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Research Article

Relationship Between Intraoperative Cerebral Desaturation and Postoperative Complications In Pediatric Patients Undergoing Congenital Heart Surgery: Prospective Cohort Study

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Konjenital Kalp Cerrahisi Geçiren Pediatrik Hastalarda Serebral Desatürasyon ile Komplikasyonlar Arasındaki İlişki: Prospektif Kohort Çalışması

ABSTRACT

Objective: *In this study, we aimed to investigate the incidence of cerebral desaturation and the possible relationship between intraoperative cerebral desaturation and postoperative complications.*
Methods: *A prospective, observational study was performed 115 patients under 18 years of age who required open heart surgery in a university hospital. Cerebral desaturation was defined as a 25% decrease in cerebral saturation (low alarm limit) when compared with the basal value. Duration (second) was referred to the amount of time the patient stays below low alarm limit. Depth (%) was referred to gap between the patient's cerebral regional oxygen saturation (rSO_2) level and the rSO_2 low alarm limit. The cerebral desaturation score was calculated using the %*seconds. The patients were divided into two groups: group 1 (desaturation score >3000 %sec) and group 2 (desaturation score ≤ 3000 %sec). The groups were compared in terms of demographic data, intraoperative and postoperative variables, postoperative complications, and duration of intensive care and hospital stays.*
Results: *In the study, 59 patients (51.3%) were male and 28 patients (24.3%) had cyanotic heart disease. A total of 55 patients (47.8%) experienced over 3000 %sec desaturation. Postoperative complications were found to be increased in group 1 (71% vs 3.3%; χ^2=57.119, p<0.001). In the multiple logistic regression analysis, desaturation score>3000 %sec (p<0.001), low body surface area (p=0.001) and prolonged cardiopulmonary bypass (p=0.006) were found to be associated with postoperative complications.*
Conclusion: *In patients undergoing congenital heart surgery, cerebral desaturation score >3000 %sec is associated with a negative effect on patient prognosis.*

Keywords: *Cardiac surgical procedures, congenital heart defects, cerebral hypoxia, complications, spectroscopy, near-infrared*

ÖZ

Amaç: *Biz bu çalışma ile bir yıl içinde konjenital kalp cerrahisi geçiren pediatrik hastalarda serebral desatürasyon oranlarını ve serebral desatürasyon ile komplikasyonlar arasındaki ilişkiyi araştırmayı amaçladık.*
Yöntem: *Çalışma prospektif gözlemsel olarak bir üniversite hastanesinde gerçekleştirildi. Çalışmaya konjenital kalp cerrahisi geçirecek 18 yaş altındaki 115 hasta dahil edildi. Serebral desatürasyon bazal değere göre %25'lik doku oksijen satürasyonunda azalma (alt alarm limiti) olarak tanımlandı. Süre (sn), hastanın düşük alarm limitinin altında kaldığı saniye olarak, derinlik (%) hastanın serebral doku satürasyonu (rSO_2) ile düşük alarm limiti altındaki rSO_2 farkı arasındaki yüzdeyi ifade etmekteydi. Serebral desatürasyon skoru (eğri altında kalan alan) %*sn kullanılarak hesaplandı. Hastalar iki gruba ayrıldı: grup 1 (desatürasyon skoru >3000 %sn) ve grup 2 (desatürasyon skoru ≤% 3000 %sn). Gruplar demografik veriler, intraoperatif ve postoperatif değişkenler, postoperatif komplikasyonlar, yoğun bakım ve hastanede kalış süreleri açısından karşılaştırıldı.*
Bulgular: *Çalışmada 59 hastayı (%51.3) erkekler oluşturmakta iken, 28 hastanın (%24.3) siyanotik kalp hastalığı mevcuttu. Ellibeş hastada (%47.8) desatürasyon skoru 3000 %sn üzerinde idi. Postoperatif komplikasyonlar Grup 1'de anlamlı olarak fazla idi (% 71 vs % 3.3; χ^2=57.119, p<0.001). Logistik regresyon analizinde desaturasyon skorunun >3000 %sn (p<0.001) olmasının, düşük vücüt yüzey alanının (p=0.001) ve uzamış kardiyopulmoner baypas süresinin (p=0.006) postoperatif komplikasyonlarla ilişkili olduğu saptandı.*
Sonuç: *Konjenital kalp cerrahisi geçiren hastalarda serebral desatürasyon skorunun 3000 %sn üzerinde olması hasta prognozunda negatif sonuçlara neden olmaktadır.*

