Nusantara Medical Science Journal
Volume 9, Issue 2, July – December 2024
P-ISSN: 2460-9757, E-ISSN: 2597-7288
Nationally Accredited Journal, Decree No. 230/E/KPT/2022.

Literature Review

Perioperative Pediatric Transfusion Strategy

Ahmad Nur Islam[1,2], Elizeus Hanindito[3], Muhammad Ramli Ahmad[4], Maman Surya Permana[5], Hanna Aulia Namirah[6]

[1] Trainee of Pediatric Anesthesiology, Department of Anesthesiology and Reanimation, Faculty of Medicine, Universitas Airlangga, Surabaya, East Java, Indonesia
[2] General Hospital Makassar, Health Ministry of Republic Indonesia
[3] Department of Anesthesiology and Reanimation, Faculty of Medicine, Universitas Airlangga, Surabaya, East Java, Indonesia
[4] Departement of Anesthesiology, Intensive Therapy, and Pain Management, Faculty of Medicine, Hasanuddin University, Makassar, South Sulawesi, Indonesia
[5] Faculty of Medicine, Hasanuddin University, Makassar, South Sulawesi, Indonesia
[6] Faculty of Medicine, Universitas Muslim Indonesia, Makassar

Corresponding Author:
Name: Ahmad Nur Islam
Email ahmad.nur.islam-2022@fk.unair.ac.id

ARTICLE INFO

Keywords:
blood transfusion; perioperative management; pediatric anesthesia.

How to cite:
Islam, A.N., Hanindito E., Ahmad M.R., Permana M.S., & Namirah H.A. (2024). Perioperative Pediatric Transfusion Strategy. Nusantara Medical Science Journal, 9(2), 38–54.

DOI:
10.20956/nmsj.vi.42398

ABSTRACT

Introduction: *In the modern healthcare system, blood transfusion is an essential treatment that plays a significant role in the clinical improvement of adult and pediatric patients. Given the physiological and hematological differences between children and adults, careful planning and an individualized approach are essential to maximize its effectiveness and avoid serious side effects.* ***Method:*** *A thorough review of the literature was performed, utilizing PubMed, Embase, and the Cochrane Library, to gather evidence on pediatric perioperative transfusion practices. The search encompassed studies published between 2013 and 2024, employing a combination of terms and free-text keywords, as well as Boolean operators, to refine the results.* ***Conclusion:*** *Intraoperative blood loss in pediatric patients requires special attention with an approach that includes pre to postoperative management. This approach must be adapted to the anatomical and physiological differences of children compared to adults. Research, development of universal transfusion strategies, and education and* *training for medical personnel are essential to improve blood management and prevention of complications.*

1. INTRODUCTION

Blood transfusions are an important part of healthcare, but inappropriate use can lead to serious side effects. Transfusions in pediatric patients require careful consideration of age group and specific blood component indications. Each year, over 400,000 units of blood are transfused into pediatric patients, with red blood cell transfusions commonly used in surgery to maintain stability and oxygen transport (1,2). The need for transfusions varies between procedures, and comprehensive data is necessary to guide administration (3). Complications such as hemolysis, transfusion-related immunomodulation (TRIM), transfusion-related acute lung injury (TRALI), and transfusion-associated circulatory overload (TACO) are frequently reported. Large volumes of red blood cell transfusions can lead to wound dehiscence and surgical site infections. Neonates often require perioperative transfusions due to small blood volume and high metabolic demand. Platelet transfusions are also common in neonates with thrombocytopenia. However, there is limited evidence-based research on pediatric blood transfusion practices, especially for non-red blood cell products. The objective of this review is to determine optimal strategies for transfusion management in pediatric patients (4,5).

2. METHODS

An extensive literature review was performed using PubMed, Embase, and the Cochrane Library, focusing on studies from 2013 to 2024 about pediatric perioperative transfusion practices. The search utilized Medical Subject Headings and free-text keywords with Boolean operators. Search terms included combinations like ("Pediatric patients" OR "Children" OR "Neonates") AND ("Blood transfusion" OR "Perioperative transfusion") AND ("Blood management"), with specific queries for complications such as ("Transfusion complications" OR "Hypocalcemia") and strategies like ("Intraoperative transfusion" AND "Transfusion thresholds"). The inclusion criteria were limited to peer-reviewed studies on pediatric surgical patients discussing transfusion strategies and outcomes. Studies unrelated to pediatrics or lacking data were excluded. This methodical search, aligned with PRISMA guidelines, ensured a systematic and transparent review process. The selected articles, which were evaluated for methodological quality and relevance, supported forming evidence-based recommendations for pediatric transfusion practices.

3. DISCUSSION

3.1. PHYSIOLOGICAL CHARACTERISTICS OF BLOOD IN CHILDREN

Children have distinct physiological attributes compared to adults, influencing their healthcare needs. With larger body surface areas relative to weight, they need more fluids and blood transfusions per kilogram, especially in burn cases. Children typically exhibit higher heart rates, which can lead to increased heart failure risks. Infants rely more on heart rate boosts rather than muscle contractility to maintain cardiac output, risking reduced oxygen transport and higher mortality in those under two with severe burns. Additionally, children have higher blood volumes and oxygen consumption rates. Neonates display immature hemostatic systems and variable hemoglobin levels, affecting oxygen delivery and increasing bleeding risks (6,7).

