared spectroscopy during off-pump coronary artery bypass grafting

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Editor's key points

- Cerebral oxygen saturation might provide better non-invasive monitor of tissue perfusion than mixed venous oxygen saturation.
- Simultaneous measurements of cerebral oxygen saturation using two near-infrared spectroscopy monitors (INVOS® and Foresight®) were compared in cardiac surgery.
- Cerebral oxygen saturation appears to provide a more responsive monitor of tissue perfusion than mixed venous saturation.

Background. We hypothesized that previously reported contradictory results regarding the equivalence of mixed venous (Smv_{O_2}) and cerebral (rS_cO_2) oxygen saturation might be related to time delay issues and to measurement technology. In order to explore these two factors, we designed a prospective clinical study comparing Smv_{O_2} with relative (INVOS®) and absolute (Foresight®) rS_cO_2 measurements.

Methods. Forty-two consenting patients undergoing elective off-pump coronary artery bypass grafting were included. Two INVOS and two Foresight sensors continuously registered rS_cO_2. Smv_{O_2} was measured continuously via a pulmonary artery catheter. Data were assessed by within- and between-group comparisons and correlation analysis.

Results. A similar time delay of 19 (4) and 18 (4) s was found for Smv_{O_2} compared with rS_cO_2 measurements by Foresight and INVOS, respectively, during haemodynamic changes. After adjusting for this time delay, the correlation between Smv_{O_2} and rS_cO_2 increased from r=0.25 to 0.75 (P<0.001) for Foresight, and from r=0.28 to 0.73 (P<0.001) for INVOS. Comparison of Foresight and INVOS revealed significant differences in absolute rS_cO_2 values (range 58–89% for Foresight and 28–95% for INVOS). Changes in rS_cO_2 in response to acute haemodynamic alterations were significantly more pronounced with INVOS compared with Foresight (P<0.001).

Conclusions. Considering the important time delay with Smv_{O_2}, rS_cO_2 seems to reflect more appropriately acute haemodynamic alterations. This might suggest its use as a valid alternative to invasive monitoring of tissue oxygen saturation. Relative and absolute rS_cO_2 measurements demonstrated significant differences in measured rS_cO_2 values and in the magnitude of rS_cO_2 changes during haemodynamic alterations.

Keywords: coronary artery bypass, off-pump; monitoring, intraoperative; oximetry; pulmonary artery catheterization; spectroscopy, near-infrared

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A primary goal of haemodynamic management of patients undergoing surgery is to provide adequate tissue oxygenation. Mixed venous oxygen saturation (Smv_{O_2}) is generally accepted as an indicator of adequacy of systemic oxygen balance, and its use for guidance of therapy has been demonstrated to improve outcome.[1] Owing to its invasiveness, this variable is not commonly incorporated into routine anaesthesia monitoring. The availability of an easy to use, reliable, and non-invasive monitor of global oxygen balance would benefit a much wider spectrum of patients at risk for anaesthesia and surgery.

Near-infrared spectroscopy (NIRS) measures regional cerebral oxygen saturation (rS_cO_2) in the cerebral cortex, which is a predominantly venous bed.[2] The findings of Murkin and colleagues[3] suggest that cerebral oximetry might be useful as an index for global oxygen delivery and consumption, indicating that NIRS might offer a continuous, non-invasive alternative for Smv_{O_2}.

Previous studies found contradictory results regarding the equivalence and interchangeability of Smv_{O_2} and rS_cO_2 data.[4–12] We hypothesized that this inconsistency might be related to two factors. First, Smv_{O_2} values were recorded intermittently, providing only isolated epochs for comparison such that time delay issues may not have been taken into account. Secondly, rS_cO_2 measurements were all performed with the INVOS cerebral oximeter (Somanetics Corporation, Troy, MI, USA), which is approved by the Food and Drug Administration (FDA) as a relative cerebral oximeter or a trend monitor [K051274 FDA 510(k) premarket notification]. Hence, the reported poor correlations might be the result of inherent limitations of the measurement technology.