Anahtar kelimeler: *Kardiyak cerrahi işlemler, doğumsal kalp kusurları, serebral hipoksi, komplikasyonlar, spektroskopi, yakın kızıl ötesi*

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INTRODUCTION

Rates of mortality and morbidity associated with heart surgery have recently fallen as a result of gaining experience and advanced technology in surgery and anesthesia; thus success rates have increased considerably. In addition, studies have been conducted with a goal of reducing complications caused by cardiopulmonary bypass (CPB). Thanks to the prediction and early diagnosis of these potential complications, their prevention and successful treatment is possible. Considering that one of the most significant factors in the pathogenesis of cardiopulmonary bypass-related complications are the changes in tissue oxygenation, the importance of monitoring tissue oxygenation during CPB is obvious. However, we know that parameters such as heart rate (HR), mean arterial pressure (MAP) and arterial oxygen saturation (SaO_2) are not always sufficient indicators of tissue oxygenation [1-3]. Studies to overcome this shortcoming in monitoring have assessed tissue oxygenation using near-infrared spectroscopy (NIRS) and cerebral regional oxygen saturation (rSO_2), among others. Although cerebral rSO_2 measured with the NIRS method has been criticized, itís usage as a trend monitoring method has been approved by the US Food and Drug Administration. Studies that monitored cerebral rSO_2 using NIRS in cardiac surgery have shown its positive effects on postoperative cognitive functional disorders, neurological complications, and length of hospitalization [4-6]. NIRS has also been shown to be efficacious in cerebral oxygenation and somatic (hepatic, renal, mesenteric) monitoring [7,8].

The primary aim of this study was to determine the rates of cerebral tissue desaturation in congenital open heart surgery. The secondary aim was to find the relationship between the desaturation scores and the complications. We hypothesized that lower cerebral NIRS values would be associated with a greater incidence of early complications in patients undergoing congenital heart surgery.

MATERIALS and METHODS

Upon receiving the approval of the Clinical Research Ethics Committee of Our Faculty (Decision Number: 12-11.1/2), the informed consent form was read to the patientsí relatives, who signed it in writing. A total of 115 patients' under 18 years of age who required open-heart surgery were included in our study. Adult patients undergoing congenital heart surgery, patients who did not require cardiopulmonary bypass, patients with missing data, patients who lost their lives during the intraoperative period and patients required emergency surgery were excluded from the study.

Nonadult patients were taken to the operating room following premedication [5 mg kg^{-1} ketamine and 10 µg kg^{-1} atropine administered intramuscularly, while adult children were given oral midazolam (0.5 mg kg^{-1}) as a premedication. All patients were monitored with electrocardiography, pulse oximetry, noninvasive pressure measurements, and NIRS (EQUANOXô, Nonin Medical Inc., Plymouth, MN, USA) under sedation. The probes of near-infrared spectroscope (pediatric sensors for patients weighing less than 40 kg and adult sensors for patients weighing ≥ 40 kg) were placed on both frontal areas after the patient's skin surface was cleaned with alcohol. Initial mean values were recorded (baseline NIRS values were obtained prior to preoxygenation) and peripheral vascular access was established. Anesthesia induction was achieved with inhaled sevoflurane [1.5-2 minimal alveolar concentration (MAC)], rocuronium 1 mg kg^{-1} and fentanyl 2 µg kg^{-1} intravenously. After the patients were intubated, a central venous catheter (through right or left internal jugular vein), an arterial catheter (through femoral or radial artery), a nasogastric heat probe were inserted and transesophageal echocardiography (it was performed in patients weighing less than 6 kg because we had not the suitable echocardiography probe) was performed. Anesthesia was maintained with a volatile anesthetic (sevoflurane 0.5-1 MAC) and fentanyl (total 5 µg kg^{-1}) titrated based on blood pressure and pulse rate of the patient; while rocuronium (0.15 mg kg^{-1}) was added for muscle relaxation. The patients were ventilated by adjusting FiO_2, tidal volume (6-8 ml kg^{-1}) and respiratory rate according to age, and pathology detected. At the beginning of CPB, ketamine (1 mg kg^{-1}) and midazolam (20 µg kg^{-1}) were given intravenously to all patients. As the starting solution for CPB, erythrocyte, fresh frozen plasma and supplementary electrolyte solution were perfused so as to achieve an average hematocrit value of 30% after CPB in all patients. According to their cardiac pathologies, the body temperatures of the patients were dropped down to 26-32°C. After aortic cross-clamping, cardiac arrest was achieved with antegrade hypothermic blood cardioplegia. Perfusion pressure was determined by centrifugal pump flow (nonpulsatile) with pressures in the range of 50-60 mm Hg. Hemofiltration was applied to hypervolemic patients during CPB. Blood gas analysis was performed with α-stat management. The patients were evaluated by transesophageal echocardiography intraoperatively and during separation from CPB. Inotropic or vasoconstrictor agents were started to *achieve target HR* and MAP values after separation from CPB. After surgery, the patients were transferred to the intensive care unit, and intubated. The patients were extubated after they become hemodynamically stable. NIRS was only performed during the intraoperative period. Cerebral desaturation was defined as a 25% decrease in cerebral oxygen saturation (low alarm limit) when compared with the baseline value. Duration in seconds was referred to the amount of time the patient stays below the low alarm limit. Depth (%) was referred to the gap between the rSO_2 low alarm limit and rSO_2 under low alarm limit (depth (%)= [rSO_2 low alarm value - rSO_2 under low alarm value] /rSO_2 low alarm value). The cerebral desaturation score (area under curve) was calculated using the duration of depth (%*seconds) and increased only when the rSO_2 level dropped below the selected low alarm limit. A value of 3000 %sec is actually the area under the curve of cerebral desaturation and automatically calculated by the NIRS monitor. The values were recorded by NIRS monitor every four seconds before induction of anesthesia until the end of surgery (Figure 1). A cut-off value of 3000 %sec was used [7]. In addition, mean NIRS data were collected and analyzed at the following time points: baseline (before anesthesia induction), after intubation, sternotomy, cannulation, initiation of CPB, separation from CPB, closure of thorax, and end of surgery.