3.2. PERIOPERATIVE ASSESSMENT

3.2.1. EVALUATION OF TRANSFUSION RISK

Preoperative planning is vital for surgeries at high risk of bleeding or in patients with relevant comorbidities. This includes reviewing medical histories, physical exams, and necessary lab tests. Tools like the Pediatric Bleeding Questionnaire (PBQ) and the International Society on Thrombosis and Hemostasis Bleeding Assessment Tool (ISTH-BAT) are considered reliable and valid to assess bleeding risk (8,9).

A comprehensive blood workup should be done for infants and children, including evaluations of hemoglobin, hematocrit, and reticulocyte count levels. In neonates, samples from both mother and baby are necessary for ABO and D group determination. Detection of sickle cell disease should be done in at-risk populations (10,11).

Table 1. Range of normal blood component values in infants and children(11)

	Preterm	Term	Adult
Hemoglobin (g/l)			
Birth	140-240	140-240	-
3 months	80-140	80-140	-
6 months – 6 years	100-140	100-140	-
7-12 years	110-160	110-160	-
Adult	-	-	115-180
Platelets ($x10^9$/l)	150-450	150-450	150-400
PT (sec)	11-22	10-16	11-14
APTT (sec)	28-101	31-55	27-40
Fibrinogen (g/l)	1.5-3.7	1.7-4.0	1.5-4.0
Blood volume (ml/kg)	90-100	80-85[a] 75-80[b]	65-75

PT, prothrombin time; APTT, activated partial thromboplastin time.
[a] Blood volume at birth.
[b] Blood volume by 6 months of age

Coagulation screening is also required when major surgery is planned. Examination and observation of the patient's height and weight should be documented. Most children receiving elective outpatient surgery are categorized as American Society of Anesthesiologists (ASA) physical status 1 or 2 and do not require extensive preoperative examination. However, children undergoing major surgery with substantial risk of blood loss (>10% of circulating volume) or those with significant comorbidities require thorough preoperative evaluation (10,11).

Preoperative anemia increases the likelihood of needing packed red blood cell (PRC) transfusions, raises mortality rates, and extends hospital stays. Studies by Piekarski et al. and Faraoni et al. confirm it as an independent predictor. Factors like age under two, ASA IV status, and septic shock also elevate transfusion needs. (12–15).

In cases where preoperative anemia screening is challenging, the anesthesiologist or senior consultant surgeon often rely on clinical judgment to determine the need for transfusions. For patients undergoing anemia screening, the Maximum Allowable Blood Loss (MABL) calculation can guide transfusion decisions. Here is the universal formula for calculating MABL:

$$\text{MABL} = \frac{\text{EBV x (H0} - \text{H1)}}{\text{H0}}$$

Based on the formula, estimated blood volume (EBV) is the estimated blood volume in milliliters; H0 represents the initial hematocrit; H1 represents the lowest acceptable/targeted hematocrit, which is generally 20-25% in children (10,16).

3.2.2 PATIENT PREPARATION

Iron supplementation via intravenous or oral routes is recommended for iron deficiency anemia, typically at 3-6 mg/kg/day for children. Combining iron with erythropoietin enhances pre-operative hematocrit and autologous blood collection, while any hemostasis conditions should be addressed before surgery. Autologous blood donation is not routinely recommended due to risks of inducing preoperative anemia and potential administrative errors. Critical measures include consulting with blood banks and performing blood group checks prior to high-risk surgeries. In emergencies, blood may be used without cross-matching. Also, thrombocytopenia in critically ill children requires careful assessment for platelet transfusions, considering the severity of the underlying condition (17–19).

Aspirin and warfarin are the most frequently prescribed oral antiplatelet and anticoagulant agents in pediatric patients, respectively. The decision to continue, discontinue, or replace with other therapies should be discussed with cardiologist, hematologists, surgeons, anesthesiologist or pediatric hematologist. If anticoagulation requires continuation, the medical team, patient, and parents should be informed of a detailed plan. For individuals taking warfarin, the anticoagulation regimen typically necessitates perioperative transition to an intravenous heparin infusion, which has a shorter half-life. As a result, patients may remain anticoagulated up until shortly before the scheduled surgical procedure (8,20).

The importance of preventing hypothermia during surgery is emphasized, as it is linked with increased transfusion requirements, blood loss, and adverse outcomes. This is especially relevant for children who are more vulnerable to hypothermia due to their body surface area ratio and lower subcutaneous fat stores. The Royal College of Anesthetists recommends intraoperative temperature measurement and environmental temperature adjustment as part of the perioperative hypothermia prevention guidelines (21).

3.2.3 PROPHYLACTIC STRATEGIES TO REDUCE THE NEED FOR TRANSFUSION

Several strategies help reduce transfusion needs and blood loss in pediatric surgery. Tranexamic acid (TXA), an antifibrinolytic, inhibits plasminogen activation and is given as a 20 mg/kg bolus followed by 10 mg/kg/hour infusion. Desmopressin increases von Willebrand factor, factor VIII, and platelet activity at a dose of 0.3 μg/kg IV. Autologous Blood Donation (ABD) is used in children >3 years or >15 kg, with 10 mL/kg phlebotomies and fluid replacement. Recombinant EPO (300 μg/kg) can boost hemoglobin preoperatively, given a week before surgery or for repeated ABD (18,21–24).

