REVIEW
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Patient Blood Management in Pediatric Patients: Current Strategies and Future Perspectives

Okur Acar S. et al.: PBM in Children: Current Perspectives

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Abstract
Patient blood management (PBM) is an evidence-based, multidisciplinary approach aimed at optimizing the care of patients who might require transfusion. While PBM has been widely adopted in adult practice, its application in pediatric settings remains limited and inconsistent despite the unique physiological and clinical challenges of this population. This review highlights the current strategies and future directions of PBM in pediatric patients. Key elements of pediatric PBM include the preservation of red cell mass and the management of preoperative anemia, strategies to minimize iatrogenic and surgical blood loss, approaches to enhance patients' physiological tolerance to anemia, and optimization of transfusion practices. Recent studies support the use of restrictive transfusion thresholds for critically ill children, neonates, and specific high-risk groups such as those with congenital heart disease, demonstrating no added benefit of liberal transfusion practices. Looking ahead, advances in precision medicine, artificial intelligence, and non-invasive monitoring technologies are expected to further individualize transfusion practices and strengthen PBM implementation in pediatric care. However, high-quality pediatric-specific research remains essential to establish standardized protocols and ensure safe, effective, and patient-centered blood management.
Keywords: Patient blood management, Pediatric transfusion, Anemia, Blood health

Introduction

Blood transfusions have long been an indispensable component of clinical practice, particularly in life-threatening situations where they serve a vital role. However, the risk of serious complications including hemolysis, infections, transfusion-related acute lung injury, transfusion-associated circulatory overload, and immune reactions is notably higher in pediatric patients, and concerns such as transfusion-related immunomodulation further underscore the need to restrict transfusions to cases with well-defined clinical indications [1,2,3,4]. Moreover, as blood is a unique and irreplaceable biological product sourced solely from humans, challenges in maintaining a sufficient and safe supply further reinforce the need for its rational and judicious use. In this context, patient blood management (PBM) is defined as an evidence-based multidisciplinary approach that focuses on optimizing the patient's own blood, minimizing blood loss and bleeding, and improving the patient's physiological tolerance to anemia to improve outcomes while reducing the need for allogeneic transfusions. Applying the principles of PBM ensures that blood

from a limited number of donors is used for the patients who need it most, reducing the need for transfusions and therefore healthcare costs [5,6,7,8].

PBM programs have gained great importance in the world in recent years due to their significant contributions to the health system and they are being used by many health institutions and health authorities with increasing frequency [9,10]. In 2021, a World Health Organization policy brief titled "The Urgent Need to Implement Patient Blood Management" provided a strategic roadmap that moves beyond theoretical awareness and advocates for the integration of PBM practices into health systems [11]. In Türkiye, the Ministry of Health, in partnership with the European Union, launched the "Think–Protect–Manage" PBM project on March 20, 2019. Operating until March 16, 2022, the initiative aimed to enhance transfusion safety and promote the judicious use of blood by developing a National Patient Blood Management Strategy and Action Plan [12].

PBM is well established for adults but underused in pediatric medicine, where the unique physiology of the patient population demands tailored strategies. Evidence supports interventions such as anemia management, cell salvage, and restrictive thresholds, but pediatric trials are needed to ensure the right components, doses, patients, timing, and reasons as the "five rights" of transfusion [13,14,15,16,17].

In light of these developments, the concept of pediatric PBM will be comprehensively addressed in this study, which provides a detailed evaluation of its core principles, considerations for specific patient populations, and future perspectives together with a review of the current literature.

Basic Concepts of PBM

PBM is structured around three core objectives:

1) To optimize and improve red cell mass by identifying and treating preoperative anemia at an early stage, thereby preventing unnecessary transfusions.

2) To minimize blood loss and maintain the hemostatic balance as effectively as possible.

3) To enhance the patient's physiological tolerance to anemia and coagulopathy, ultimately aiming to reduce transfusion requirements (Table 1) [5,6,7,8,9,18].

