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ORIGINAL RESEARCH

Continuous hemoglobin measurement during frontal advancement operations can improve patient outcomes

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Abstract

Massive hemorrhage in pediatric cranioplasty operations may necessitate blood transfusion, which may cause many complications. Radical-7 Pulse CO-Oximeter (Massimo Corporation, Irvine, CA) can provide continuous hemoglobin concentration (SpHb) measurements noninvasively. In this study, we aimed to evaluate the effects of SpHb measurement on perioperative transfusion management and postoperative patient outcomes. For this retrospective case–control study, we collected the data of pediatric patients undergoing fronto-orbital advancement surgery for plagiocephaly and trigonocephaly between 2018 and 2021. Perioperative SpHb monitoring was performed for patients in the SpHb Group. Other patients that were managed conventionally were considered as the control group (C Group). The data on patients' demographic and clinical characteristics, intraoperative hemodynamic and laboratory variables such as blood gases, intraoperative blood losses, the amount of the transfused blood products, the length of postoperative intensive care unit (ICU) stay, and the duration of hospital stay were collected. The data of 42 patients were collected, and 29 of these patients were males (69%). In 16 of the patients, SpHb monitoring was performed. The demographic, clinical, and perioperative hemodynamic characteristics of the patients were comparable between the groups. Compared to the C Group, the SpHb Group had significantly lower perioperative packed red blood cell (PRBC) transfusion (136.3 ± 40.1 vs. 181.5 ± 74.8 mL, P = 0.015), less postoperative drainage (125.3 ± 47.7 vs. 185.8 ± 97.6 mL, P = 0.013), and shorter ICU stay (37.1 ± 12.0 vs. 64.8 ± 24.9 h, P < 0.001). There was a positive correlation between the amount of PRBC transfusion and the length of ICU stay (r = 0.459, P = 0.003). Patients with perioperative continuous SpHb measurement have lower intraoperative PRBC transfusion, less postoperative bleeding, and shorter ICU stay. When necessary, SpHb, together with clinical judgment and laboratory confirmation, can be used in decision-making for perioperative PRBC transfusion.

Keywords Hemorrhage · Noninvasive hemoglobin · Pediatric · Transfusion

1 Introduction

Maintaining the continuity of perfusion by providing oxygen delivery to the tissues is critical. The main clinical determinants include hemoglobin (Hb) concentration and cardiac output [1]. In craniofacial reconstruction surgery, tissue activators triggered by tissue damage caused by wide incisions result in hyperfibrinolysis, which reduces the stability of the clot and increases the consumption of fibrinogen and coagulation factors, leading to an uncontrolled increase in bleeding during surgery [2]. For this reason, in this patient group, an adequate patient blood management (PBM) policy should be followed, and blood products should be transfused if necessary, considering the risks of massive transfusion [3].

Pulse CO-Oximetry is a pulse oximeter that continuously and noninvasively measures hemoglobin concentration (SpHb) using light-absorbing diode sensors of different wavelengths. In this method, the absorption properties of total hemoglobin are measured from the finger [4]. The reliability of SpHb measurement with pulse CO-Oximetry

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in pediatric patients undergoing intracranial surgery and craniofacial reconstruction has been demonstrated [5]. However, in the pediatric patient group, the evidence demonstrating the effectiveness of this method on PBM in hemorrhagic and long-lasting surgeries such as frontal advancement is insufficient, and further studies are needed in this regard. The most significant advantage of continuous Hb measurement over intermittent techniques is that it instantly detects sudden decreases in Hb concentration. In this way, the clinician can provide a stable hemoglobin concentration to the patient and prevent hemodynamic instability resulting from severe anemia and perfusion disorders [6]. Hemoglobin trend monitoring can be useful since it shows decreases in Hb value when Hb concentration is considered stable and provides information about the increase in Hb after transfusion. A decrease in the trend prevents the clinician from being late for transfusion and helps them take other measures to reduce bleeding in the early period, while a stable trend prevents inappropriate transfusions.