The following maneuvers were applied when

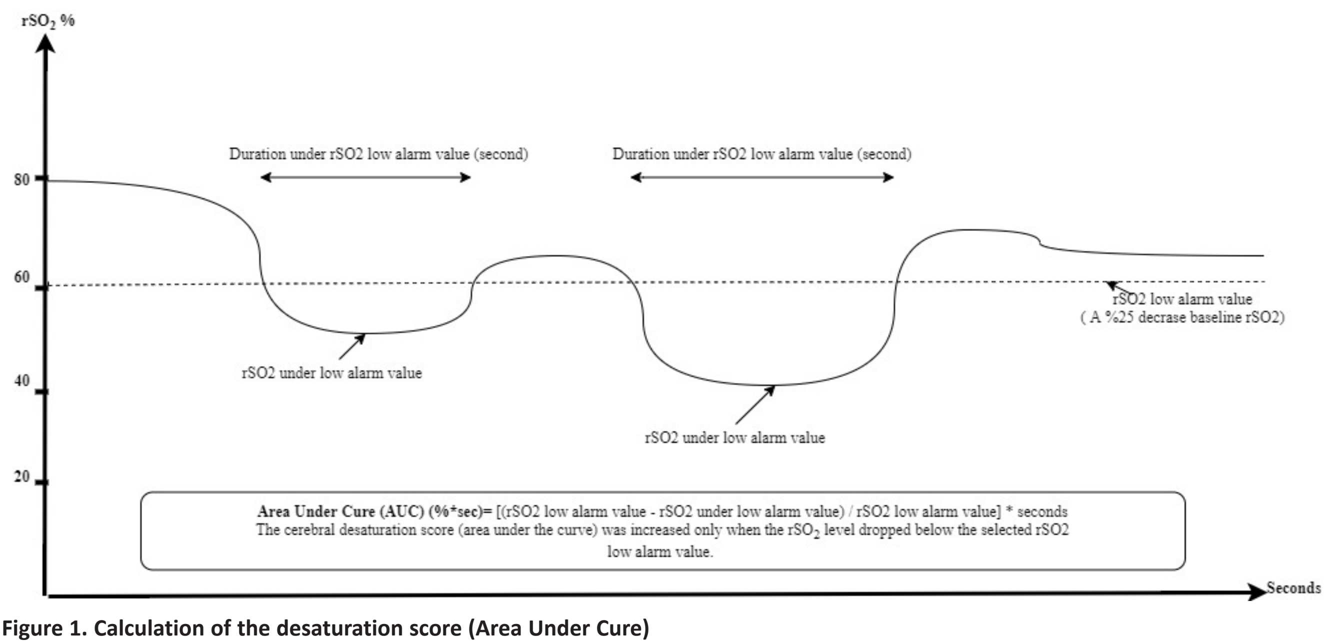

Figure 1. Calculation of the desaturation score (Area Under Cure)
Abbreviations: rSO_2; cerebral regional oxygen saturation
Desaturation score was calculated and accumulated by NIRS monitor every four seconds.

