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Postoperative Cerebral Oxygen Saturation in Children After Congenital Cardiac Surgery and Long-Term Total Intelligence Quotient: A Prospective Observational Study

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OBJECTIVES: During the early postoperative period, children with congenital heart disease can suffer from inadequate cerebral perfusion, with possible long-term neurocognitive consequences. Cerebral tissue oxygen saturation can be monitored noninvasively with near-infrared spectroscopy. In this prospective study, we hypothesized that reduced cerebral tissue oxygen saturation and increased intensity and duration of desaturation (defined as cerebral tissue oxygen saturation < 65%) during the early postoperative period, independently increase the probability of reduced total intelligence quotient, 2 years after admission to a PICU.

DESIGN: Single-center, prospective study, performed between 2012 and 2015.

SETTING: The PICU of the University Hospitals Leuven, Belgium.

PATIENTS: The study included pediatric patients after surgery for congenital heart disease admitted to the PICU.

INTERVENTIONS: None.

MEASUREMENTS AND MAIN RESULTS: Postoperative cerebral perfusion was characterized with the mean cerebral tissue oxygen saturation and dose of desaturation of the first 12 and 24 hours of cerebral tissue oxygen saturation monitoring. The independent association of postoperative mean cerebral tissue oxygen saturation and dose of desaturation with total intelligence quotient at 2-year follow-up was evaluated with a Bayesian linear regression model adjusted for known confounders. According to a noninformative prior, reduced mean cerebral tissue oxygen saturation during the first 12 hours of monitoring results in a loss of intelligence quotient points at 2 years, with a 90% probability (posterior β estimates [80% credible interval], 0.23 [0.04–0.41]). Similarly, increased dose of cerebral tissue oxygen saturation desaturation would result in a loss of intelligence quotient points at 2 years with a 90% probability (posterior β estimates [80% credible interval], –0.009 [–0.016 to –0.001]).

CONCLUSIONS: Increased dose of cerebral tissue oxygen saturation desaturation and reduced mean cerebral tissue oxygen saturation during the early postoperative period independently increase the probability of having a lower total intelligence quotient, 2 years after PICU admission.

KEY WORDS: cerebrovascular circulation; follow-up studies; heart defects, congenital; hypoxia; intensive care units, pediatric; spectroscopy, near-infrared

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Half of all children with congenital heart disease (CHD) undergo surgery in the first months of life (1, 2). Despite high survival rates, many of the surviving children can suffer from long-term neurodevelopmental deficits (3–6), as a result of white matter lesions following hypoxic or ischemic events (2, 3, 7, 8). To maximize outcomes, the treating team pursue adequate oxygen delivery during the entire perioperative period. Cerebral perfusion can be monitored with near-infrared spectroscopy (NIRS), which continuously monitors regional cerebral tissue oxygen saturation ($Scto_2$) in the frontal lobe (9, 10).

Perioperative reduced $Scto_2$ is associated with longer length of stay (LOS) in the PICU, longer duration of mechanical ventilation, and increased risk of major postoperative complications and mortality (11–16). It remains unclear whether reduced $Scto_2$ is also associated with long-term neurocognitive deficits (14). Several studies have been performed to address this question, but with contradictory results, due to the limited number of the patients enrolled and the lack of a uniform protocol to treat nonoptimal $Scto_2$ (14).

In this study, we used a large single-center dataset to investigate the association between $Scto_2$ in pediatric patients after surgery for CHD and total intelligence quotient (IQ) at 2-year follow-up. The associations were analyzed with Bayesian inference, which allows accounting for uncertainty in parameter estimates.

MATERIALS AND METHODS

Study Design

This study includes children with CHD admitted in the PICU of the University Hospitals Leuven, Belgium, between 2012 and 2015. It derives from a protocol amendment to a blinded prospective observational study to investigate the independent association of continuous $Scto_2$ measurements in children admitted after congenital cardiac surgery, on organ failure, PICU, and hospital outcomes (13, 17). Seventy-nine of the children (91%) included in this study were also included in the paediatric early versus late parenteral nutrition in critical illness (PEPaNIC) multicenter, randomized, controlled trial (18).