Our primary aim in this retrospective case–control study was to determine the effect of SpHb monitoring on perioperative blood transfusion management in pediatric patients undergoing frontal advancement surgery. Our secondary aim was to reveal the effectiveness of SpHb monitoring on postoperative patient outcomes. The hypothesis of this study is that blood management with continuous SpHb values during pediatric frontal advancement surgery will both result in less perioperative blood product use by reducing the amount of transfusion and lead to fewer adverse postoperative complications compared to management based on Hb measurement with intermittent blood sampling.

2 Materials and methods

2.1 Ethics

The Investigational Review Board of Marmara University Medical School approved the study (Protocol No: 09.2021.904). As this is a retrospective study, consent was waived, but we adhered to the rules regarding patient privacy during data recording.

2.2 Population

In this retrospective case–control study, the data of 2–24 months old pediatric patients with American Society of Anesthesiologists (ASA) I-II physical risk status, who underwent frontal advancement surgery with the diagnosis of plagiocephaly and trigonocephaly at our University Hospital between 2018 and 2021 were analyzed. Cases with a known cardiac or vascular disease such as heart failure or hypertension, those with a bodyweight of less than 5 kg, who underwent emergency surgery, who had any major surgical complications during the operation, whose operations lasted longer than 4 h were excluded from the study.

2.3 Study procedures

Patients' electronic records in the hospital information system and records from follow-ups at the anesthesia and intensive care units were reviewed, and data were obtained. Perioperative SpHb monitoring was performed for patients in the SpHb Group. Other patients that were managed conventionally were considered as the control group (C Group).

In our hospital, we have standard anesthesia protocols for pediatric craniosynostosis cases. Preoperative preparation of the patient was performed in the outpatient anesthesia clinic in accordance with our standard anesthesia practice protocols. For the patient, anesthesia risk was determined, blood products such as packed red blood cells (PRBC) and fresh frozen plasma (FFP) were prepared, and an intensive care unit (ICU) bed was reserved. On the day of the surgery, the patient's airway and respiratory system were examined once again by the anesthesiologist in the preoperative evaluation room. The body temperature was checked, and the patient was taken to the operating room after the fasting time was confirmed. Electrocardiography (ECG), pulse oximetry (SpO_2), noninvasive blood pressure (NIBP), and skin-based body temperature monitoring were routinely performed. After intravenous anesthesia with thiopental or inhalation anesthesia with sevoflurane, inhalation-narcotic-based anesthesia was maintained. A central venous catheter (preferably right internal jugular vein) and an arterial catheter (preferably left radial artery) were placed. After the intraarterial line was secured, blood pressure monitoring continued invasively. Blood loss was calculated by monitoring the aspirator and the number of gauzes used, observation of the surgical field, and communication with the surgical team.

The balanced crystalloid solution was given to the patient as intravenous fluid, and the use of colloid solution was left to the discretion of the anesthesiologist if needed. Administration of blood products such as PRBC and FFP when needed is also left to the discretion of the anesthesiologist. Preoperative Hb values of the patient, laboratory values such as activated partial thromboplastin time (aPTT) and international normalized ratio (INR), estimated amount of intraoperative blood loss, and intraoperatively measured Hb values were used in the decision-making of blood product transfusion. For the monitorization of intraoperative Hb values, an arterial or venous blood gas analysis in the operating

room laboratory, conventional hemogram measurement in the central laboratory, or noninvasive peripheral Hb measurement methods performed at the bedside were left to the discretion of the primary anesthesiologist as well.