cerebral desaturation was detected: venous cannula and head position were checked, FiO_2 was increased, mean arterial pressure >50 mmHg was maintained, iincreased depth of anesthesia was maintained, $PaCO_2$ was optimized at 30-40 mmHg, hematocrit was established at <20% and then erythrocyte suspension was transfused. The patients were divided into two groups: desaturation score >3000 %sec (Group 1) and desaturation score ≤3000 %sec (Group 2). The groups were compared in terms of demographic data, intraoperative and postoperative variables, complications, and duration of intensive care and hospital stays. Complications were defined as follows:

Cardiac complications: postoperative myocardial infarction, right or left heart failure, atrial or ventricular arrhythmias requiring treatment, requirement for mechanical circulatory support (intra-aortic balloon pump, ventricular assist device, and extracorporeal membrane oxygenation [ECMO]).

Respiratory complications: pneumonia, re-intubation, tracheotomy, acute respiratory distress syndrome and prolonged mechanical ventilation (>48 hours).

Cerebrovascular complications: convulsion, stroke, transient ischemic attack, cerebral hemorrhage, and cerebral infarct.

Renal dysfunction: 50% decrease in the estimated creatinine clearance rate, urine output <0.5 mL kg^{-1} h^{-1} for 16 hours, and the need for renal replacement treatment/hemodialysis (the pediatric RIFLE criteria).

Gastrointestinal complications: ileus, and mesenteric ischemia.

Hematologic complications: massive transfusion (transfusion of >40 mL kg^{-1}), hemolysis, and disseminated intravascular coagulation.

Multiple organ dysfunction (MODS): dysfunction of two or more organs.

Need for reoperation: need for revision due to bleeding or for any other indication.

Statistical Analysis

Statistical procedures were carried out on SPSS 21.0 (SPSS for Windows Inc., IL, USA). The data were presented as mean±standard deviation (SD), median (range) and percentage (%). The distribution of demographic data, intraoperative and postoperative variables, and duration of intensive care and hospital stays were first evaluated using the Kolmogorov-Smirnov test. In the statistical analyses of the comparisons between groups, chi-square and Fisherís exact tests were used for categorical variables; independent samples t-test (parametric data) and the Mann-Whitney U test (nonparametric data) were utilized for quantitative data. Any complication was considered as one of the outcome measures. Binary logistic regression analysis was used to determine the risk factors associated with complications. When choosing for the independent variables in the regression analysis, absence of collinearity among predictors was taken into account (If tolerance <0.2 or variance inflation factors (VIF) was >10, the variable was removable from the model). A value of p≤0.05 was considered significant.

RESULTS

Among 115 patients enrolled in the study (Figure 2), 59 patients (51.3%) were male and 28 patients (24.3%) had cyanotic heart disease. The most common diagnoses were atrial septal defect (23.5%), ventricular septal defect (14.8%) and tetralogy of Fallot (9.6%). Details on the diagnoses and patientsí preoperative and intraoperative variables are presented in Tables 1 and 2. There were 55 patients in Group 1 (desaturation score >3000 %sec) and 60 patients in Group 2 (desaturation score ≤3000 %sec). Baseline mean MAP values (76±18 mm Hg vs. 81±16 mm Hg, p=0.105) were similar in both groups, while Group 2 had lower baseline HR [117 bpm (73-160) vs 142 bpm (74-192), p=0.006] values when compared with Group 1. Group 1 had lower baseline SaO_2 [98% (73-100) vs. 99% (84-100), p=0.013], lower mean baseline hemoglobin (12.4±1.9 mg dL-1 vs. 13.2±1.6 mg dL-1, p=0.022) and rSO_2 [75.1%±9.6 (44-93) vs 80.8%±8.6 (50-91), p=0.001] values when compared with Group 2. Baseline mean rSO_2 value in cyanotic patients was 74%±9.5 (44-89), while baseline mean rSO_2 value in noncyanotic patients was 79.4%±9.2 (50-93) (p=0.010).