3.3 INTRAOPERATIVE STRATEGY

3.3.1 ANESTHESIA TECHNIQUES THAT SUPPORT REDUCTION OF TRANSFUSION REQUIREMENTS

Anesthetic techniques play a crucial role in minimizing blood loss during pediatric surgeries, with combined general and regional anesthesia proving more effective than general anesthesia alone. Peripheral nerve blocks reduce opioid consumption, alleviate pain, and lower postoperative hyperalgesia risks, making them increasingly recommended for children. Studies have shown regional anesthesia can lessen analgesic requirements, shorten hospital stays, and reduce intraoperative blood loss and surgery time. Despite varying impacts in emergencies, maintaining proper patient positioning and using antifibrinolytic agents can further decrease blood transfusion needs. Additionally, surgical precision, efficient procedure times, and maintaining normothermia are vital for reducing perioperative bleeding(5,25–29).

3.3.2 HEMODYNAMIC AND HEMOSTASIS MONITORING

The requirement for perioperative blood transfusion is contingent upon various factors, encompassing the magnitude and rate of blood loss, the patient's blood volume, preoperative hematocrit, overall medical conditions including cardiac or pulmonary disease, the type of surgical procedure, hemodynamic stability, and the risk-benefit assessment of transfusion. Ensuring appropriate and sufficient replacement of blood loss is crucial to mitigate morbidity and mortality in pediatric surgical patients (10).

One method to calculate the volume of blood to be transfused to achieve the target hematocrit is to use the following formula(10):

$$\text{Transfusion volume} = \text{EBV} \times (\text{Ideal hematocrit} - \text{actual hematocrit})/\text{hematocrit of transfused blood}$$

Blood loss can be substituted with Ringer Lactate fluid of three times the volume of blood lost, or with hetastarch or 5% albumin of the same volume. Once blood loss reaches a certain limit, PRC transfusion should be started(10).

According to the recommendations of Adapted ADAPTE, the amount of PRC required for pediatric patients should be prescribed in milliliters, unless there is a specific protocol in the hospital that specifies transfusion units. The volume of PRC prescribed should not exceed the volume normally transfused in adults(1).

$$\text{Transfusion volume (ml)} = \text{Desirable Hb} - \text{Actual Hb x body weight (kg)x } \frac{40}{10}$$

* Hemoglobin used in units of g/dl

For non-bleeding pediatric patients, it is important to determine the hemoglobin level prior to transfusion and ensure the post-transfusion Hb does not exceed the prescribed threshold by more than 2 g/dL. Massive blood loss (MBL) is defined as 2-3 ml/kg/minute, 40 ml/kg in 3 hours, or 80 ml/kg in 24 hours. Hemodynamic signs indicating hypovolemia or serious bleeding are often the trigger for action.

Key principles for managing major bleeding loss (MBL) in pediatric patients include early risk identification through clinical and pre-operative lab assessments, readiness to implement bleeding control protocols, and prompt resuscitation. It is crucial to consult experts, provide O RhD-negative red blood cells promptly, and calculate transfusions in ml/kg for children under 50 kg. Early treatment of thrombocytopenia and coagulopathy with fresh frozen plasma, cryoprecipitate, and platelets is essential. Use of tranexamic acid in trauma and prevention of complications like hypothermia, hypocalcemia, acidosis, and hyperkalemia are also vital (1)

Recommended transfusion aliquots are (1):

a. **Red blood cells**: 20 ml/kg (maximum four adult units), RhD-negative or ABO and RhD specific.
b. **FFP**: 20 ml/kg (maximum four adult units).
c. **Platelets**: 15-20 ml/kg (maximum one adult dose), considered after transfusion of 40 ml/kg red blood cells.
d. **Cryoprecipitate**: 10 ml/kg (maximum two pools).
e. **Initial transfusion**: 20 ml/kg of red blood cells (up to four adult units).

Early resuscitation for major bleeding shows no significant difference between using red blood cells, platelets, and plasma in 1:1:1 versus 1:1:2.5 ratios. The recommended minimum is a 1 FFP:2 PRCs ratio, shifting to 1:1 in severe trauma. Continued bleeding warrants the addition of cryoprecipitate and platelets, adjusting based on lab results. Therapeutic targets include maintaining Hb ≥ 8 g/dL, fibrinogen > 1.5 g/L, PT ratio < 1.5, and platelet count > 75 × 10^9/L, with vigilant monitoring to prevent circulatory overload and further complications (1)

There are multiple methods to monitor blood loss and assess tissue perfusion, though none are completely definitive. Techniques include visual estimates from surgical gauze and the operating field, quantifying blood on cotton and in suction bottles, and using cardiovascular indices like blood pressure and heart rate, which are late indicators of hypovolemia. Biochemical markers like lactate levels above 4 mmol/l and base deficits exceeding -4 mmol/l suggest impaired perfusion. The oxygen extraction ratio, differentiating central venous from arterial saturation, flags significant hypovolemia over 30% and shock above 50%. Central venous pressure trends and cardiac output monitoring are also valuable, especially in pediatric practice (11)

3.3.3 BLOOD LOSS MANAGEMENT

In pediatric patients, the highest transfusion rates occur in cardiac surgery with cardiopulmonary bypass (CPB) at 79%, followed by spinal fusion and craniosynostosis surgeries. Variability in these rates stems from factors like hemoglobin thresholds, surgical and anesthetic methods, pre-operative anemia, and inconsistent transfusion protocols. Strategies to reduce blood use include pre-operative iron and erythropoietin supplementation, autologous predonation, tranexamic acid, and cell salvage. Intraoperatively, the initial administration of crystalloids or colloids must avoid causing dilutional coagulopathy. Monitoring with vasopressors during severe bleeding, and tracking markers such as lactate and urine output, helps ensure adequate organ perfusion while conserving blood (Figure 1) (30–33).

