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Skin pigmentation interferes with the clinical measurement of regional cerebral oxygen saturation

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Editor's key points

- Near-infrared spectroscopy is increasingly being used to assess regional cerebral oxygen saturation (rSO_2).
- The authors studied preoperative rSO_2 values in a cardiac surgery population.
- Skin pigmentation was found to independently influence preoperative rSO_2.
- Low preoperative rSO_2 values were associated with worse mortality in all racial groups.

Background. Devices utilizing near-infrared (NIR) spectroscopy have been used to assess regional intracerebral oxygen saturation (rSO_2) during anaesthesia for a decade. The presence of wide differences among individuals reduces their applicability to steady-state measurements. Current devices may not adequately account for variations in skin pigmentation.

Methods. From our ongoing departmental registry, 3282 consecutive patients underwent cardiac surgery between 2010 and 2012 and their pre-induction measurements of rSO_2 were available. Of these, 2096 identified themselves as Caucasian (Cauc) and 1186 as African-American (AA). Pre-induction rSO_2, clinical and operative features were compared.

Results. Clinical and operative details of these patients differed widely between the two populations. High-risk features were more common in AA patients, but no difference in mortality was observed (4.8% in AAs *vs* 4.7% in Caucs, $P=0.87$). Preprocedure rSO_2 was systematically higher in Cauc (65.5% *vs* 53.3%, $P<0.001$). After multivariate linear regression adjustment, AA ethnicity proved to be associated independently with low rSO_2 [odds ratio (OR) −8.28, 95% confidence interval (CI) −9.12 to −7.44, $P<0.001$]. Multivariate logistic regression analysis showed that preprocedural rSO_2 was independently associated with operative mortality both in the Cauc group (OR 0.97, 95% CI 0.96–0.99, $P=0.001$) and in the AA group (OR 0.97, 95% CI 0.95–0.99, $P=0.01$).

Conclusions. AAs have a lower rSO_2 than Caucs as measured by the INVOS 5100C cerebral oximeter. Reasonably, this could be attributed to attenuation of the NIR light by skin pigment. Despite this limitation, in both ethnic groups, lower preoperative rSO_2 was predictive of greater operative mortality.

Keywords: cardiovascular anaesthesia; regional cerebral oxygen saturation; skin pigmentation

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Since Food and Drug Administration approval in 1993, devices utilizing near-infrared (NIR) spectroscopy have been used to assess regional intracerebral oxygen saturation (rSO_2) during anaesthesia and surgery.[1 2] The cranium and extracranial soft tissue are relatively transparent to light in the NIR region of the spectrum. Thus, rSO_2 can be assessed using differences in the intensity of transmitted and received light as delivered in specific wave lengths. NIR light transmitted in the wave lengths for oxyhaemoglobin and deoxyhaemoglobin are absorbed to different degrees in their passage through tissue and from the differences between these measurements, the percentage of oxyhaemoglobin in the superficial layers of the frontal cortex can be estimated. This technique has found clinical utility in monitoring deviation in rSO_2 from a baseline level during anaesthesia and surgery. Episodes of declining rSO_2 levels may be identified and corrective measures undertaken to improve oxygen delivery to the cerebral circulation.[3–5]

Steady-state rSO_2 levels have been thought to be subject to wide individual variability and, as a consequence, of little clinical use. Heringlake and colleagues[5] recently published data suggesting that low preoperative rSO_2 levels are associated with worse clinical outcomes in cardiac surgery and thus are, in fact, useful for assessing surgical risk. Unpublished data from this institution using only Caucasian (Cauc) patients are consistent with these observations.

African-American (AA) patients make up an important minority of our practice. We have been concerned that skin pigmentation in this group may interfere with the measurement of rSO_2 and compromise the association of rSO_2 with surgical outcome. The predominant skin pigment in AAs, melanin, is known to attenuate NIR light transmission and thus to impede NIR spectroscopy signals.[4] Accordingly, it is recommended that melanin-containing hair be avoided when the transmitting and receiving optodes are placed.[4] Although

melanin in the skin has not been regarded as a problem, our experience with the large number of AAs in our surgical practice has suggested that this assumption may not be true, and that melanin in the skin may, in fact, interfere with baseline measurements made for this purpose.