Fifty-five patients (47.8%) had desaturation over

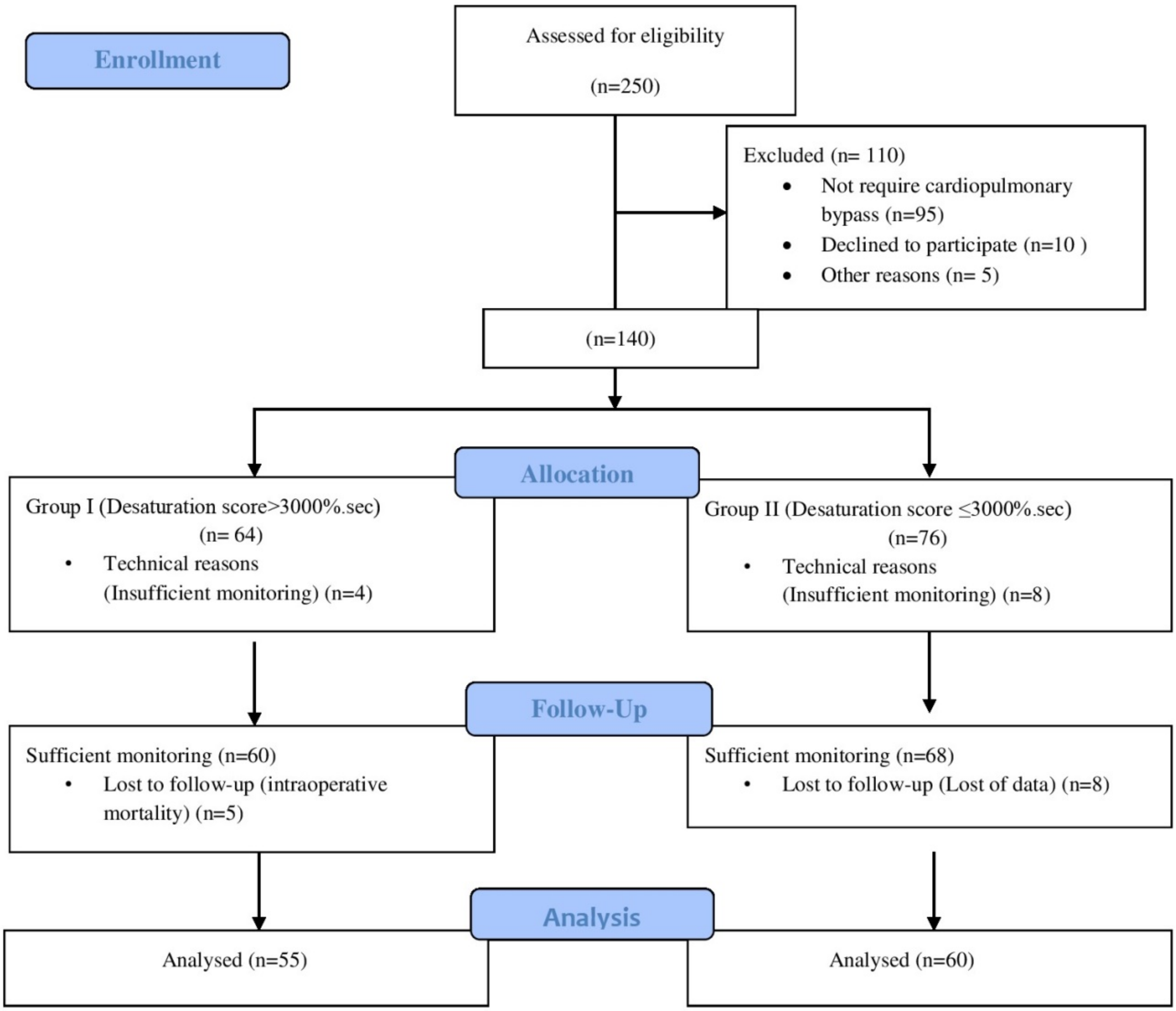

Figure 2. Patients' flow diagram.

3000 %sec. Postoperative complications were found to be increased in Group 1 (71% vs 3.3%). Forty-one (35.7%) patients developed at least one complication. Patients had cardiac (n=26:22.6%), respiratory (n=27:23.5%), neurologic (n=8: 7%), renal (n=11: 9.6%), gastrointestinal (n=7: 6.1%), hematologic (n=14:12.2%) complications, sepsis (n=13:11.3%), MODS (n= 15:13%), and 7 patients (6.1%) required revision surgery (Table 3). In the multiple logistic regression analysis; desaturation score >3000 %sec (OR=50.016; 95% CI= 6.2– 401; p<0.001), decreased body surface area (OR=0.003; 95% CI= 00.001 – 0.105; p=0.001) and prolonged cardiopulmonary bypass (OR= 1.037; 95% CI= 1.01 – 1.065; p=0.006) were found to be independent risk factors associated with postoperative complications (Table 4). In Group 1, rSO_2 values were lower than those in Group 2 in all time points (Figure 3). Two patients had their surgery under total circular arrest (TSA). A patient who underwent Jatene operation required venoarterial ECMO support as a result of respiratory and cardiac insufficiency at the end of surgery. Seven (6.1%)

Table 1. Diagnosis and baseline rSO_2 values of patients (baseline NIRS values were obtained prior to preoxygenation before induction of anesthesia).