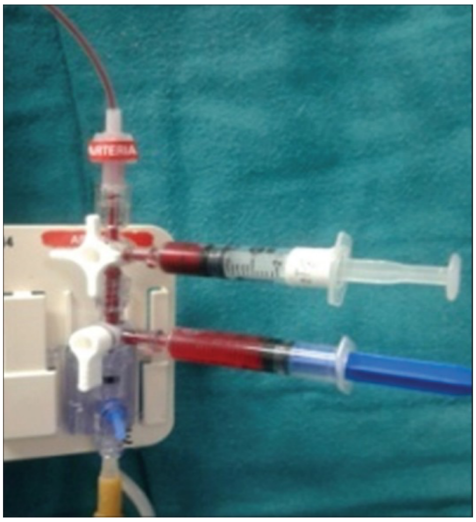

Figure 1. Double stopcock technique (24).

Acute normovolemic hemodilution in pediatric cardiac surgery reduces blood loss by withdrawing 10-15% of total blood volume, replacing it with crystalloids or colloids, and maintaining a hematocrit above 30%. Blood oxygenation is monitored using Near Infrared Spectroscopy (NIRS), and anticoagulated blood is re-transfused during cardiopulmonary bypass, with calcium chloride countering CPDA effects. Cell Salvage (CS) complements other blood conservation techniques, minimizing allogeneic transfusion needs and preventing postoperative anemia. Blood is collected intraoperatively via suction and postoperatively through drainage, then treated for reinfusion, potentially reducing allogeneic blood exposure by up to 54%. In surgeries with unpredictable blood loss, CS is used in collection mode, processing blood only when volumes exceed 500 ml. Postoperative CS is recommended for significant losses exceeding 500 ml, such as in tourniquet-assisted procedures. CS is avoided in

P-ISSN: 2460-9757, **E-ISSN**: 2597-7288

tumor surgeries or when irrigation solutions damage red cells. Techniques like pre-emptive embolization, topical hemostatic agents, antifibrinolytics, and CATS™ systems improve bleeding control and blood management (18,24,34).

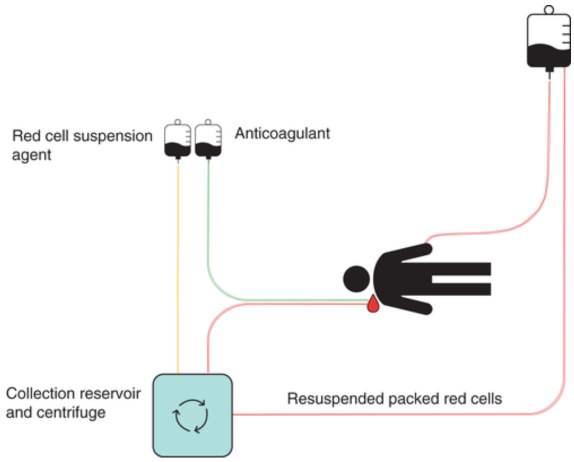

Figure 2. Standard salvage cell circuit(35).

3.3.4 TRANSFUSION INDICATIONS AND PROTOCOLS

3.3.4.1 INDICATIONS FOR TRANSFUSION IN PEDIATRIC PATIENTS

If there is a significant risk of blood loss (>7 ml/kg) as listed in the World Health Organization's Safe Surgery Checklist, transfusion is required despite laboratory confirmation of low anemia or clinical suspicion. Other factors such as active bleeding, long duration of operation, emergency operation, and the presence of malnutrition or hemoglobinopathy are also considerations in guiding the transfusion decision. Generally, the transfusion dose used is 20 mL/kg body weight. The blood transfusion threshold will vary based on age, Hb level, and other factors as follows(10,16):

Infants <4 months old need a red blood cell transfusion if(10):

a. Hb < 12 g/dl in the first 24 hours of life
b. Hct < 20% with symptoms of anemia with a decreased reticulocyte count
c. Hct < 30% on oxygen therapy with FiO2 > 35%/sustained positive airway pressure or with clinical signs such as low weight gain, tachycardia, bradycardia, and apnea
d. Hct > 35% on oxygen in the hood or on intermittent mandatory ventilation (IMV) with mean airway pressure (MAP) > 6 cm H2O
e. Hct > 45% in the presence of cyanotic congenital heart disease
f. Blood loss > 10%.

Infants older than 4 months need red blood cell transfusion if(10):

a. Acute loss >15% of EBV
b. Hypovolemia unresponsive to other treatment
c. Postoperative anemia (Hb < 10 g/dl)
d. Preoperative Hb < 12 g/dl in the presence of severe cardiopulmonary disease
e. Severe chronic anemia with Hb < 7 g/dl.

Plasma is administered to critically ill pediatric patients for various reasons, including coagulopathy, bleeding, and prevention of bleeding in those undergoing invasive procedures. Initiation of ECMO in critically ill children often leads to reduced thrombocytopenia, hemolysis, fibrinogen depletion, and coagulation factors, particularly in individuals with vitamin deficiencies, malabsorption syndrome, liver disease, or extrahepatic bile duct atresia. Other conditions requiring FFP transfusion include hereditary angioedema and microvascular bleeding with prolonged PT and TPT(19,23).

Indications for platelet transfusion include thrombocytopenia, acute bleeding with a platelet count below 50,000/mm³, preparation for invasive procedures when the platelet count is less than 50,000/mm³, and central nervous system procedures when the platelet count is below 100,000/mm³. Cryoprecipitate transfusion is indicated in fibrinogen concentrations below 150 mg/dl with microvascular bleeding, massive transfusions with fibrinogen below 150 mg/dl, as well as fibrinogen deficiency, dysfibrinogenemia, and afibrinogenemia(23).

