

Calibration and Validation of the Noninvasive Regional Oximeter with Cerebral Sensor

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INTRODUCTION

Over the past 30 years, the routine use of noninvasive pulse oximetry and capnography has contributed to dramatic improvement in the safety of anesthesia^{1,2} However, there are limitations to pulse oximetry technology, most notably an inability to provide a reading in a non-pulsating state such as cardio-pulmonary bypass (CPB).

Recently near infra-red spectroscopy (NIRS) regional oximeters have been developed to noninvasively estimate cerebral tissue oxygen saturation. This measure represents the oxygen level within brain tissue and is a composite value based on the relative proportions of arterial and venous blood within the tissue. Cerebral oximetry provides a measurement of changes in oxygen saturation relative to delivered oxygen and cerebral metabolism. Unlike conventional pulse oximetry, NIRS cerebral oximetry does not rely on a pulsating flow and therefore is able to provide a reading during non-pulsating flow such as CPB.

Over the last decade numerous reports have shown that the onset of cerebral oxygen desaturation frequently occurs in the absence of change in any of the routine monitors (pulse oximeter, EKG, blood pressure) and that this desaturation can be detected by cerebral oximetry. Thereby cerebral oximeters can be used to avoid potential complications.³⁻⁶

Despite declines in overall mortality after cardiac surgery, the rates of cognitive dysfunction have not improved. In some reports, impaired cognitive performance incidence is as high as 60%.^{7,8} Although the etiology of neuropsychological impairment is controversial, evidence supporting the relationship between poor cerebral regional oxygen saturation (rSO_2) and poor outcome following cardiac surgery continues to grow. Patients undergoing cardiac surgery with cerebral oxygen desaturation events tend to have longer hospital stays and poorer cognition post-operatively.^{8,9}

A prospective two-phase clinical study in healthy, adult subjects was conducted. The study objective was to calibrate and validate a new NIRS regional oximeter with a cerebral sensor and to determine the accuracy in measuring cerebral oxygen saturation.

STUDY DEVICE

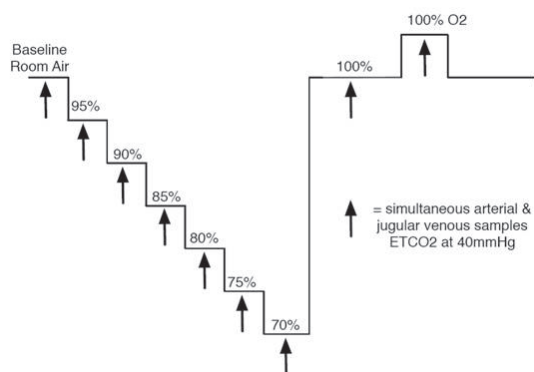
The study device developed by Nonin Medical, Inc. measures regional blood oxygen saturation utilizing Equanox™, a patented technology with a dual emitter/detector sensor topology. Equanox has the potential to provide improved accuracy and repeatability when measuring regional tissue oxygenation. Existing NIRS cerebral oximeters use a single emitter and two detectors for the optical measurements. The optical measurement from the shorter path (representing extracranial blood oxygen) is subtracted from the longer path (representing intracranial and extracranial blood oxygen) to give measurements for intracranial blood oxygen.¹⁰ Any surface and shallow tissue variation between the two detector sites introduces error into the measurement. With the Nonin sensor, two emitters and two detectors are used in each sensor to cancel out surface and shallow tissue variations in order to improve accuracy and repeatability of measurements. The system is completely non-invasive. The emitters are light emitting diodes (LEDs) with three wavelengths in the 700 to 900 nanometer range.

METHODS AND MATERIALS

All testing was conducted at Duke University Human Physiology Lab (HPL) under the direction of the lead author. Institutional Review Board (IRB) approval was obtained prior to study initiation. The study consisted of two phases with no overlap of subjects: the calibration phase and the validation phase. The testing methods represent the industry standard for assessing regional cerebral oximetry accuracy.

An internal jugular venous catheter and a radial artery catheter were placed. The venous catheter position was confirmed with a lateral skull x-ray. The subjects were placed in a semi-recumbent position on the bed. Two Equanox cerebral sensors were placed bilaterally on the forehead and a pulse oximeter was placed on the ear. Hypoxia was induced and managed via a dedicated facemask and breathing apparatus (RespirAct™).¹¹ Subjects underwent a standard, breath-down protocol to allow for a clinically relevant range of oxygenation values. (See Figure 1 on the following page.)

Figure 1. Summary of the step-down plateaus



Target oxygenation levels were identified based on the pulse oximeter and were stabilized during blood samples. At each plateau, jugular bulb blood sample and two arterial blood samples were drawn simultaneously. Co-oximetry was used to determine the jugular venous saturation (SvO_2) and arterial saturation (SaO_2). The arterial samples were averaged to provide one SaO_2 value for that plateau. The arteriovenous ($SavO_2$) saturation was then calculated as a 70:30 ratio of venous to arterial blood: $SavO_2 = 0.70 \times SvO_2 + 0.30 \times SaO_2$. $SavO_2$ is a measured approximation of the cerebral oxygen saturation and was used as the reference value for assessing accuracy.¹² Data collected during unstable plateaus, blood draw difficulties, co-oximeter errors, or other similar circumstances were excluded.

Accuracy was determined using A_{RMS} , a common statistic for oximetry devices which estimates the agreement between a test device and an accepted reference value. A_{RMS} consists of two components: mean bias and precision. Mean bias is the average difference between the test device value and the reference value across all observations. Precision is the scatter of possible test device values around the mean bias for a single reference value.

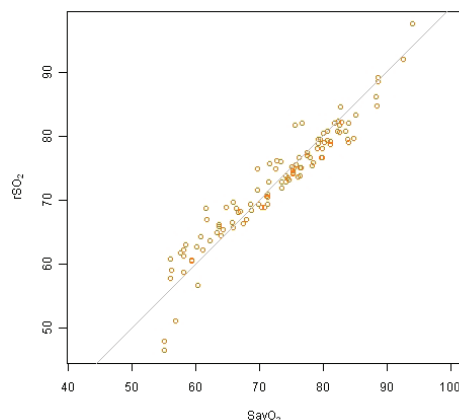
RESULTS

All findings and accuracy results are based on the validation phase of the project which consists of 106 normocapnic plateaus from nine subjects. There were five males and four females ranging in age from 21 to 34 years. All subjects were healthy, current non-smokers.

The trending accuracy of rSO_2 compared to $SavO_2$ as measured by A_{RMS} is 2.7%. Trending accuracy is a measure of how well a device measures a change in rSO_2 compared to a change in the reference value after accounting for any individual subject bias. Figure 2 provides a graphical representation of the trending accuracy. The observed rSO_2 values (adjusted) are plotted against the measured $SavO_2$ values. The line of identity is provided for reference. If the device had an A_{RMS} of 0, all data would lie on the line of identity indicating perfect agree-

ment. A predominate amount of data is centered around the reference line, indicating close agreement between the adjusted rSO_2 values and the $SavO_2$ reference values.

Figure 2. Adjusted rSO_2 versus $SavO_2$



CONCLUSION

The Nonin regional oximeter with Equanox technology and cerebral sensor provides an accurate measure of trends in cerebral oxygen saturation. Observed changes in rSO_2 would indicate a corresponding change in $SavO_2$.

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