Beyond these pillars, PBM provides a comprehensive framework that spans from early diagnosis and the effective treatment of anemia to preserving blood homeostasis [15]. The concept of "blood health" views the circulatory system as a functional organ, promoting minimal medical intervention to preserve its physiological balance. It emphasizes holistic assessment, including hemostasis, thrombosis risk, and oxygen delivery, over a narrow focus on anemia [15]. Importantly, the modern PBM approach prioritizes patient safety, focusing on individualized, patient-centered decision-making and encouraging active patient participation in care [19].

In the following subsections, strategies supporting the three core pillars of the PBM approach will be discussed in detail (Table 1).

Optimization of Red Cell Mass

The presence of anemia during hospitalizations or in the preoperative period has been associated with increased mortality [20]. Meyer et al. [21] found preoperative anemia in 46.2% of pediatric cases, identifying it as an independent risk factor for postoperative morbidity. The most recent guidelines recognize preoperative anemia as a strong predictor of transfusion and poor clinical outcomes [22]. Therefore, the cause of anemia should be thoroughly investigated even in patients with mild and asymptomatic anemia, as it may have a profound impact on treatment and outcomes.

Treatments Targeting the Underlying Cause of Anemia

Anemia is a highly prevalent condition in the pediatric age group, particularly in children under the age of 5, and it is most commonly associated with nutritional deficiencies such as iron, vitamin B12, and folic acid. In cases of nutritional anemias such as iron, B12, or folate deficiency, hematological response typically begins within days, with hemoglobin levels improving significantly within 1-2 weeks and full correction expected in 1-2 months [23]. Therefore, especially for elective surgeries, it is recommended to perform screening for anemia at least 3-6 weeks prior to the scheduled operation and to initiate diagnostic and therapeutic measures tailored to the underlying etiology if anemia is detected [22,24]. Oral iron remains the first-line treatment for pediatric iron deficiency anemia due to its safety and effectiveness. While oral treatment is typically sufficient, studies in adults suggest that parenteral iron provides faster correction [25,26,27]. Parenteral formulations should be reserved for cases of oral intolerance, malabsorption, or urgent need for rapid hemoglobin improvement, such as preoperative or severely symptomatic patients. In cases of iron deficiency anemia, rapid correction via transfusion has been associated with an increased risk of postoperative complications [28]. In cases of hemodynamic instability,

a single-unit red blood cell transfusion may be needed to correct microvascular hypoxemia and reduce morbidity; further transfusions should be avoided once stability is achieved [29].

Use of Erythropoiesis-Stimulating Agents (ESAs)

Another preoperative approach involves the use of ESAs such as erythropoietin. Assessment of iron status is essential prior to the initiation of erythropoietin treatment. Adult studies support the efficacy of ESAs in reducing transfusions, and limited data suggest similar potential in children [30]. In pediatric cardiac surgery, a single preoperative erythropoietin dose has been shown to significantly decrease transfusion needs [31]. Additionally, the successful use of ESAs has been reported in the children of Jehovah's Witnesses, who refuse blood transfusions for religious reasons [32]. Given the paucity of pediatric evidence, current recommendations suggest reserving ESAs for cases where transfusion is unacceptable or associated with high levels of risk.

Other measures to preserve red cell mass include providing iron prophylaxis during infancy, delayed cord clamping at birth, and, in neonates, the use of intensive phototherapy or intravenous immunoglobulin when appropriate to reduce the need for exchange transfusion.

Strategies to Minimize Blood Loss

Minimization of Iatrogenic Blood Loss

Iatrogenic blood loss from frequent tests and procedures is a major but preventable cause of anemia, especially in neonates and critically ill children. To mitigate this risk, strategies such as minimizing unnecessary blood draws, using low-volume collection tubes, employing closed blood sampling systems, and optimizing test frequency should be adopted. In addition, surgical techniques play a critical role in minimizing blood loss. The use of minimally invasive approaches, meticulous surgical dissection, electrocautery, and topical hemostatic agents such as fibrin sealants and oxidized cellulose can significantly reduce intraoperative bleeding [33]. Furthermore, the preoperative correction of coagulopathy, intraoperative temperature control, and the use of antifibrinolytic agents contribute to optimal surgical hemostasis. A thorough preoperative medication review is also essential, particularly for patients using antiplatelet or anticoagulant therapy, to plan appropriate perioperative management and bridging strategies. In this context, institutional protocols and staff training are important to minimize iatrogenic blood loss and improve patient outcomes.