3.3.4.2 TRANSFUSION PROTOCOL

Based on a clinical study from Egypt entitled *Adapted ADAPTE* regarding blood component transfusion in the pediatric population, the following are the thresholds and indications for PRC transfusion in acutely ill neonates without other comorbidities(1).

Table 2. Transfusion threshold recommendations for preterm neonates* (1)

Post-natal age	**Hb recommended transfusion threshold (g/dl)**		
	Ventilated	Oxygen/NIPPV attached	Without oxygen
First 24 hours	< 12	< 12	< 10
≤ 1 week	< 12	< 10	< 10
2 weeks	< 10	<9,5	< 7.5†
≥ 3 weeks	< 10	<8,5	< 7.5†

NIPPV: *non-invasive positive pressure ventilation*

* Standard definition of preterm is <37 weeks gestational age at birth but the table applies to very preterm neonates (<32 weeks)
† Clinicians may use up to 85 g/dl depending on the clinical situation

While Table 2 does not provide recommended transfusion thresholds for term neonates or moderate to late preterm (>32 weeks gestational age), clinicians may consider utilizing thresholds similar to those used for preterm infants without oxygen requirement, as there is limited evidence regarding appropriate transfusion parameters for these patient populations (1).

Table 3. Transfusion threshold recommendations for infants and children based on Pediatric Critical Care(11).

Blood product	Clinical condition	Transfusion threshold
RBC	**Infant < 4 months of age**	**Hemoglobin**
	Preterm/term born anemic	120 g/dl
	Chronic oxygen dependency	110 g/l
	Severe pulmonary disease	120 – 140 g/l
	Late anemia stable patient	70 g/l
	Acute blood loss > 10% EBV	120 g/l
RBC	**Infant > 4 months of age**	**Hemoglobin**
	Stable infant	70 g/l
	Infant/child critically unwell	70-80 g/l
	Infant/child with preoperative bleeding	80 g/l
	Infant/child with cyanotic congenital heart (have an increased oxygen demand)	90 g/l
	Child with thalassemia major (to slow bone marrow stimulation)	90 g/l
	Child with SCD (>90 g/l if previous CVA)	70-90 g/l
	Child with SCD for major surgery (aim for 90 – 110 g/l and HbS < 30%, < 20% for thoracic or neurosurgery)	90 g/l
Platelets		**Platelets**
	Neonate with bleeding	50×10^9/l
	Sick neonate not bleeding	30×10^9/l
	Stable neonate not bleeding	20×10^9/l
	Stable infant > 4 months/child	10×10^9/l
	Infant/child ICU	20×10^9/l
	Any infant/child for an invasive procedure or surgery	$50 - 100 \times 10^9$/l
FFP		**Coagulation**
	Neonate/child with bleeding	APTT and PT > 1.5 control for age
	DIC or prior to an invasive procedure	
Cryoprecipitate	Neonate/child with bleeding or DIC not corrected with FFP	Fibrinogen < 1 g/l

RBC, red blood cell; SCD, sickle cell disease; HbS, sickle hemoglobin; ICU, intensive care unit; DIC, disseminated intravascular coagulation; APTT, activated partial thromboplastin time; PT, prothrombin time; FFP, fresh frozen plasma.

Two recent neonatology trials addressing PRC transfusion thresholds confirmed the safety of the restrictive transfusion approach recommended in the cross-sectional guideline (CSG). Different transfusion thresholds are applied to preterm infants and neonates, based on their age and clinical status, as stipulated in the guidelines developed by the British Committee for Standards in Hematology (BCSH). For preterm neonates in room air, the hemoglobin concentration in Table 1 is used as the threshold for perioperative transfusion, as higher thresholds are not supported by evidence. Additionally, the CSG advises the administration of red blood cell concentrate (RCC) as an acute intervention for preterm and term infants experiencing volume deficiency due to blood loss (Level 1 recommendation C+) (6).

Pediatric transfusion guidelines advise not relying on a single transfusion threshold. However, a hemoglobin level of 8 g/dL is the accepted standard during significant intraoperative bleeding, while 7 g/dL suffices for clinically stable, severely ill children. This hemoglobin is equivalent to a hematocrit of 21-25%. Red blood cell transfusion volume is calculated using the formula: weight (kg) × desired hemoglobin increase (g/dL) × 5. In patients with sustained bleeding, platelets of at least 50,000/µL need to be maintained, with an increase of 50,000-100,000/µL post-transfusion of 5-10 mL/kg Thrombocyte Concentrate. For infants under 1 year or weighing <10 kg, **Wake Up Safe** recommends the use of fresh blood (<1 week old) to prevent fatal hyperkalemia. Transfusion should be done carefully to minimize the risk of adverse effects, such as bacterial contamination (18).

FFP transfusion should be ABO compatible, and AB plasma is the universal donor. The typical dose of FFP is 10-20 mL/kg, which increases coagulation factor levels by 15-25%, allowing hemostasis to occur. In massive bleeding, platelets are administered to maintain platelet counts >50 × 10^9/L or above 100 × 10^9/L in patients on ECMO(19).