The protocol of the study was preregistered (ClinicalTrials.gov: NCT01706497). Both the original study and the amendment obtained ethical approval of the ethics committee research UZ/KU Leuven (EC research).

Participants

Pediatric patients younger than 12 years old, admitted to the PICU of the University Hospitals Leuven, Belgium, who underwent corrective or palliative cardiac surgery for a congenital heart defect, were eligible for the study. A complete list of the cardiac surgery procedures amenable for inclusion is reported in **Supplemental Digital Content 1** (http://links.lww.com/CCM/G138). The enrolled children had to be mechanically ventilated upon PICU admission, have an arterial catheter in place, and have an expected PICU LOS longer than 24 hours. Patients with actual or suspected brain damage, for example, children who had cardiopulmonary resuscitation, severe traumatic brain injury, or chronic neuropathy, were excluded from the study. Additional reasons for exclusion were the presence of clinical or physiologic conditions that prevented the correct placement of the NIRS sensors on the patients' forehead or further admissions to PICU before the long-term follow-up. Baseline characteristics including age, gender, educational level of the parents (as described in Supplemental Digital Content 1, http://links.lww.com/CCM/G138), severity of illness (Pediatric Index of Mortality 3 [PIM3] score), presence of cyanosis before and after surgery, and predefined syndrome (as described in Supplemental Digital Content 1, http://links.lww.com/CCM/G138) were recorded upon PICU admission. The nutrition strategy (early or late initiation of parenteral nutrition, as described in **Supplemental Digital Content 2**, http://links.lww.com/CCM/G139) was recorded. Surgery information such as the Risk Adjustment for Congenital Heart Surgery 1 score, whether the child underwent cardiopulmonary bypass (CPB), or whether the child underwent deep hypothermic circulatory arrest and duration of CPB was recorded.

Cerebral NIRS Monitoring

$Scto_2$ was monitored continuously using the FORESIGHT cerebral oximeter (manufactured by CAS Medical Systems, Branford, CT. The unit of measurement of $Scto_2$ is in %). The attending bedside clinicians did not have access to the NIRS data in order not to influence the independent predictive value of the signal. For that purpose, the monitor screens were blinded with a sealed screen cover. Monitoring data were stored in the Patient Data Management System (MetaVision; iMDSoft, Needham, MA), with a minute-by-minute time resolution. The signals were assessed through visual inspection by experienced clinicians and considered of "low-quality" if, among others, the signal was absent or presented clear artifacts for more than 50% of the monitoring time or if it was shorter than 2 hours.

Neurocognitive Outcomes

Total IQ of the included children was assessed 2 years after PICU admission by trained psychologists with the Wechsler IQ tests (19, 20). Namely, the Wechsler Preschool and Primary Scale of Intelligence (WPPSI-III-NL) (19) was used for children between 2.5 and 5 years and 11 months old, whereas the Wechsler Intelligence Scale for Children (WISC-III-NL) (20) was used for children between 6 and 16 years and 11 months old. Seventy-nine of the included children were assessed in the framework of the PEPaNIC study (18). The children were assessed at the hospital or at home. The second option was offered to the parents or caregivers not able or not willing to travel to the hospital.

Scto$_2$ Predictors

The Scto$_2$ traces obtained from the left and right electrodes were averaged. Obvious artifacts (Scto$_2$ values below 20%) were removed and single missing values were imputed through linear interpolation. Desaturation was defined as Scto$_2$ below 65%. Mean Scto$_2$ and dose of desaturation were computed from the continuous Scto$_2$ signal as possible predictors of lower total IQ at 2-year follow-up (13, 15, 16). The dose of desaturation combines the intensity and the duration of Scto$_2$ less than 65% (unit of measurement in %·min)—a detailed description of the computation method is included in Supplemental Digital Content 2 (http://links.lww.com/CCM/G139). An example of dose of desaturation is visualized in **Figure 1** with the dark-gray area between the signal and the gray dashed line, which indicates the 65% desaturation threshold. The Scto$_2$ predictors were extracted from the beginning of the postoperative monitoring up to the first 12 hours and up to the first 24 hours of Scto$_2$ monitoring. To be included, children had to have at least 2 hours of continuous Scto$_2$ monitoring, to account for the variation in the duration of the Scto$_2$ recordings the dose was computed as percentage.