The aim of this analysis was two-fold. First, it was intended to identify and quantify any systematic difference associated with skin pigmentation in the estimation of steady-state rSO_2 by means of NIR spectroscopy. Secondly, we sought to determine if any detected pigment-related interference had clinical relevance with regard to the preoperative risk estimation in cardiac surgery. For these purposes, we utilized a large, consecutive series of patients undergoing cardiac surgery in which rSO_2 was measured before the induction of anaesthesia.[5]

Methods

Patients

The records of all patients included in the computerized registry of cardiac surgical procedures performed in the Division of Cardiac Surgery between January 1, 2010, and December 31, 2012, were examined. The 3282 patients who underwent rSO_2 assessment before cardiac surgery were included in this analysis, provided they identified themselves as either Cauc or AAs. The study was approved by the institutional review board.

Data collection and entry

As is routine in our department, baseline patient and clinical characteristics together with the details of the operative procedure were prospectively collected as part of routine clinical care and entered into the registry by the staff of the data-coordinating centre. Variables were defined and sourced according to the Society of Thoracic Surgeons National Cardiac Surgery Database Guidelines and Definitions (http://www.STS.org/STS national database).

Operative procedures

Operations were performed by experienced cardiac surgeons. Selection of patients and choice of the operative procedure were at the discretion of the responsible surgeon.

Cerebral oxygen saturation

rSO_2 was measured before the induction of anaesthesia by means of the INVOS 5100C cerebral oximeter (Semantics Corporation, Troy, MI, USA). Each patient was receiving 100% oxygen through a face mask to which an oxygen flow of 3–5 litre min^{-1} was being delivered. After cleaning the patient's skin with an alcohol pad, paired transmitting and receiving optodes were positioned on either side of the patient's forehead. Each optode was covered to prevent ambient light from reaching it.

Statistical analysis

Preoperative characteristics are presented as proportions and percentage for dichotomous variables. Differences between ethnic groups were tested by means of the χ^2 analysis or Fisher's exact test. Continuous variable (e.g. rSO_2) measurements are presented as the mean and standard deviation and tested for differences by means of Student's *t*-test for normally distributed data or the Wilcoxon rank-sum test for non-parametric data. A two-sided *P*-value of <0.05 was chosen as the level of significance.

To examine the effect of ethnic group on rSO_2, a multivariate linear regression model was used to adjust for preoperative factors that were potentially confounding. Included as candidate variables were those with a univariate difference $P<0.15$. From this model, parameter estimates and 95% confidence interval (CI) were calculated.

To evaluate the association of baseline rSO_2 and operative mortality in each ethnic group, a multivariable logistic regression model was constructed. Candidate variables were chosen among both preoperative and intraoperative factors. Odds ratio (OR) with 95% CI are reported.

All analyses were performed with SAS version 9.1 (SAS Institute, Cary, NC, USA).

Results

Clinical patient characteristics

Clinical characteristics of these patients are shown in Table 1. Of the 3282 patients undergoing preprocedural rSO_2 measurement, 1186 (36.1%) identified themselves as AA and 2096 (63.9%) as Cauc. There are striking contrasts between the ethnic groups. Importantly, many of the differences suggest the likelihood of a greater risk of operative mortality in AA patients. Reflecting this preponderance, the STS mortality risk score was significantly higher in AAs (1.2 in Caucs *vs* 1.6 in AAs, $P<0.001$).

Procedural details

Selected details of the operative procedures are compared in Table 2. AAs underwent more complex operations than Caucs. They less often underwent elective surgery (25.7% *vs* 34.5%, $P<0.001$) and more often required cardiopulmonary bypass (80.8% *vs* 70.5%, $P<0.001$).

Thus, both baseline clinical characteristics and the nature of the operative procedure predict a higher operative mortality for AA patients. Surprisingly, no difference was observed (4.8% in AA patients *vs* 4.7% in Cauc patients, $P=0.87$).

Preoperative cerebral oxygen saturation

Table 3 reports the group mean and standard deviation for each pair of optodes both before operation and at the time of skin closure. At each of the optode pairs and at each of the two time points, the saturation was significantly lower in AAs by ~12% points.

Figure 1 demonstrates that the difference between the two ethnic groups occurred across all levels of rSO_2 values. Moreover, the normal distribution of these values in each ethnic group is noteworthy.

Table 4 reports the association between rSO_2 level and preprocedural clinical characteristics (Table 1) as determined by multivariate linear regression analysis. After adjustment for