3.3.4.3 MASSIVE TRANSFUSION PROTOCOL (MTP)

Massive Blood Loss (MBL) is defined as losing one blood volume in 24 hours or 50% in 3 hours, but it can be difficult to assess clinically. Rapid evaluation of pathology, cardiovascular status, and comorbidities is vital in severe hemorrhage. Early use of platelets, FFP, and PRC improves outcomes by addressing coagulopathy. Unlike adults, no ideal system exists for predicting MTP activation in children, leaving decisions to physician discretion. Clear criteria are needed for timely access to blood products. Pediatric MTPs reduce coagulopathy and thromboembolic events, but further research is required to refine activation points and optimize protocols.(11,36).

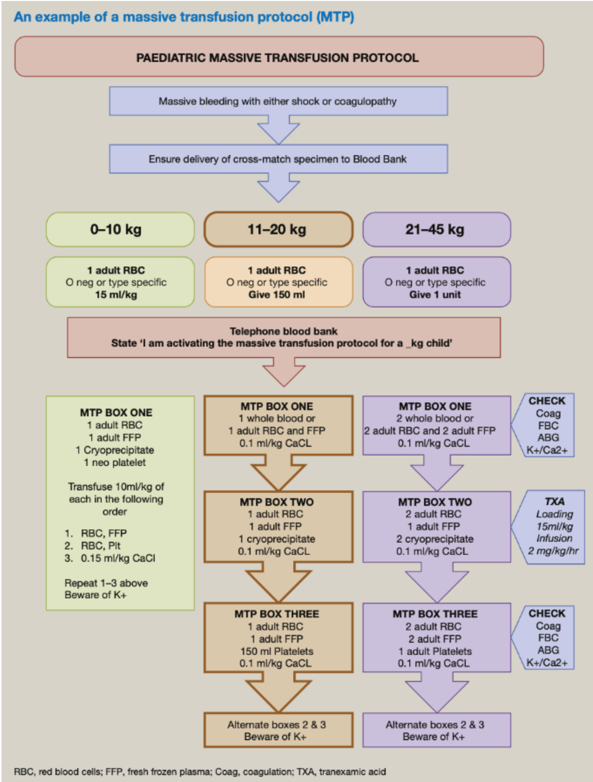

Figure 3. Example of a MTP(11).

3.4 POST-OPERATIVE STRATEGY

3.4.1 POST-TRANSFUSION MONITORING

Post-transfusion care involves monitoring Hb levels and assessing the child's clinical condition. Patients should be observed for 24 hours to detect delayed reactions, while outpatients must be informed about possible side effects. Vital signs should be measured 15 minutes after the transfusion starts and every 30 minutes thereafter. Hemodynamic monitoring and vigilance for postoperative bleeding are essential, particularly in major surgeries with significant blood loss. If bleeding persists, surgical re-exploration may be needed to avoid unnecessary transfusions. Blood loss can be managed using a CS system, and clotting issues treated with antifibrinolytics, vitamin K, or calcium. Over-transfusion risks complications, with studies showing 19% of elective surgery cases exceeding transfusion targets, often defined as Hb >10 g/dL (3,10).

3.4.2 MANAGEMENT OF TRANSFUSION COMPLICATIONS

Intraoperative transfusion has been associated with an increase in perioperative complications, with children particularly at risk of metabolic complications due to the proportion of blood volume replaced during transfusion (23).

Transfusion-related Acute Lung Injury (TRALI)

TRALI is a serious complication of blood product transfusion and is the leading cause of transfusion-related death. Although its etiology and incidence are not fully understood, it is estimated that TRALI occurs in one in 5,000 blood product transfusions. There is no specific treatment for TRALI, and transfusions should be stopped immediately after diagnosis. Additional support is required to maintain hemodynamic stability, but diuretics should be avoided. In patients who survive, symptoms usually improve within 96 hours, and there are rarely any long-term sequelae. However, in about 20% of patients, hypoxemia and pulmonary infiltrates may persist for more than seven days. Although rare, there have been reports of children dying from TRALI (37,38).

Transfusion-associated Circulatory Overload (TACO)

TACO happens when a patient's cardiovascular system is overwhelmed by excessive volumes of blood transfusion, leading to pulmonary edema. Symptoms of TACO which can manifest during or within 6 hours after transfusion and common signs are increased heart rate and widening of the pulse pressure. Physical examination may reveal abnormal lung sounds and chest x-rays may show signs of congestive heart failure. The first step in treating TACO is to stop the blood transfusion and provide supportive care. Diuretics are the main treatment for TACO, with the goal of preventing further accumulation of fluid in the lungs(39).

Hypocalcemia

Hypocalcemia is common with FFP due to its high citrate content, especially in neonates and children with liver dysfunction who cannot metabolize citrate efficiently. Neonates are more vulnerable as their cardiac function relies on calcium. Citrate-induced hypocalcemia can cause severe myocardial dysfunction, worsened by halogenated anesthetics. Prevention includes limiting blood infusion rates to 1 ml/kg/min, reducing halogenated anesthetics, and giving prophylactic calcium. Treatment involves IV calcium gluconate (15-30 mg/kg) or calcium chloride (5-10 mg/kg). In persistent blood loss, such as liver transplantation, continuous calcium chloride infusion (10 mg/kg/hour) can prevent dysfunction, particularly during the anhepatic phase (23).