Children who experienced prolonged hyperoxia (Scto$_2$ > 85% for more than 10% of the entire monitoring time) were excluded from the analysis.

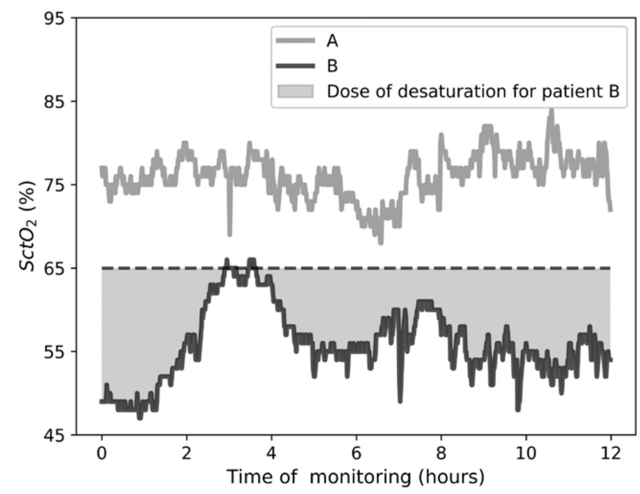

Figure 1. Sequences of regional cerebral tissue oxygen saturation (Scto$_2$) recordings, first 12 hr of monitoring time. Signal A desaturation dose: 0%·min, mean Scto$_2$: 74%. Signal B desaturation dose: 917 %·min; mean Scto$_2$: 57%. For signal B, the desaturation dose below 65% (unit of measurement: %·min) is represented by the dark-gray area between the signal and the gray dashed line, which indicates the 65% desaturation threshold. According to the enthusiastic prior, there is an 80% probability that the dose of desaturation of signal B results in a loss of 4–15 IQ points as compared with signal A. Similarly, there is an 80% probability that the mean Scto$_2$ of signal B results in 2.8–7.4 IQ points lower total IQ than signal A 2-yr after pediatric intensive care medicine admission.

Statistical Analysis

The independent association between Scto$_2$ predictors and total IQ was investigated through Bayesian multivariable linear regression models. In Bayesian analysis, the final β estimates of the linear regression model (posterior β estimates) integrate prior knowledge (results of previous studies or common knowledge) with the information provided by the analyzed data.

Three models with different types of prior probability distributions for the Scto$_2$ predictors under analysis were built: 1) neutral prior distribution: it is a noninformative prior and assumes no association between the Scto$_2$ predictors and outcomes, 2) enthusiastic prior distribution: it assumes that desaturation is associated with lower total IQ, and 3) skeptical prior distribution: it assumes that desaturation is associated with higher total IQ. The SDs of the skeptical and enthusiastic priors, which quantify the uncertainty of the parameter, were set to, respectively, twice and half their prior most likely value.

In Bayesian statistics, the credible interval of the posterior distribution indicates the range of values to which the posterior β estimate belongs with a certain probability. In this study, the 80% credible interval was used.

The model was adjusted for cofactors that have been shown to affect neurocognitive outcomes in previous studies, namely, age, nutrition strategy, presence of syndrome, presence of cyanosis after surgery, and PIM3 score (18, 21–27). The model was adjusted for nutrition strategy since part of the included children were also included in the PEPaNIC trial (18), which aimed at investigating the effect of early versus late administration of parenteral nutrition on the short- and long-term outcomes of the children involved. Detailed information on the principles and construction of the Bayesian model, including informative priors set for the presence of syndrome and presence of cyanosis, is reported in Supplemental Digital Content 1 (http://links.lww.com/CCM/G138).

Results of the Bayesian model were compared with a frequentist multivariable linear regression model (traditional statistical method), adjusted for the same cofactors of the Bayesian model. Statistical significance was set at a *p* value of 0.05.