SpHb monitoring was performed with the Radical-7 Pulse CO-Oximeter (Masimo Corp., Irvine, CA) device in our hospital. After induction of anesthesia, a disposable adhesive probe suitable for the patient's age and body weight was applied to the proximal of the 2nd, 3rd, 4th finger or thumbnail bed of the upper extremity contralateral to the arterial catheter. The adhesive SpHb probe is a tape-shaped probe that can be attached to a finger or wrist, just like a conventional SpO_2 sensor. The probe was wrapped with an opaque cover to prevent optical interference. The probe, which contains light-emitting diodes and signal processing algorithms, was connected to the Radical-7 device, and the device was connected to the computer that makes the data logging software. In this way, SpHb and signal quality were measured continuously. Arterial blood gas samples were analyzed with the GEN-S hematology analyzer, (Beckman-Coulter, Miami, FL) device in the operating room laboratory of our hospital. After the blood sample was taken from the patient's arterial catheter, it was examined in the blood gas analyzer device located at a place that takes approximately 1 min to walk from the operating room. It takes an average of 5–10 min from sample collection to obtain the results. An initial in vivo calibration of the device was done according to the user manual using basal arterial blood gas Hb values.

2.4 Outcomes

After recording the demographic data of the patients, indications for surgery, duration of anesthesia and surgery, length of intensive care unit and hospital stay, heart rate (HR), mean arterial blood pressure (MAP), body temperature (T) were measured at the beginning and the end of the operation in both groups. Also, the information on the amount of crystalloid and colloid fluids administered intravenously, the amount of blood products such as PRBC and FFP transfused, estimated amount of bleeding and urine output during surgery, and the amount of drainage from the postoperative surgical area was obtained from the patients' records. The arterial blood gas results at the beginning and the end of the surgery were obtained from the surgery follow-up forms of the patients, and pH, partial oxygen pressure (pO_2), Hb, base excess (BE), bicarbonate (HCO_3), and lactate values were recorded. Hb values measured via hemogram; INR, fibrinogen, and platelet values; blood gas values such as pH, BE, HCO_3, and lactate recorded at admission and discharge from the ICU were obtained from the intensive care follow-up records of the patients. Furthermore, the amounts of PRBC and FFP transfused in the ICU were recorded. Noted complications, if any, were also recorded.

2.5 Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences 27.0 version (SPSS, Chicago, IL). For the descriptive statistics of the data, the mean, standard deviation, median, lowest, highest, frequency, and ratio values were used. The distribution of variables was measured with the Kolmogorov–Smirnov test. The independent sample t-test and the Mann–Whitney U test were used in the analysis of quantitative independent data. The Chi-square test was used in the analysis of qualitative independent data. $P < 0.05$ was considered statistically significant.

3 Results

A total of 42 patients' data were analyzed for the study and 29 (69%) of them were males. The patients' mean age was 8.6 ± 3.9 months, and mean body weight was 8.6 ± 1.7 kg. The patients' demographic and clinical characteristics by groups C and SpHb are presented in Table 1. There were no significant differences regarding age, sex, body weight, surgical indication, anesthesia, and surgery duration between the groups. SpHb Group had a significantly shorter length of ICU stay compared with C Group (37.1 ± 12.0 vs.

Table 1 Demographic and clinical characteristics of the patients

	C Group (n = 26)	SpHb Group (n = 16)	P
Age (months)	8.4 ± 3.3	8.8 ± 4.7	0.937
Sex			
Male	20 (76.9)	9 (56.3)	0.159
Female	6 (23.1)	7 (43.8)	
Body weight (kg)	8.7 ± 1.7	8.5 ± 1.8	0.523
Diagnosis			
Trigonocephaly	11 (42.3)	7 (43.8)	0.927
Plagiocephaly	15 (57.7)	9 (56.3)	
Anesthesia duration (minutes)	249.4 ± 61.0	223.8 ± 23.2	0.152
Surgery duration (minutes)	193.3 ± 50.2	173.1 ± 21.6	0.236
ICU length of stay (hours)	64.8 ± 24.9	37.1 ± 12.0	< 0.001*
Hospital length of stay (days)	5.0 ± 2.4	4.2 ± 1.3	0.310

Numerical variables are expressed as mean ± standard deviation (SD), and categorical variables as number of the patients with the percentage in the parentheses