Noncyanotic patients	Frequency (%)	rSO_2 values Mean ±SD (range)
Atrial Septal Defect (ASD)	27 (23.5)	80.8±10.3 (50-91)
Ventricular Septal Defect (VSD)	17 (14.8)	80.2±9 (61-91)
ASD+VSD	5 (4.3)	75.6±3.3 (72-79)
Atrioventricular canal defect (AVCD)	9 (7.8)	76.9±10.2 (57-93)
Pulmonary stenosis	6 (5,2)	81.74±7.2 (70-88)
Pulmonary regurgitation	8 (7)	77.4±10.3 (64-89)
Other valve disease	11 (9.6)	80±8 (63-91)
Ebstein Anomaly	2 (1.7)	73±1.4 (72-74)
Coronary Anomalies (ALPACA)	2 (1.7)	82±2 (79-85)
Cyanotic patients		
Tetralogy of Fallot (TOF)	11 (9.6)	78.5±5.4 (70-89)
Single Ventricle	3 (2.6)	77.7±3.2 (73-81)
Anomalous Pulmonary Venous Return	4 (3.5)	68.8±11.9 (61-82)
Truncus Arteriosus	1 (0.9)	63
Transposition of the Great Arteries (TGA)	6 (5.2)	68.4±7.7 (61-79)
Double Outlet Right Ventricle (DORV)	3 (2.6)	68±21.2 (44.82)
Total	**115 (100)**	**78.1±9.5 (44-93)**

Abbreviations: rSO_2; cerebral oxygen saturation, SD; standard deviation.

Table 2. Demographic and intraoperative data of patients (Independent-Samples T Test and Mann-Whitney U Test).

	Group 1 (n=55)	Group 2 (n=60)	p
Age (month)	13 (0.07-192)	69 (0.67-204)	<0.001
Gender (Female) (%)	26 (47.3)	30 (50)	0.852
Weight (kg)	8 (2.2-66)	18.5 (3.4-68)	<0.001
Height (cm)	76 (50-164)	112.5 (52-162)	<0.001
BSA (m2)	0.4 (0.2-1.72)	0.78 (0.21-1.7)	<0.001
Cyanotic (%)	16 (29.1)	12 (20)	0.257
RACHS-1			
I-III	48	57	0.030
IV-VI	7	3	
CPB time (minutes)	84.4±34.1	69.5± 32.8	0.019
Aortic cross-clamp time (minutes)	65.3±30.5	55±25.4	0.057
Operation time (minute)	220 (150-360)	222 (105-390)	0.739
Duration of anesthesia (minutes)	284± 54.5	278.3±57.6	0.619
Mechanical ventilation time (hours)	8 (2-600)	4 (2-192)	<0.001
ICU stay (hours)	46 (20-600)	22 (16-576)	<0.001
Hospital stay	7 (1-90)	7 (5-53)	0.052

Abbreviations: rSO_2; cerebral oxygen saturation, SD; standard deviation.

patients died because of postoperative MODS and all of them had >3000 %sec desaturation.

DISCUSSION

The main finding of this study is that cerebral desaturation of 47.8% of the patients undergoing pediatric open-heart surgery were over 3000%.sec. Therefore, all of the observed postoperative complications were found to be related to cerebral desaturation (71% vs 3.3%).

Cerebral desaturation may occur as a result of a decrease in oxygen supply due to insufficient blood flow to brain (ischemia), low arterial oxygen intake (hypoxia), low hemoglobin concentration (anemia), or increased brain metabolism. The exposure of

Table 3. Intraoperative cerebral desaturation and postoperative complications.

Complications (n, %)	Group 1 (n=55)	Group 2 (n=60)	p
Cardiac	25 (45.5)	1 (1.7)	<0.001
Respiratory	25 (45.5)	2 (3.3)	<0.001
Neurological	7 (12.7)	1 (1.7)	0.027
Renal	11 (20)	0 (0)	<0.001
GI	7 (12.7)	0 (0)	0.005
Hematologic	14 (25.4)	0 (0)	<0.001
MODS	14 (25.4)	1 (1.7)	<0.001
Sepsis	11 (20)	2 (3.3)	0.007
Revision	6 (10.9)	1 (1.7)	0.053

Abbreviations: GI; gastrointestinal, MODS; multiple organ dysfunction syndrome.