A sensitivity analysis for the definition of desaturation was performed, using as desaturation thresholds 60% and 55%. In addition, two sensitivity analyses were performed on the effect of additional adjusting factors. The multivariable linear model was additionally adjusted for the educational level of the parents and, in a separate analysis, for the duration of CPB. The analyses were limited to the subsets of patients that had the required information. In addition, an interaction effect analysis was performed to investigate the effect of presence of cyanosis after surgery on $Scto_2$ mean and dose of desaturation.

Ordinal and continuous variables were reported using mean and SD for normal distributions and using median and 25–75th interquartile range (IQR) for nonnormal distributions.

Analyses were performed using Python Version 2.7 (Python Software Foundation, http://www.python.org), Scipy Version 0.19 (https://www.scipy.org), and Pymc3 Version 3.5 (https://docs.pymc.io).

RESULTS

Study Population

Three-hundred children were recruited for the study. Of the enrolled patients, 78 patients were lost at follow-up, of the remaining 222 patients, 126 patients had low-quality NIRS, and nine died. Eighty-seven patients were included in the analysis (see flow diagram for patient inclusion in **Figure 2**).

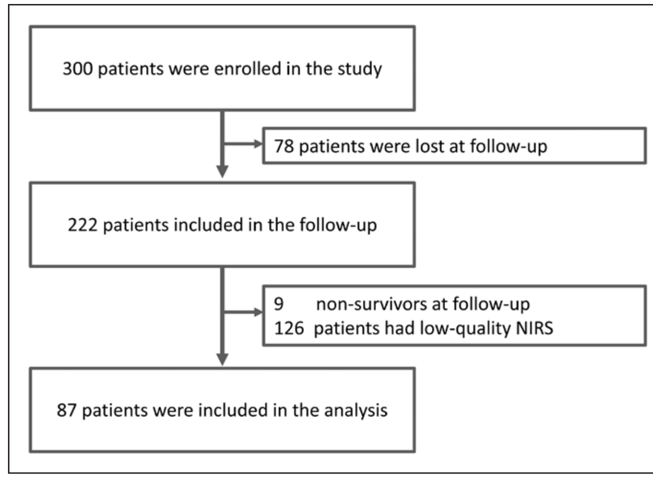

Figure 2. Flow diagram for study participants inclusion. NIRS = near-infrared spectroscopy.

Table 1 reports baseline demographics and clinical characteristics in PICU of the children included in the study. At PICU admission, the median (IQR) age of the children was 4 months (1–13 mo). The median (IQR) PIM3 was –3.37 (–3.93 to –2.67). A syndromic diagnosis was present in eight patients (9%), and 27 patients (31%) had the presence of cyanosis after surgery. Parenteral nutrition was withheld in the first week of PICU stay in 43 patients (49%). Children had a mean (SD) 2-year follow-up total IQ of 91.9 (13.7). The mean $Scto_2$ for both the first 12 and 24 hours of monitoring time was equal to a mean (SD) of 71 (7)%, whereas the dose of desaturation was equal to a median (IQR) of 0.42 (0–53)%·minutes and 0.64 (0–49)%·minutes for the first 12 and 24 hours of monitoring time, respectively. Examples of dose of desaturation for some patients are reported in **Supplemental Digital Content 3** (http://links.lww.com/CCM/G140).

Association Between $Scto_2$ Predictors and 2-Year Neurocognitive Development

Bayesian analysis using neutral, skeptical, and enthusiastic priors provided consistent results. In fact, in each analysis, an increased dose of $Scto_2$ desaturation and a reduced mean $Scto_2$ during the first 12 and 24 hours of $Scto_2$ monitoring independently increased the probability of lower total IQ at 2-years follow-up, results are reported in **Table 2** as posterior β estimates (80% credible interval). The credible interval indicates

TABLE 1.
Baseline Demographics, Clinical Characteristics, and Outcomes of Participating Children