ICU intensive care unit; *C Group* control group; *SpHb Group* group with the SpHb measurement

*P < 0.05

Table 2 Perioperative clinical characteristics of the patients

	C Group (n = 26)	SpHb Group (n = 16)	P
HR_0 (beats/min)	125.7 ± 17.2	128.8 ± 27.6	0.325
HR_{End} (beats/min)	120.3 ± 13.9	114.8 ± 15.9	0.136
MAP_0 (mm Hg)	69.3 ± 12.5	70.1 ± 13.0	0.948
MAP_{End} (mm Hg)	53.9 ± 11.1	58.6 ± 10.0	0.475
T_0 (°C)	35.4 ± 0.9	35.7 ± 0.7	0.336
T_{End} (°C)	35.3 ± 1.0	35.2 ± 1.1	0.805
Crystalloid (mL)	458.8 ± 156.2	479.4 ± 133.4	0.380
Colloid (mL)	22.3 ± 39.1	50.0 ± 44.0	0.025*
PRBC tx (mL)	181.5 ± 74.8	136.3 ± 40.1	0.015*
IO hemorrhage (mL)	192.7 ± 106.8	164.4 ± 51.8	0.540
IO urination (mL)	56.0 ± 47.1	54.0 ± 42.2	0.959
PO drainage (mL)	185.8 ± 97.6	125.3 ± 47.7	0.013*

Data is expressed as mean ± SD

C Group control group; *SpHb Group* group with the SpHb measurement; HR_0/HR_{End} heart rate at the start and the end of the operation; MAP_0/MAP_{End} mean arterial pressure at the start and the end of the operation; T_0/T_{End} body temperature at the start and the end of the operation; *PRBC tx* packed red blood cell transfusion; *IO* intraoperative; *PO* postoperative

*P < 0.05

Table 3 Intraoperative laboratory variables of the patients

	C Group (n = 26)	SpHb Group (n = 16)	P
pH_0	7.39 ± 0.06	7.39 ± 0.05	0.84
pH_{End}	7.31 ± 0.08	7.36 ± 0.03	0.05
$(pO_2)_0$ (mm Hg)	197.1 ± 79.2	203.4 ± 45.0	0.746
$(pO_2)_{End}$ (mm Hg)	177.1 ± 55.0	177.1 ± 22.4	0.190
Hb_0 (g/dL)	10.4 ± 1.2	10.5 ± 0.8	0.746
Hb_{End} (g/dL)	11.4 ± 1.9	10.7 ± 1.3	0.551
BE_0 (mmol/L)	− 3.49 ± 1.98	− 2.76 ± 1.70	0.312
BE_{End} (mmol/L)	− 5.76 ± 4.84	− 4.32 ± 2.45	0.200
$(HCO_3)_0$ (mmol/L)	21.5 ± 2.6	22.4 ± 1.6	0.103
$(HCO_3)_{End}$ (mmol/L)	18.3 ± 4.2	20.7 ± 2.2	0.050
$Lactate_0$ (mmol/L)	0.98 ± 0.31	1.25 ± 0.42	0.019*
$Lactate_{End}$ (mmol/L)	1.25 ± 1.26	1.02 ± 0.39	0.419

Data is expressed as mean ± SD

C Group control group; *SpHb Group* group with the SpHb measurement; pH_0/pH_{End} pH at the start and the end of the operation; $(pO_2)_0/(pO_2)_{End}$ arterial oxygen partial pressure at the start and the end of the operation; Hb_0/Hb_{End} hemoglobin measured by arterial blood gas analyzer at the start and the end of the operation; BE_0/BE_{End} base excess at the start and the end of the operation; $(HCO_3)_0/(HCO_3)_{End}$ bicarbonate at the start and the end of the operation; $Lactate_0/Lactate_{End}$ lactate at the start and the end of the operation

*P < 0.05

64.8 ± 24.9 h, P < 0.001). No significant difference was observed between the groups regarding the length of hospital stay.