Table 4. Logistic regression analysis of risk factors associated with complications.

	Univariate analysis		Multivariate analysis	
	OR (95% CI)	p	OR (95% CI)	p
Age	0.954 (0.934-0.975)	**<0.001**		
Weight	0.766 (0.684-0.858)	**<0.001**		
Heigh	0.929 (0.904-0.956)	**<0.001**		
BSA	0.001 (0.001-0.0011)	**<0.001**	0.003 (0.001-0.105)	**0.001**
Cyanotic	3.307 (1.370-7.980)	**0.008**		
RACHS-1	2.452 (1.497-4.018)	**<0.001**		
Baseline MAP	0.951 (0.927-0.977)	**<0.001**		
Baseline HR	1.053 (1.030-1.080)	**<0.001**		
Baseline O_2 saturation	0.884 (0.806-0.969)	**0,008**		
Baseline rSO_2	0.926 (0.885-970)	**0.001**		
CPB time	1.024 (1.01-1.04)	**<0.001**	1.037 (1.01-1.065)	**0.006**
Aortic cross-clamp time	1.023 (1.01-1.04)	**0,003**		
Duration of anesthesia	1.008 (1.001-1.015)	**0,003**		
Desat. score ≥3000%.sec	70.69 (15-38-324.8)	**<0.001**	50.016 (6.2-401)	**<0.001**

Abbreviations: BSA; Body surface area, MAP; Mean arterial pressure, HR; Heart rate, CPB; Cardiopulmanary bypass, Desat. score; Cerebral desaturation score, RACHS-1; Risk-adjusted Classification for Congenital Heart Surgery, OR; Odds ratio, rSO_2; cerebral regional oxygen saturation, 95% CI; 95% confidence interval.

brain to insufficient oxygenation directly affects its activity and function. Therefore, the time spent during desaturation is critically important and real-time method is needed to identify its occurrence and provide timely intervention. Computed tomography and magnetic resonance imaging are late-term diagnostic methods to identify brain damage. Unfortunately, there is no bioanalytical method that can detect the onset of brain damage. Near-infrared spectroscopy is a continuous and noninvasive method that allows for early detection of cerebral desaturation and helps to reduce postoperative complications. Cerebral oximetry can assess the brainís supply-demand oxygen balance and the results are comparable to other invasive techniques such as jugular venous blood saturation measurement methods [1-3].

Postoperative complications associated with pediatric cardiac surgery were observed more frequently in younger age, underweight patients, patients undergoing complex congenital heart surgery, and prolonged bypass [9,10]. Vida VL et al. [10] stated that the patients who developed complications were underweight, at younger age and with higher desaturation scores. They found that the development of complications (51% vs 22%, p=0.007) and mortality (15% vs 4.3%, p=0.05) rates were higher in the neonatal group than in the infant group. Flechet M

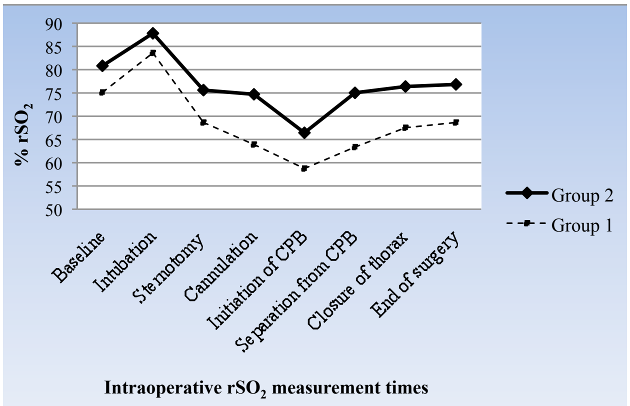

Figure 3. Intraoperative rSO_2 trends in Groups
Abbreviations: rSO_2; cerebral regional oxygen saturation, CPB; cardiopulmanary bypass (At all measurement time points, rSO_2 values in Group 1 were lower than Group 2, p<0,001).

et al. [11] stated that the rSO_2 values were lower in patients with cyanotic heart disease compared to the noncyanotic patient group, whereas baseline hemoglobin values were higher.

Similarly, in our study, patients in the higher desaturation score group (Group 1) were relatively younger, underweight, and had lower BSA. At the same time, hemoglobin and arterial oxygen saturation were lower in Group 1. For this reason, baseline rSO_2 values were significantly lower in the this group. Moreover, the baseline rSO_2 values of the cyanotic group were lower than the noncyanotic group. The BSA, baseline values for hemoglobin, arterial oxygen saturation, rSO_2, being cyanotic, RACHS-1 score, desaturation score (over 3000% sec), and CPB time were included in the Binary Logistic Regression Analysis; while age, weight and height were excluded from the regression model due to multicollinearity. However, only three parameters (BSA, CPB time and desaturation score) were found to be independent predictive markers for complications.