Preoperative Autologous Blood Donation

Preoperative autologous blood donation in children began in the 1980s amid rising concern over transfusion-transmitted infections. However, evidence regarding its effectiveness in children remains conflicting. While some evidence suggests that autologous donation may reduce allogeneic transfusion requirements in pediatric spinal surgery, other studies have highlighted that donated units are often unused, making this strategy less cost-effective [34,35].

Moreover, adverse effects such as hypotension, irritability, and venous access complications have been reported more frequently in children than in adults during the donation process [36,37,38].

Acute Normovolemic Hemodilution (ANH)

ANH, performed in the preoperative period, involves the removal of 1-2 units of whole blood from the patient, followed by isovolemic replacement with crystalloids or colloids. The collected autologous blood is stored at room temperature for up to 8 hours and can be transfused back to the patient during or after surgery [13,23].

This technique offers two key advantages. First, intraoperative blood loss occurs with diluted blood, thereby reducing the total red blood cell loss. Second, since the reinfused blood is whole blood, it contributes not only to oxygen-carrying capacity but also to hemostatic function [13].

Typically, blood is withdrawn to reduce the hematocrit level to 20%-25%, depending on preoperative values. However, these target levels may vary based on individual factors such as the patient's age, body weight, hematological profile, and type of surgical procedure.

Although evidence from the literature indicates that ANH is a safe and feasible option in pediatric patients [39,40], its clinical use has recently declined due to inconsistent outcomes and a lack of standardization. Therefore, referring to the Standards for Perioperative Autologous Blood Collection and Administration may aid its implementation [41].

Cell Salvage

Cell salvage is an effective intraoperative blood management strategy, particularly in surgeries where blood loss of approximately 1-2 units is anticipated, or in patients with rare blood types [42,43]. With this technique, blood aspirated from the surgical field using dual lumen suction systems is anticoagulated with heparin, filtered, and then processed by centrifugation to wash the red blood cells. This process separates

the erythrocytes from plasma, platelets, leukocytes, and residual heparin, resulting in concentrated red blood cells, which are subsequently reinfused into the patient [43].

With advances in technology, cell salvage has become increasingly feasible and practical in pediatric surgical cases [44]. For example, in a prospective randomized trial involving 100 neonates and infants undergoing open-heart surgery, Cholette et al. [45] reported that cell salvage significantly reduced transfusion requirements. Moreover, compared to preoperative autologous blood donation, cell salvage is considered to be a more cost-effective option [46].

A drawback of this technique is dilutional coagulopathy, increasing bleeding risk. However, the SAME™ device enables reinfusion of both red cells and platelets, with promising pediatric outcomes reported [47].

Antifibrinolytic Agents

Tranexamic acid (TXA) is an effective antifibrinolytic for reducing blood loss in cases of pediatric surgery and trauma. In a randomized, double-blind, placebo-controlled trial, TXA was shown to significantly reduce transfusion requirements in pediatric patients undergoing craniosynostosis surgery [48]. Similarly, in major surgeries such as cardiac, orthopedic, and cranial reconstructive procedures, the use of TXA has been associated with reduced intraoperative bleeding and allogeneic blood transfusion rates, without a significant increase in serious adverse events [49,50,51]. A comprehensive meta-analysis demonstrated that prophylactic epsilon-aminocaproic acid administration significantly reduced the need for red blood cell, platelet, and fresh frozen plasma (FFP) transfusions in children, and also decreased the rate of surgical reexploration. Based on these findings, the prophylactic use of antifibrinolytic agents has become a recommended strategy in current pediatric cardiac surgery practices [52].