Intraoperative hemodynamic variables, body temperature, intravenous fluid/PRBC administration, hemorrhage, and urination variables, as well as the amount of postoperative drainage from the surgical site, are presented in Table 2. There was no significant difference regarding hemodynamic variables and body temperature between the groups. Although there was no difference between the groups regarding intraoperative crystalloid administration, SpHb Group received a significantly higher amount of colloid fluid intraoperatively (P = 0.025). PRBC transfusion was lower in SpHb Group compared with C Group (P = 0.015). Three patients in C Group and one patient in SpHb Group received FFP. There were no significant differences in intraoperative hemorrhage and urination amounts between the groups. Postoperative drainage was lower in SpHb Group compared with C Group (P = 0.013). A positive correlation was established between transfused PRBC amount and the length of ICU stay (r = 0.459, P = 0.03).

Intraoperative blood gas analysis variables measured at the start and the end of the operation are shown in Table 3. There were no significant differences regarding pH, pO_2, Hb, BE, and HCO_3 values between the groups. Lactate levels measured at the beginning of the operation were significantly higher in SpHb Group compared to C Group

Table 4 Postoperative laboratory variables and blood product transfusion data of the patients

	C Group (n = 26)	SpHb Group (n = 16)	P
Hb_{first} (g/dL)	11.3 ± 1.8	11.1 ± 1.1	0.623
Hb_{last} (g/dL)	11.8 ± 1.6	11.5 ± 1.9	0.641
INR_{first}	1.43 ± 0.28	1.34 ± 0.16	0.378
INR_{last}	1.18 ± 0.19	1.19 ± 0.12	0.584
$Fibrinogen_{first}$ (mg/dL)	160 ± 50	175 ± 52	0.362
$Fibrinogen_{last}$ (mg/dL)	242 ± 67	229 ± 65	0.523
$Platelet_{first}$ (× 1000/mm^3)	285 ± 79	336 ± 86	0.057
$Platelet_{last}$ (× 1000/mm^3)	219 ± 71	240 ± 53	0.314
pH_{first}	7.30 ± 0.06	7.30 ± 0.04	0.642
pH_{last}	7.42 ± 0.05	7.40 ± 0.03	0.106
BE_{first} (mmol/L)	− 6.65 ± 4.83	− 5.12 ± 3.48	0.186
BE_{last} (mmol/L)	0.68 ± 2.93	0.05 ± 2.92	0.437
$(HCO_3)_{first}$ (mmol/L)	17.9 ± 3.5	19.8 ± 3.4	0.068
$(HCO_3)_{last}$ (mmol/L)	24.4 ± 3.1	24.7 ± 2.9	0.756
$Lactate_{first}$ (mmol/L)	2.90 ± 1.68	2.79 ± 1.69	0.540
$Lactate_{last}$ (mmol/L)	1.49 ± 0.64	1.24 ± 0.59	0.190
PRBC tx (mL)	128.9 ± 107.3	93.0 ± 67.8	0.211
FFP tx (mL)	53.6 ± 72.3	35.0 ± 68.0	0.359

Data is expressed as mean ± SD. *C Group* control group; *SpHb Group* group with the SpHb measurement; *Hb* hemoglobin; *INR* international normalized ratio; *BE* base excess; HCO_3 bicarbonate. Values represent the "first" variables on the intensive care unit (ICU) admission, and "last" variables before the discharge from the ICU

(P = 0.019); however, there was no difference in this regard at the end of the operation.

The patients' initial and final postoperative laboratory variables measured in the ICU are demonstrated in Table 4. There were no significant differences regarding the variables between C Group and SpHb Group. PRBC and FFP transfusion data in ICU are also provided in Table 4. There were no significant differences between the groups.

4 Discussion

The main findings of our study were that patients managed with continuous SpHb monitorization during craniofacial surgery for craniosynostosis had lower intraoperative PRBC transfusions, lower postoperative surgical site drainage, and lower postoperative ICU length of stay.