Characteristics	Descriptive Statistics (*n* = 87)
Demographics	
Age (mo), median (IQR)	4 (1–13)
Gender (male), *n* (%)	56 (64)
Educational level of the parents[a]	
Level 1, *n* (%)	3 (3)
Level 1.5, *n* (%)	7 (8)
Level 2, *n* (%)	19 (22)
Level 2.5, *n* (%)	20 (23)
Level 3, *n* (%)	27 (31)
Unknown, *n* (%)	11 (13)
Clinical situation at admission	
PIM3 score, median (IQR)	−3.34 (−3.93 to −2.67)
PIM3 probability of death (%), median (IQR)	3 (2–6)
Patients with syndrome, *n* (%)	8 (9)
Children with cyanosis before surgery, *n* (%)	54 (62)
Surgery	
Risk Adjustment for Congenital Heart Surgery 1 score, median (IQR)	2 (2–3)
Patients that underwent CPB, *n* (%)	78 (89)
Patients that underwent deep hypothermic circulatory arrest, *n* (%)	3 (4)
CPB duration[b] (min), median (IQR)	77 (58–109)
Postoperative clinical situation	
Children with persistent cyanosis after surgery, *n* (%)	27 (31)
Nutrition strategy (late parenteral nutrition), *n* (%)	43 (49)
Duration of $Scto_2$ monitoring (hr), median (IQR)	16 (9–28)
PICU length of stay (d), mean (SD)	7 (10)
Total intelligence quotient, mean (IQR)	91.9 (13.7)
$Scto_2$ features, first 12 hr of monitoring	
$Scto_2$ mean (%), mean (SD)	71 (7)
$Scto_2$ dose of desaturation (%·min), median (IQR)	0.42 (0–53)
$Scto_2$ features, first 24 hr of monitoring	
$Scto_2$ mean (%), mean (SD)	71 (7)
$Scto_2$ dose of desaturation (%·min), median (IQR)	0.64 (0–49)

CPB = cardiopulmonary bypass, IQR = interquartile range, PIM3 = Pediatric Index of Mortality 3, $Scto_2$ = cerebral tissue oxygen saturation.
[a]The educational level of the parents was computed as the mean of the level of the maternal and paternal educational levels. The single score is based on a 3-point scale (1 is low, 2 is middle, and 3 is high; see Supplemental Digital Content 1, http://links.lww.com/CCM/G138).
[b]Data available only for children that underwent CPB and the statistic is computed on this subset of children.

TABLE 2.
Multivariable Linear Regression Analysis for the Association Between Cerebral Tissue Oxygen Saturation Features and Total Intelligence Quotient

Variables	Desaturation Dose: Posterior β Estimates (80% Credible Interval)	Desaturation Dose: Probability That the Posterior β Estimate is Strictly Negative (–)/ Positive(+)	Mean $Scto_2$: Posterior β Estimates (80% Credible Interval)	Mean $Scto_2$: Probability That the Posterior β Estimate is Strictly Negative (–)/ Positive(+)
First 12 hr of $Scto_2$ Monitoring				
Skeptical prior	−0.007 (−0.015 to 0.000)	90% (−)	0.208 (0.015–0.412)	90% (+)
Neutral prior	−0.009 (−0.016 to −0.001)	90% (−)	0.227 (0.037–0.412)	90% (+)
Enthusiastic prior	−0.011 (−0.017 to −0.005)	97.5% (−)	0.300 (0.166–0.436)	97.5% (+)
First 24 hr of $Scto_2$ monitoring				
Skeptical prior	−0.006 (−0.014 to 0.001)	85% (−)	0.226 (0.030–0.426)	90% (+)
Neutral prior	−0.008 (−0.016 to 0.000)	90% (−)	0.237 (0.055–0.435)	90% (+)
Enthusiastic prior	−0.011 (−0.018 to −0.005)	97.5% (−)	0.305 (0.172–0.442)	97.5% (+)

$Scto_2$ = cerebral tissue oxygen saturation.