Coagulation Factor Concentrates

Hypofibrinogenemia is a frequent intraoperative issue and a key predictor of bleeding risk [53]. In a study of pediatric craniosynostosis and scoliosis surgeries, fibrinogen replacement guided by viscoelastic tests showed reduced transfusion needs with early intervention (maximum clot firmness of <13 mm vs. <8 mm). The effect was less notable in scoliosis cases due to lower blood loss [54].

Regarding prothrombin complex concentrate (PCC), its use in 14 pediatric cardiac surgery patients under 1 year of age resulted in significantly less bleeding and transfusion needs compared to controls [55]. In a study by Faraoni et al. [56], pediatric patients with bleeding following cardiopulmonary bypass received either PCC or recombinant activated factor VII (rFVIIa). While both groups showed comparable blood loss and transfusion volumes, the incidence of thromboembolic complications was significantly higher in the rFVIIa group (30% vs. 8%).

Although these findings highlight the potential benefits of factor replacement therapy, further research is needed to establish optimal thresholds, dosing strategies, and specific indications for its use in pediatric surgical settings.

Use of Viscoelastic Testing

When evaluating hemostasis in children, it is essential to consider age-specific reference ranges alongside the personal and family history of bleeding. A history-based assessment remains the most reliable approach for predicting bleeding risk [57]. In patients with bleeding diathesis, timely identification of bleeding risk factors and their elimination or minimization, when possible, helps to reduce blood loss to the lowest possible level. For minor or moderate procedures, routine coagulation tests are generally not deemed necessary [58,59]. In recent years, the use of viscoelastic tests such as thromboelastography (TEG) and rotational thromboelastometry in addition to conventional coagulation assays has gained increasing importance. These dynamic assessments of hemostasis may support more accurate and individualized perioperative transfusion decisions [60,61,62]. In pediatric cardiac surgery, TEG-guided management reduces platelet and cryoprecipitate use, lowering transfusion costs [63].

Enhancement of the Patient's Physiological Tolerance to Anemia and Optimization of Transfusion Practices

The third PBM pillar focuses on enhancing tolerance to anemia and coagulopathy by optimizing cardiopulmonary function and using restrictive transfusion thresholds [15]. While adult PBM strategies show clear benefits [64], pediatric applications remain challenging due to differences in hemostasis, bleeding patterns, and transfusion needs. Therefore, transfusion in children should be individualized, considering the anemia etiology, symptom severity, and cardiopulmonary status rather than fixed hemoglobin thresholds [13,14].

Recent studies show that monitoring technologies such as near-infrared spectroscopy (NIRS), when combined with hemodynamic and biochemical parameters (e.g., lactate, base deficit, pH), can assess oxygen delivery and consumption more precisely [65]. This technology has been particularly valuable for

preterm neonates of very low birth weight, where assessments based solely on hemoglobin levels may be insufficient. In such cases, cerebral and somatic oxygenation status evaluated by NIRS has been reported to reflect hypoxia more accurately compared to hemoglobin-based assessments alone [66,67]. Hypothermia and acidosis, by impairing coagulation pathways and platelet function, contribute to bleeding and increased transfusion needs, especially in surgical cases or critically ill patients. Addressing these factors through normothermia and acid-base balance is therefore integral to PBM strategies [68].

Pediatric PBM strategies increasingly emphasize restrictive transfusion thresholds as a key component in optimizing transfusion practices. This approach is supported by multiple studies showing that restrictive strategies are at least as effective as liberal transfusion practices in critically ill neonates and children, with the added benefits of reduced exposure to transfusion-related risks [69,70,71].

A key source of guidance in this area is the Transfusion and Anemia Expertise Initiative (TAXI), which published a consensus statement in 2018 providing hemoglobin-based transfusion recommendations tailored to specific clinical scenarios. According to these recommendations, transfusion is not indicated for clinically stable critically ill children when hemoglobin is ≥5 g/dL, in cases of respiratory failure when hemoglobin is ≥5-7 g/dL, or in cases of hemorrhagic shock if hemoglobin is ≥7 g/dL. In contrast, for high-risk conditions such as acute brain injury or congenital heart disease, higher hemoglobin thresholds are recommended, typically ranging from 7 to 10 g/dL [72].