A potential benefit of continuous Hb measurement is the ability to detect sudden decreases in Hb concentration, and thus, prevent severe hemodynamic derangements due to severe anemia. Moreover, it prevents unnecessary blood transfusion in patients whose Hb is stable [5]. Intermittent Hb measurement methods via blood sample collection have some limitations. The major limitation for the intraoperative period is its processing time, which can result in the delay of the detection of anemia. In our study, we used an operating room laboratory blood gas analyzer for intermittent Hb analysis, where the optimal time to obtain results is about 3 min and may become even longer in some situations. Using the central laboratory units for analysis would certainly result in longer times. Additionally, blood draws can be a potential cause for infection, and excessive amount can result in iatrogenic anemia in small children [4, 7]. More colloids were used in the SpHb group compared to the control group in our study. This might have been the effect of the fact that the anesthesiologist relied on SpHb values and preferred to support the patient's intravascular volume with colloids rather than PRBC.

Hemoglobin level detection was performed via arterial blood analysis or SpHb. Several studies demonstrated a good relationship between conventional invasive and non-invasive SpHb measured Hb levels [8–11]. Park et al. [3] assessed the relationship between Hb measured by arterial blood CO-oximeter and SpHb in children undergoing neurosurgery and found an overall bias of 0.90 ± 1.35 g/dL (limits of agreement − 1.74 to 3.54 g/dL) with good correlation (r = 0.53, P < 0.001). Patino et al. [5] in their validation study of Hb measured by SpHb and conventional hematology analyzer on perioperative children undergoing major surgery demonstrated a bias of 0.4 ± 1.3 g/dL with a correlation of 0.70 (95% CI 0.6–0.77), where after an in-vivo adjustment the bias decreased further. An in-vivo adjustment is a software property that allows clinicians to equalize the first measured Hb value with another reference method. It is also important to note that SpHb measurements depend on Hb concentration. Park et al. [3] demonstrated that the bias is lower when Hb is above 11 g/dL. In their study, the bias were -0.03, 1.17, and 1.24 for Hb levels ≥ 11, 9–11, and < 9 g/dL, respectively. SpHb can give falsely elevated values when actual Hb is low, so additional confirmation is suggested when dealing with patients with Hb < 9 g/dL. This phenomenon has been demonstrated in other studies, as well [3, 8, 12, 13]. Similarly, in those studies, SpHb overestimated actual Hb at its lower values. This can lead to a delay in blood transfusion. Hb levels below 9 g/dL were not seldom encountered in our study population, so we always kept this fact in mind and made confirmation with laboratory CO-oximetry. Moreover, Hb values > 18 g/dL have also been demonstrated to decrease the accuracy of SpHb measurement [14]. Barker et al. [6], in their review, pointed out important aspects of SpHb monitoring. They emphasized that SpHb should not replace laboratory-measured Hb, rather support it by providing continuous and real-time data. Variability should always be considered. The trend accuracy of SpHb should be the primary consideration while accuracy is the second, but it is still important. In vivo adjustment should be considered, as it decreases bias. Latest devices including sensors and software should be used, as old ones have been shown to yield a great variation in absolute and trend accuracy, resulting from the peripheral perfusion and different inspired oxygen fraction [12, 15]. SpHb measurement will supplement laboratory Hb and guide in the decision-making for transfusion. Moreover, it is equally important to decide when not to make a transfusion since unnecessary transfusions are associated with complications. Some studies have evaluated the clinical applicability of SpHb in the optimization of blood transfusion and demonstrated that SpHb reduced unnecessary PRBC transfusions [6]. SpHb trends have been demonstrated to monitor hemoglobin during surgery and estimate the timing for invasive measurement better than clinicians do by subjectively looking at the vital signs and hemorrhage [16]. The applicability of SpHb in the detection of occult bleeding has been proved in the ward, intensive care, and operating room settings [17, 18]. In our study, patients' in-vivo adjustment was routinely performed at the beginning of the operation. SpHb monitoring guided the anesthesiologist in transfusion decision-making, but possible problems of variability and bias were not ignored, and confirmation with CO-oximetry was made when necessary. Indeed, as we mentioned earlier, the SpHb monitorization group received a greater amount of colloids and less PRBC intraoperatively. This result is consistent with the literature [19]. We believe that this was the major effect