the range of β estimates at which the posterior β value belongs with an 80% probability. In addition, Table 2 reports the probability that the posterior β estimate is strictly negative (or strictly positive). An increased dose of $Scto_2$ desaturation during the first 12 hours of monitoring resulted in a loss of IQ points at 2-year follow-up with a 90%, 90%, and 97.5% probability, respectively, for the skeptical, neutral, and enthusiastic priors (posterior β estimates [80% credible interval] equal to –0.007 [–0.015 to 0.000], –0.009 [–0.016 to –0.001], and –0.011 [–0.017 to –0.005], respectively). The corresponding results from the frequentist approach (traditional statistical method) did not show a statistically significant association (β estimates [CI] per %·minutes increase equal to –0.009 [–0.021 to 0.003], R^2 = 0.19, p = 0.14). Reduced mean $Scto_2$ during the first 12 hours of monitoring resulted in lower total IQ at 2-year follow-up with a 90%, 90%, and 97.5% probability for the skeptical, neutral, and enthusiastic priors, respectively (posterior β estimates [80% credible interval] equal to 0.208 [0.015–0.412], 0.227 [0.037–0.412], and 0.300 [0.166–0.436], respectively). A representation of the priors and posterior probability distributions for the mean $Scto_2$ is shown in **Figure 3**. The corresponding results from the frequentist approach did not show a statistically significant association (β estimates [CI] per % increase equal to 0.36 [–0.084 to 0.811], R^2 = 0.20, p = 0.11). Similar results were obtained when taking into account the first 24 hours of monitoring (Table 2). Figure 1 shows an example of $Scto_2$ episodes associated with reduced neurocognitive outcomes. According to the enthusiastic prior, there is an 80% probability that the dose of desaturation of signal B (Fig. 1) results in a loss of 4–15 IQ points compared with signal A (Fig. 1). Similarly, there is an 80% probability that the mean $Scto_2$ of signal B (Fig. 1) results in 2.8–7.4 IQ points lower total IQ than signal A (Fig. 1) 2 years after PICU admission. Additional examples of $Scto_2$ episodes associated with reduced neurocognitive outcomes are reported in Supplemental Digital Content 3 (http://links.lww.com/CCM/G140). Posterior β estimates and representation of prior and posterior distributions for all covariates are reported in **Supplemental Digital Content 4** (http://links.lww.com/CCM/G141).

Sensitivity analyses for the definition of desaturation provided consistent results with the previous analyses—see Supplemental Digital Content 4 (http://links.lww.com/CCM/G141). Similarly, sensitivity analyses on