According to the TAXI guidelines, routine red blood cell transfusion is not recommended for hemodynamically stable pediatric patients with hemoglobin levels of ≥7 g/dL. Instead, these patients should undergo an etiology-focused evaluation, and if transfusion is deemed necessary, the target post-transfusion hemoglobin level should be 9.5 g/dL [72].

In older pediatric populations, the TAXI-CAB consortium has suggested that prophylactic platelet transfusion may be considered for critically ill children with thrombocytopenia secondary to bone marrow failure, malignancy, or hematopoietic stem cell transplantation when platelet counts fall below $10x10^9$/L. Additionally, it has been noted that prior to invasive procedures, transfusion may be recommended if the platelet count is below $20x10^9$/L, whereas for counts between $20x10^9$/L and $50x10^9$/L, evidence supporting a clear benefit of transfusion remains insufficient [73]. Threshold values for different clinical situations are summarized in Table 2.

In FFP transfusion, the decision-making process should not rely solely on laboratory parameters. Current recommendations emphasize that isolated values, such as the international normalized ratio, are insufficient for guiding transfusion decisions based on a fixed threshold. The clinical context must also be taken into account. In pediatric practice, FFP is primarily indicated for active bleeding in the setting of documented coagulation factor deficiencies, or prior to invasive procedures for patients with significant coagulopathy. Routine prophylactic use of FFP to correct mild laboratory abnormalities without clinical bleeding, or its use solely as a protein supplement in hypoalbuminemic states, is not recommended. In the absence of moderate or severe bleeding, the benefit of prophylactic FFP transfusion is considered limited in conditions such as acute liver failure, disseminated intravascular coagulation, sepsis, or major surgery [73].

Although no significant differences in clinical outcomes have generally been found between liberal and restrictive transfusion strategies, this does not indicate that the restrictive approach can be safely applied to all patient groups. In particular, there remains a need for advanced studies to establish safe hemoglobin thresholds in pediatric patients with active bleeding, hemodynamic instability, or a history of malignancy and hematopoietic cell transplantation.

Blood Management in Special Pediatric Populations

Neonates (Preterm Infants and NICU Patients)

Large-scale randomized controlled trials such as TOPS [74] and ETTNO [75] have supported the safety of restrictive red blood cell transfusion strategies in various clinical scenarios. Studies have shown that restrictive transfusion thresholds of 7-9 g/dL for stable, growing preterm infants and thresholds of 9-11 g/dL for critically ill or ventilated neonates are associated with outcomes comparable to liberal strategies. Similarly, British guidelines recommend a hemoglobin threshold of 7 g/dL for transfusion in stable, non-cyanotic pediatric patients [76]. These findings suggest that a hemoglobin threshold of 7 g/dL is safe and may significantly reduce transfusion requirements.

Restrictive strategies are now also being extended to other blood components. The multicenter PlaNeT-2 trial, conducted with preterm neonates, demonstrated that a lower prophylactic platelet transfusion threshold of $25x10^9$/L was safer than a higher threshold of $50x10^9$/L, significantly reducing bleeding, morbidity, and mortality [77].

In neonates, platelet transfusion thresholds vary according to the underlying clinical condition. In high bleeding-risk scenarios, such as patients on extracorporeal membrane oxygenation support or those requiring systemic anticoagulation, a threshold between $50x10^9$/L and $100x10^9$/L is generally recommended. In cases of intracranial hemorrhage, a target platelet count of >$100x10^9$/L is advised [77,78,79,80].

For cases of neonatal alloimmune thrombocytopenia, a more restrictive approach is typically used, with a threshold of $50x10^9$/L during the first week of life and $30x10^9$/L thereafter [81,82].

Hematology and Oncology Patients

Pediatric hematology and oncology patients frequently require transfusion support due to chemotherapy-induced cytopenia, bone marrow failure, or disease-related complications such as bleeding or anemia. Despite this, restrictive transfusion thresholds are increasingly emphasized to minimize transfusion-related complications such as alloimmunization, iron overload, and transfusion reactions. The American Association of Blood Banks and British guidelines suggest a restrictive red blood cell transfusion threshold of 7-8 g/dL in stable, non-bleeding patients, with individualized thresholds for symptomatic or hypoxic patients [76,83].