Hyperkalemia

Hyperkalemia is a serious complication of blood transfusions that can be fatal because of its association with arrhythmias. The risk is highest with red blood cell units nearing their expiration date, total blood, and irradiated red blood cells. To lower the chances of hyperkalemia, it is advised to use red blood cell units collected within one week and to ensure a transfusion rate of no more than 1 ml/kg/min. Should arrhythmia occur as a result of hyperkalemia, recommended treatments include the intravenous administration of calcium gluconate (60 mg/kg), calcium chloride (20 mg/kg), or sodium bicarbonate (1 meq/kg). Other methods to decrease potassium levels in the blood involve administering insulin with dextrose, hyperventilation, and the use of beta-mimetics. Furthermore, consulting a pediatrician specialized in cardiovascular conditions is crucial for appropriate management (23).

Hypomagnesemia

Hypomagnesemia is another complication that occurs due to massive transfusion as citrate chelates magnesium and calcium. Magnesium is essential for stabilizing membrane potential and maintaining cardiovascular stability. If arrhythmias (ventricular tachycardia or ventricular fibrillation) occur and are unresponsive to calcium administration, consider hypomagnesemia and give magnesium sulfate 25-50 mg/kg IV. It is also necessary to consult a pediatrician with a cardiovascular specialty (23).

Hypothermia

Children are highly susceptible to hypothermia due to their larger body surface area relative to weight, which increases risks of morbidity and mortality. Preventive measures include using warming blankets and regular core temperature monitoring, with continuous monitoring recommended for high-risk patients postoperatively. Intraoperative hypothermia can result from factors like cold room temperatures, anesthetic gases, evaporation, and cold IV fluids. High-risk groups include young children, the elderly, and those undergoing prolonged surgeries. NICE advises maintaining room temperatures of at least 21°C, monitoring every 30 minutes, and using warming devices, though pediatric-specific temperature management guidelines remain lacking (21,35).

4. CONCLUSION

Managing blood loss in pediatric surgery requires coordinated efforts across preoperative, intraoperative, and postoperative phases, involving anesthesiologists, surgeons, hematologists, and laboratory teams. Emphasis should be placed on developing standardized transfusion protocols, improving preoperative preparation, intraoperative monitoring, and addressing post-transfusion complications. Training for pediatric specialists should focus on effective blood management techniques, including bleeding prevention and transfusion strategies, to enhance outcomes and minimize risks during pediatric surgeries. Collaboration and education are key to achieving these goals.

ACKNOWLEDGMENT

We would like to thank the staff of the Pediatrics Anesthesia Subdivision, Department of Anesthesiology and Reanimation, Faculty of Medicine Universitas Airlangga for their support, direction, and guidance in the preparation of this article.

REFERENCES

1. Mokhtar G, Adly A, Baky AA, Ezzat D, Hakeem GA, Hassab H, et al. Transfusion of blood components in pediatric age groups: an evidence-based clinical practice guideline adapted for the use in Egypt using "Adapted ADAPTE". Ann Hematol. 2024 Apr;103(4):1373–88.
2. McCormick M, Delaney M. Transfusion support: Considerations in pediatric populations. Semin Hematol. 2020 Apr;57(2):65–72.

3. Zhou H, Lan J, Zhu H, Tan X, Liu J, Xiang L, et al. Evaluation for Perioperative Blood Transfusion during Major Abdominal Procedures in a Pediatric Population: A Retrospective Observation Cohort Study. Transfus Med hemotherapy Off Organ der Dtsch Gesellschaft fur Transfusionsmedizin und Immunhamatologie. 2020 Feb;47(1):68–74.
4. Govender K, Kemp E, Motshabi Chakane P. Intraoperative transfusion practice and associated outcomes following neonatal surgery in a middle-income country: A 5-year single center retrospective review. Paediatr Anaesth. 2023 Sep;33(9):720–7.
5. Adler AC, Hensch LAH, Bryant BE, Chandrakantan A, Nguyen HY, Nathanson BH, et al. Factors affecting need for blood transfusion in paediatric patients undergoing open surgery for hip dysplasia. Vox Sang. 2022 Dec;117(12):1384–90.
6. Wittenmeier E, Piekarski F, Steinbicker AU. Blood Product Transfusions for Children in the Perioperative Period and for Critically Ill Children. Dtsch Arztebl Int. 2024 Jan;121(2):58–65.
7. Palmieri TL. Children are not little adults: blood transfusion in children with burn injury. Burn trauma. 2017;5:24.
8. Coccolini F, Shander A, Ceresoli M, Moore E, Tian B, Parini D, et al. Strategies to prevent blood loss and reduce transfusion in emergency general surgery, WSES-AAST consensus paper. World J Emerg Surg. 2024 Jul;19(1):26.
9. Laoaroon N, Empremsilapa S, Sirachainan N. Pediatric standardized bleeding assessment tool for screening bleeding disorder in school-age children. Vol. 44, Hematology, transfusion and cell therapy. Brazil; 2022. p. 453–5.
10. Bharadwaj A, Khandelwal M, Bhargava SK. Perioperative neonatal and paediatric blood transfusion. Indian J Anaesth. 2014 Sep;58(5):652–7.
11. Reeve K, Jones H. Transfusion guidelines in children: I. Anaesth Intensive Care Med. 2017 Oct 1;18.
12. Piekarski F, Neef V, Meybohm P, Rolle U, Schneider W, Zacharowski K, et al. Independent Risk Factors for RBC Transfusion in Children Undergoing Surgery. Analysis of 14,248 Cases at a German University Hospital. Child (Basel, Switzerland). 2021 Jul;8(8).
13. Faraoni D, DiNardo JA, Goobie SM. Relationship Between Preoperative Anemia and In-Hospital Mortality in Children Undergoing Noncardiac Surgery. Anesth Analg. 2016 Dec;123(6):1582–7.
14. Goobie SM, DiNardo JA, Faraoni D. Relationship between transfusion volume and outcomes in children undergoing noncardiac surgery. Transfusion. 2016 Oct;56(10):2487–94.
15. Stey AM, Vinocur CD, Moss RL, Hall BL, Cohen ME, Kraemer K, et al. Variation in intraoperative and postoperative red blood cell transfusion in pediatric surgery. Transfusion. 2016 Mar;56(3):666–72.
16. Charuvila S, Aziz TT, Davidson SE, Naznin U, Sinha S, Ahmed S, et al. An Observational Study of Paediatric Preoperative Transfusion Practice in a Resource-Limited Setting. World J Surg. 2022 Mar;46(3):709–17.
17. Spilka J, Goobie SM. Perioperative Blood Management in the Pediatric Patient. Pediatr Anesth. 2020;(February):6–11.