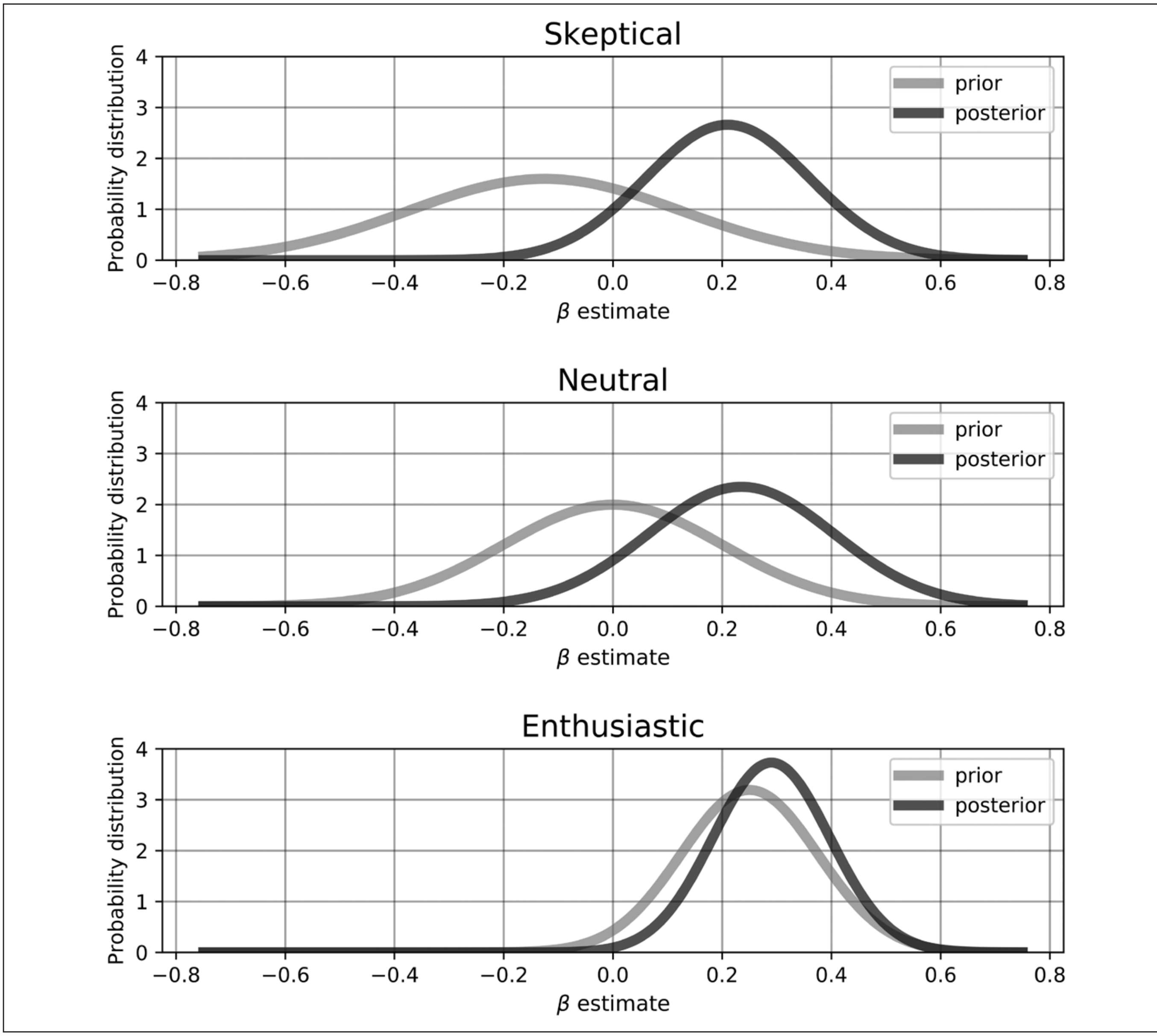

Figure 3. Comparison between the β priors and β posteriors probability distribution of the skeptical, neutral, and enthusiastic priors of the multivariable Bayesian model on the relation between mean regional cerebral tissue oxygen saturation ($Scto_2$) and total IQ. Only the distributions of the β estimate of the mean $Scto_2$ (first 12 hr of monitoring time) are shown.

the effect of additional adjusting factors to the multivariable linear model provided consistent results—see Supplemental Digital Content 4 (http://links.lww.com/CCM/G141). No interaction effect was observed between presence of cyanosis, mean $Scto_2$, and desaturation—see Supplemental Digital Content 4 (http://links.lww.com/CCM/G141).

DISCUSSION

Although the survival of pediatric patients after cardiac surgery has improved over the last decades (28), a significant proportion of them still suffers from neurocognitive impairments (6). As a result, vast attention has been given to identifying those factors, related to or independent of the clinical practice, which could affect the neurocognitive development of these children. We used Bayesian statistics to analyze the association between $Scto_2$ desaturation and mean $Scto_2$ and total IQ, 2 years after PICU admission.

In this study, increased dose of $Scto_2$ desaturation and lower mean $Scto_2$ in the first 12 and 24 hours of monitoring independently increased the probability of having a lower total IQ 2 years after PICU admission. These findings are in line with previous studies that showed high vulnerability of the immature brain to prolonged periods of cerebral desaturation (2, 3, 7, 13, 29–31).

Validated critical thresholds for harmful cerebral $Scto_2$ are lacking. In literature, desaturation is heterogeneously defined, with thresholds that range from 45% to 65% (29, 30, 32–34). Although relatively high, the 65% threshold used in this study permitted to identify periods of desaturation of which dose independently increased the chances of lower total IQ at 2-year follow-up. Sensitivity analyses and interaction effect analysis confirmed the robustness of the results. The results may indicate that impaired brain oxygenation already occurs at higher oxygen saturation thresholds.