Platelet transfusions are often prophylactically administered in this population. A threshold of 10-$20x10^9$/L is commonly applied for stable patients, while higher thresholds of 30-$50x10^9$/L are applied for invasive procedures or active bleeding. In patients with fever, sepsis, or coagulopathy, platelet thresholds may need adjustment [76,84].

Pediatric Cardiac Surgery Patients

Cholette et al. [69] evaluated arteriocerebral oxygen content and lactate levels in 60 pediatric patients with cyanotic congenital heart disease who received postoperative red blood cell transfusions. No significant differences were found between the restrictive (hemoglobin of <9 g/dL) and liberal (≤13 g/dL) transfusion strategies in terms of these parameters. However, patients in the restrictive group received significantly fewer red blood cell transfusions (mean of 0.43 units vs. mean of 2.1 units) and had lower donor exposure. This supports the feasibility of restrictive transfusion practices in pediatric cardiac patients, warranting further studies to confirm their safety and efficacy.

Critically Ill Children in Intensive Care Units

Evidence from multicenter randomized controlled trials in pediatric critical care has consistently shown no additional benefit of liberal transfusion strategies compared to restrictive thresholds [70,71]. For example, a trial involving 637 hemodynamically stable critically ill children demonstrated that a liberal threshold (hemoglobin of ≥9.5 g/dL) offered no clinical advantage over a restrictive threshold (≥7 g/dL) [70,71]. Similarly, in pediatric patients with sepsis or septic shock, no significant differences were observed between liberal and restrictive strategies regarding multiorgan dysfunction, length of stay in the intensive care unit, or mortality [84]. These findings are consistent with adult data from the Transfusion Requirements in Septic Shock trial [86].

Reflecting this evidence base, the previously mentioned TAXI consensus provides hemoglobin-based recommendations tailored to specific clinical contexts, endorsing restrictive transfusion practices in most scenarios but allowing for higher thresholds in selected high-risk conditions [72].

Children with Bleeding Disorders

In children with inherited or acquired bleeding disorders (e.g., hemophilia, von Willebrand disease, platelet function disorders), PBM focuses on optimizing hemostasis through targeted factor replacement rather than empirical transfusions. Prophylactic or on-demand clotting factor concentrates such as FVIII, FIX, or von Willebrand factor (vWF) form the cornerstone of therapy [87,88].

Blood component therapy is reserved for situations such as major trauma or surgery, life-threatening bleeding unresponsive to factor concentrates, and rare bleeding disorders with no specific replacement product.

In hemophilia patients, non-factor therapies (e.g., emicizumab) and antifibrinolytics have also contributed to reduced transfusion needs by maintaining baseline hemostasis [89,90]. In addition, desmopressin (DDAVP) can be used in children with mild hemophilia A or type 1 von Willebrand disease to transiently increase factor VIII and vWF levels, further supporting hemostatic control in selected cases [87].

Importantly, minimizing iatrogenic blood loss, ensuring early diagnosis, and using point-of-care testing for coagulation assessment help reduce unnecessary transfusion exposure.

Multidisciplinary Approach and Clinical Implementation

Effective implementation of PBM in pediatric settings necessitates a well-coordinated multidisciplinary approach [91]. PBM teams typically include pediatricians, hematologists, anesthesiologists, surgeons,

nurses, and laboratory personnel, each contributing to anemia management, transfusion decision-making, intraoperative blood conservation, and postoperative monitoring [92]. The development of standardized clinical protocols is essential for the consistent application of PBM principles. However, implementation in pediatric practice presents unique challenges, including the lack of robust pediatric-specific evidence, limited awareness among healthcare providers, and the absence of institutional protocols tailored to children. Addressing the barriers will require institutional support, the integration of PBM into electronic health records, and comprehensive, team-based education to foster a culture of safe and individualized blood management in pediatric care. In Türkiye, significant steps have been taken to facilitate the clinical implementation of PBM through a joint project launched by the Ministry of Health and the European Union in 2019 and completed in 2022. Over this 3-year period, extensive training programs for clinicians were conducted, national PBM guidelines were published, and a decision-support software tool was implemented to assist healthcare professionals in evidence-based transfusion decision-making [12].