18. Goobie SM, Haas T. Perioperative bleeding management in pediatric patients. Curr Opin Anaesthesiol. 2016 Jun;29(3):352–8.
19. Kahn S, Chegondi M, Nellis ME, Karam O. Overview of Plasma and Platelet Transfusions in Critically Ill Children. Front Pediatr. 2020;8:601659.
20. Dabbous MK, Sakr FR, Malaeb DN. Anticoagulant therapy in pediatrics. J basic Clin Pharm. 2014 Mar;5(2):27–33.
21. McArdle J, Ladak N. Paediatric blood transfusion. Anaesth Intensive Care Med. 2023 Oct 1;24.
22. Vega RA, Lyon C, Kierce JF, Tye GW, Ritter AM, Rhodes JL. Minimizing transfusion requirements for children undergoing craniosynostosis repair: the CHoR protocol. J Neurosurg Pediatr. 2014 Aug;14(2):190–5.
23. Zuluaga Giraldo M. Management of perioperative bleeding in children. Step by step review. Colomb J Anesthesiol [Internet]. 2013 Jan 1;41(1 SE-Narrative review):50–6. Available from: https://www.revcolanest.com.co/index.php/rca/article/view/637
24. Singh SP. Strategies for blood conservation in pediatric cardiac surgery. Ann Card Anaesth. 2016;19(4):705–16.
25. Hopkins PM. Does regional anaesthesia improve outcome? Br J Anaesth. 2015 Dec;115 Suppl:ii26-33.
26. Müller SD, Both CP, Sponholz C, Voelker MT, Christiansen H, Niggli F, et al. Association between Intraoperative Blood Transfusion, Regional Anesthesia and Outcome after Pediatric Tumor Surgery for Nephroblastoma. Cancers (Basel). 2022 Nov;14(22).
27. Ponde V. Recent trends in paediatric regional anaesthesia. Indian J Anaesth. 2019 Sep;63(9):746–53.
28. Osmani F, Ferrer F, Barnett NR. Regional anesthesia for ambulatory pediatric penoscrotal procedures. J Pediatr Urol. 2021 Dec;17(6):836–44.
29. Sebastian R, Ahmed MI. Blood Conservation and Hemostasis Management in Pediatric Cardiac Surgery. Front Cardiovasc Med. 2021;8:689623.
30. Salazar JH, Goldstein SD, Swarup A, Boss EF, Van Arendonk KJ, Abdullah F. Transfusions in Children's Surgery: Characterization and Development of a Model for Benchmarking. J Surg Res. 2020 Aug;252:47–56.
31. Yoshihara H, Yoneoka D. National trends in the surgical treatment for lumbar degenerative disc disease: United States, 2000 to 2009. Spine J. 2015 Feb;15(2):265–71.
32. Bowen RE, Gardner S, Scaduto AA, Eagan M, Beckstead J. Efficacy of intraoperative cell salvage systems in pediatric idiopathic scoliosis patients undergoing posterior spinal fusion with segmental spinal instrumentation. Spine (Phila Pa 1976). 2010 Jan;35(2):246–51.
33. Sotoudeh Anvari M, Hashemi SZ, Mirzaaghayan M, Abdollahi A, Haghi Ashtiani MT, Akbari A. Maximum Surgical Blood Ordering Schedule in Common Pediatric Cardiac Surgeries in a Tertiary Center. Iran J Pathol. 2023;18(4):398–402.
34. Klein AA, Bailey CR, Charlton AJ, Evans E, Guckian-Fisher M, McCrossan R, et al. Association of Anaesthetists guidelines: cell salvage for peri-operative blood conservation 2018. Anaesthesia. 2018 Sep;73(9):1141–50.
35. Shah A, Palmer AJR, Klein AA. Strategies to minimize intraoperative blood loss

during major surgery. Br J Surg. 2020 Jan;107(2):e26–38.

36. Evangelista ME, Gaffley M, Neff LP. Massive Transfusion Protocols for Pediatric Patients: Current Perspectives. J Blood Med. 2020;11:163–72.
37. Gauvin F, Robillard P, Hume H, Grenier D, Whyte RK, Webert KE, et al. Transfusion-related acute lung injury in the Canadian paediatric population. Paediatr Child Health. 2012 May;17(5):235–9.
38. Sahutoglu C, Balci C, Balcioglu T. Transfusion-related acute lung injury and treatment with high-flow oxygen therapy in a pediatric patient: a case report. Brazilian J Anesthesiol. 2024;74(5):744339.
39. Semple JW, Rebetz J, Kapur R. Transfusion-associated circulatory overload and transfusion-related acute lung injury. Blood. 2019 Apr;133(17):1840–53.

Conflict of Interest Statement:

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.