Adoption of skeptical, neutral, and enthusiastic priors had almost no effect on the posterior β estimates, but it rather affected the level of certainty of the estimates, as shown by the SDs of the probability distributions in Figure 3. Hence, the association between $Scto_2$ predictors and total IQ results not only when an a priori association is hypothesized (enthusiastic priors) but also when an a priori lack of association (neutral priors) or a negative association (skeptical priors) is hypothesized.

The corresponding frequentist approach did not provide statistically significant results; this is likely due to a lack of statistical power. However, it is worth to observe that: 1) Bayesian and frequentist analyses provide comparable β estimates values and 2) the credible interval resulting from the Bayesian model is always included in the 95% CI resulting from the frequentist model.

Due to the limited size of the dataset and the data distribution, this study uniquely focused on the deleterious effects of desaturation on the developing brain. However, no observations can be made on the harmfulness of hyperoxia, of which long-term consequences should be further investigated in future studies.

It remains unclear whether $Scto_2$ desaturation and lower mean $Scto_2$ are similarly associated with neurocognitive outcomes when evaluated at later time points, for instance, at 4- or 10-year follow-up. In addition, although these results have no therapeutic implications, they may represent a foundation for future randomized clinical trials (RCTs). The target of a possible RCT may be the maintenance of $Scto_2$ between 65% and the current $Scto_2$ upper range supported by literature (around 85%).

This study has some limitations. First, due to the single-center design of the data set, the results may not be generalizable and require external validation in a larger prospective cohort. Second, this is an observational study of prospectively collected data. Hence, only associations and not causality are shown by the results. Third, the $Scto_2$ was quantified with NIRS, which monitors the oxygen saturation of a regional area of the frontal lobe. In addition, the trace was obtained by averaging recordings from the right and left electrodes. Therefore, considerations on the perfusion status of other areas of the brain outside the NIRS optical field or of one specific hemisphere cannot be made. Fourth, in this study, we only focus on the cerebral oximetry during the first 12 and 24 hours after surgery, but brain damage could have been occurred at other moments in time (preoperatively, perioperatively, or late postoperatively) and in other areas of the brain. Fifth, readings of the NIRS oximeter may vary among brands. Sixth, clinical or pathologic causes of potentially harmful doses of $Scto_2$ desaturation were not investigated, but they should be explored in a future randomized prospective study. Seventh, given the reduced size of the dataset, desaturation was defined by using a cutoff of 65% also for children with cyanosis, for whom a lower threshold might be more appropriate. Eighth, the multivariable linear regression model was not adjusted for the duration of PICU stay. We acknowledge that the duration of PICU stay has been previously associated with poor neurodevelopment, and hence, it might play a role in explaining the long-term outcomes of children with CHD. However, it was excluded from the list of adjusting factors given the limited size of the dataset and given that it resulted highly correlated with the PIM3 score. Last, although multiple confounders were taken into account when performing the analyses and although sensitivity analyses on additional adjusting factors provided consistent results, we cannot exclude the eventuality of other factors that affect outcomes but were not included in the analysis.

Despite these limitations, this represents the first study that analyzes the association between $Scto_2$, measured by NIRS, and total IQ at 2-year follow-up in a large cohort of pediatric patients after cardiac surgery. A strength of this study is the exclusion of treatment bias, as the NIRS monitor was blinded to clinicians. Furthermore, given the prospective design, the study could count on detailed data collection.

CONCLUSIONS

In critically ill children admitted to the PICU after congenital heart surgery, increased dose of desaturation, defined as the combination of time and intensity of $Scto_2$ < 65%, and lower mean $Scto_2$ in the first 12 and 24 hours of monitoring time independently increased the probability of a lower total IQ at 2-year follow-up. Whether interventions to prevent desaturation and reduced mean $Scto_2$ would result in improved outcomes remains to be investigated.

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