of monitoring SpHb, as it decreased unnecessary PRBC transfusions and its adverse effects, including those on the hemostatic system. Dilutional thrombocytopenia and coagulation factor deficiencies after transfusion of large amounts of PRBC are the most prominent adverse effects. We believe that in our study low PRBC transfusion in the SpHb group prevented adverse effects of the transfusion on the hemostatic system, resulting in less postoperative surgical site drainage, compared with the control group. Even though not statistically significant, this difference resulted in less postoperative PRBC transfusion in the SpHb Group. A higher number of patients would have yielded statistical significance. On the other hand, the postoperative ICU stay of the patients undergoing SpHb monitoring was shorter compared to the control group. This finding is consistent with the current literature, as restrictive blood product transfusion strategy has been shown to be non-inferior or even superior in the terms of length of stay at ICU [20, 21].

Another problem with SpHb measurement is its potential inaccuracy due to peripheral perfusion. Perfusion index (PI), the ratio of the pulsatile blood flow to the non-pulsatile, has been shown to affect SpHb accuracy. Several studies have demonstrated improved accuracy of SpHb measurement with increased PI [22, 23]. Miller et al. [24, 25] used digital nerve block to increase PI and demonstrated increased accuracy and decreased bias of SpHb. Coquin et al. [26] showed that noradrenaline infusion, by decreasing PI, resulted in a greater number of unavailable measurements of SpHb. Lee et al. [27] demonstrated negative effects of peripheric vascular disorders on SpHb measurement. Miller et al. [8] reported better measurement accuracy for SpHb with PI > 4.0. Nevertheless, Paksu et al. [28] found no effect of PI on the correlation between SpHb and laboratory-based measurements. Altogether, peripheral perfusion issues including vasopressor agent use should be considered and PI should be closely monitored when considering the SpHb measurements as a guide to important decision-making. In our study, we didn't evaluate the data of the patients with vasopressor use in the SpHb group. PI was routinely monitored, and necessary adjustments were made to increase PI and improve accuracy, like repositioning the probe, fluid administration, and vasopressor use.

Our study had some limitations: the first one is its retrospective design. Second, the data about the simultaneous SpHb recordings along with CO-oximetry Hb measurements were lacking. If they were present, those data would give valuable information about their correlation. This is also pertinent to the first measurements done for calibration. Lag times between basal SpHb and blood gas Hb measurements could have given inconsistent results also due to dilutional effects. Third, there was a lack of data about the perioperatively measured PI values. PI values would have been valuable in considering the accuracy of SpHb measurements as well as in guiding the transfusion decision. Finally, there was no standardized fluid management or blood transfusion protocol of the attending anesthesiologist, as there was no standardized indication for SpHb monitoring. It could be that the anesthesiologist using SpHb monitoring has a specific preference for fluid and transfusion policy.

In conclusion, intraoperative SpHb measurement in pediatric craniofacial surgery for craniosynostosis is a safe, noninvasive tool to monitor Hb values and help transfusion decision-making, when used keeping in mind bias and inaccuracies of the device. Patients with continuous SpHb monitoring had decreased intraoperative PRBC transfusions, reduced postoperative surgical site bleeding, and shorter postoperative ICU stay.

Author contributions Study conception and design were performed by ZA and AS. Data collection and analysis were performed by RA, MS, BS and FGI. The first draft of the manuscript was written by RA and AS, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

Ethical approval This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Marmara University School of Medicine (09.2021.904).

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