Lassnigg et al. [8] reported that the decrease in hemoglobin level (from 11.7 mg dL^{-1} to 8.5 mg dL^{-1}) during CPB caused a decrease in NIRS values. There is an increase in cerebral blood flow and oxygen extraction to compensate for the reduced oxygen transport due to hemodilution.

Tortoriello et al. [12] compared cerebral oxygen saturation measurements in 20 patients undergoing congenital heart surgery (15 single ventricle and 5 biventricular repairs) using noninvasive (rSO_2 with NIRS) and invasive (mixed venous oxygen saturation (SvO_2) in blood samples obtained via a pulmonary artery catheter or central venous oxygen saturation ($ScvO_2$) in blood samples obtained through a central venous catheter) methods and found significant correlations between noninvasive and invasive measurements at all time points. Tanidir et al. [9] studied cerebral tissue oxygenation during cardiac catheterization in 123 patients. The procedures were carried out for treatment purpose in 73 patients (59%). Thirty-nine of these patients developed 41 complications. İncluding desaturation (n=18: 9.5%), arrhythmia (n=10: 8.1%), respiratory failure (n=3: 2.4%), cardiac arrest (n=6: 4.8%), anemia requiring transfusion (n=3: 2.4%) and one patient (0.8%) developed a hypoxic episode. The decreases of 9% in the cranial NIRS values were associated with 2.3% of the complications. However, decreases of over 32% in the cranial NIRS values increased complication rates up to 13.5%. The authors reported that NIRS monitoring could detect development of cyanotic spell 10-15 second earlier than its manifestation on the pulse oximetry in Tetralogy of Fallot.

In their study of 104 infants undergoing biventricular repair, Kussman et al. [13] reported a desaturation rate of 22% (23 patients). The investigators considered a rSO_2 value of ≤ 45% as desaturation; the NIRS values used in CABG operations were used as a reference. Their study was conducted with a relatively homogeneous cardiac surgery population and they reported early postoperative outcomes. Thus, a critical threshold value was not possible to determine in that study. Norwood procedures or complex surgical procedures like interrupted aortic arch repair could show different postoperative outcomes.

In their retrospective study, Zulueta et al. [7] examined 22 congenital heart surgery patients and found desaturation in 13 patients (desaturation score >3000 %sec). The investigators found that central venous oxygen saturation (SvO_2, p=0.002), cardiac index (CI, p=0.004) and oxygen delivery index (DO_2I, p=0.0004) were lower, while the oxygen extraction rate was higher (ERO_2, p=0.0005) in all desaturated patients. Nine patients had prolonged postoperative hospital stays, and all of these patients had received high inotropic and ECMO support. One patient died because of cardiac failure and an inability to come off ECMO.

In our study, 47.8% of the patients experienced over 3000 %sec desaturations. While, 25% of instant drop in the baseline NIRS values over 3000 %sec were found to be related to postoperative complications, the duration of mechanical ventilation, and intensive care unit stay. The complex surgical procedures and the prolonged CPB period are the most important risk factors for the complications which manifested themselves by the decrease in NIRS values. Nearly one-third of the patients developed at least one complication. Cardiac and respiratory complications were observed in nearly one-fourth of the patients, whereas the incidence of neurological complications was approximately 7%. All of these findings were consistent with the literature. Seven patients died because of MODS; all of these patients developed desaturations over 3000 %sec and underwent complex surgical procedures.

This study has some limitations: First, the study was designed as a prospective observational study and it needs to be supported by prospective randomized controlled trials. Second, this study was designed to include all pediatric patients undergoing congenital open heart surgery; thus it did not include patients belonging to a particular disease group. Further studies in homogeneous patient groups may be required.

In conclusion, complications following pediatric heart surgery continue to be a serious problem. Effective monitoring of tissue oxygenation would be expected to lead to a decrease in these complications. In this respect, NIRS seems to be the best monitor currently available. In the multiple logistic regression analysis, desaturation score >3000 %sec, low body surface area and prolonged cardiopulmonary bypass were found to be independent risk factors associated with complications. This finding shows that NIRS can be used to predict postoperative complications in pediatric patients undergoing congenital heart surgery. This technique may also be used in different areas of the body, but that seems to be an area requiring further investigations.

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