In order to explore these two hypotheses, we designed a prospective observational clinical study comparing continuously measured Smv_{O_2} with both relative and absolute rS_cO_2 measurements. Because we wanted to evaluate both experimental questions in a wide range of haemodynamic changes, we chose a model of off-pump coronary artery bypass (OPCAB) surgery, as the course of this procedure entails significant haemodynamic alterations during surgical exposure and cardiac manipulation. The Foresight cerebral oximeter (CAS Medical Systems, Branford, CT, USA) was chosen as a comparative NIRS technology, since it claims to be an absolute cerebral oximeter (www.casmed.com), providing absolute rS_cO_2 values.[13 14]

Methods

This trial is registered at ClinicalTrials.gov (NCT01673841). After Institutional Ethics Committee approval and written informed consent, 42 patients undergoing elective OPCAB surgery for at least three-vessel coronary artery disease were included. Patients with arteriovenous shunts, intracardiac shunts, a previous history of cerebrovascular accident, or stenosis of the internal carotid artery of $>60\%$ were excluded.

Description of NIRS devices

The physical principles upon which NIRS is based have been described.[15] In general terms, NIRS utilizes the absorption and reflectance spectra of near-infrared light to quantify oxygenation of tissues underlying the sensor. Both INVOS and Foresight use the modified Beer–Lambert law to measure tissue oxygen saturation, and eliminate the contribution of extracerebral tissue by using the principle of spatial resolution (depth of photon penetration proportional to the source–detector separation). However, some important technical differences exist. The INVOS 5100 generates two wavelengths of light at 730 and 810 nm from light-emitting diodes, while Foresight uses laser-emitting diodes to generate light at four different wavelengths (690, 778, 800, and 850 nm). The spacing of the light detectors from the light emitter, which influences the sample volume and depth of penetration, is at 3 and 4 cm distance for INVOS 5100, and at 1.5 and 5 cm for Foresight. There is also a difference in assumed cerebral arterial:venous ratio upon which the oximetry values are calculated (assumed ratio of 25:75 for INVOS and 30:70 for Foresight). Owing to the technical differences and the different computational algorithms for the calculation of tissue saturation, the comparability between INVOS 5100 and Foresight is not clear.

Study design

On the morning of surgery, subjects were allowed to take their routine medication, except for angiotensin-converting enzyme inhibitors. Four disposable oxygenation sensors [two INVOS sensors (INVOS 5100, Somanetics Corporation) and two Foresight sensors (CAS Medical Systems)] were applied bilaterally on the forehead for continuous registration of rS_cO_2. The sensors of one monitor were placed just above the eyebrows, and the sensors of the other monitor were placed just above the former sensors. Sensor placement was determined at random by a computerized randomization list. Baseline values were obtained at least 1 min after placement of sensors until values were stabilized. Anaesthesia was induced with diazepam 0.1 mg kg^{-1}, fentanyl 5 μg kg^{-1}, propofol 1 mg kg^{-1}, and rocuronium 1 mg kg^{-1}. The lungs were ventilated mechanically with oxygen-enriched air (fractional inspired oxygen 0.6) adjusted to keep end-tidal carbon dioxide (E'_{CO_2}) around 4.7 kPa. Anaesthesia was maintained with boluses of fentanyl up to a total dose of 25–35 μg kg^{-1} and sevoflurane at a minimum concentration of 1.5 vol%. Standard monitoring was used throughout the procedure, including ECG, pulse oximetry, capnography, invasive arterial, central venous and pulmonary artery pressure monitoring, continuous Smv_{O_2} monitoring [Swan–Ganz CCOmbo pulmonary artery catheter (Edwards Lifesciences, Irvine, CA, USA)], and transoesophageal echocardiography.

Haemodynamic management was at the discretion of the attending anaesthetist. All variables were recorded continuously with RUGLOOP® (Demed, Temse, Belgium) and were analysed at 2 s intervals. Types and volumes of all fluids were recorded, as well as doses of any drugs given.

To explore interference when Foresight and INVOS were operating simultaneously, we included a methodological evaluation of the reliability of our data. During preparation of the internal thoracic artery—which includes a haemodynamically stable period—the monitors were switched off one at a time for 5 min. During these periods, the mean rS_cO_2 and standard deviation (SD) were measured for each monitor separately and compared with the mean (SD) obtained during the 5 min preceding this intervention when both monitors were operating simultaneously (Fig. 1).

The response of rS_cO_2 to major haemodynamic disturbances was explored during placement of deep pericardial stitches. During every heart retraction, which induced a substantial decrease in mean arterial pressure (MAP), relative changes in MAP, rS_cO_2, and Smv_{O_2} were calculated at 5 (T1) and 10 s (T2) after start of heart retraction, at the minimum value of MAP (T3), and at 5 (T4), 10 (T5), 15 (T6), and 20 (T7) s after release of heart retraction. Relative change was defined as the percentage difference between the value just before heart retraction and the value at the different time moments. The integrated value or area under the curve (AUC) for rS_cO_2 during placement of the pericardial