Future Perspectives

As pediatric PBM continues to evolve, future developments are expected to focus on precision medicine, technology integration, and system-wide implementation. One promising area is the application of artificial intelligence to support real-time clinical decision-making, allowing for individualized transfusion thresholds and more accurate predictions of bleeding risk. Additionally, advances in NIRS, transcutaneous hemoglobin sensors, and continuous viscoelastic assays will likely enhance physiological assessment and reduce the rate of unnecessary transfusions [93,94]. The development of age- and condition-specific PBM algorithms, supported by high-quality randomized controlled trials, remains a key research priority. Furthermore, integrating PBM principles into electronic health records, enhancing interdisciplinary education, and implementing standardized protocols will be essential to achieve widespread adoption in pediatric practice.

Conclusion

PBM for pediatric patients is not solely aimed at regulating transfusion practices; it constitutes a comprehensive patient-centered approach focused on improving patient safety and clinical outcomes. Recent studies have demonstrated that the effective management of preoperative anemia, reduction of intraoperative blood loss, and postoperative hematopoietic support can significantly reduce transfusion requirements. Moreover, the integration of restrictive transfusion thresholds, iron therapy, antifibrinolytic agents, cell salvage systems, and viscoelastic testing has further enhanced the effectiveness of PBM strategies. PBM has now evolved beyond strategies that merely aim to reduce transfusion needs to encompass the broader concept of blood health, which emphasizes the holistic preservation of circulatory system integrity.

In conclusion, although PBM has not yet been widely adopted in pediatric populations, the current literature supports its use as a safe, effective, and cost-efficient approach in children. The development of evidence-based transfusion thresholds, viscoelastic test-guided algorithms, and personalized applications tailored to neonates and children will facilitate the broader implementation of PBM in pediatric clinical practice and promote the more rational and efficient use of blood as a resource.

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Table 1. Strategies targeting the three core pillars of pediatric patient blood management.

1. Optimization of red cell mass	• Definition and detection of anemia according to age • Placental transfusion • Delayed cord clamping • Iron supplementation • Prophylactic iron in preterm and term infants • Nutritional deficiency: dietary recommendations and treatment • Detection and management of preoperative anemia (oral/parenteral) • Other types of nutritional anemia (e.g., B12, folate deficiency) • Use of ESAs • Reducing the need for exchange transfusion in neonatal jaundice • Use of IVIG if necessary • Intensive phototherapy		
2. Minimization of blood loss	**Blood conservation strategies** • Minimizing blood loss from phlebotomy • Use of non-invasive techniques and point-of-care testing devices • Autologous blood donation • ANH • Cell salvage	**Optimization of coagulation/hemostasis** • Preoperative planning for patients with known bleeding disorders • Use of hemostatic agents (antifibrinolytic agents, platelets, FFP, cryoprecipitate, fibrinogen, PCC, rFVIIa) in the prevention of bleeding	**Surgical and anesthesia techniques** • Appropriate surgical technique • Avoiding hypothermia • Viscoelastic testing • Use of topical hemostatic agents
3. Enhancement of the patient's physiological tolerance to anemia and optimization of transfusion practices	• Use of age-appropriate hematological parameters for neonates, infants, and children • Transfusion decisions based not only on hemoglobin levels but also on the patient's clinical status and underlying condition • Restrictive transfusion strategy • Maintaining a single-unit transfusion policy • Maintaining normothermia • Ensuring acid-base balance		
ESAS: Erythropoietin-stimulating agents; IVIG: intravenous immunoglobulin; ANH: acute normovolemic hemodilution; FFP: fresh frozen plasma; PCC: prothrombin complex concentrate; rFVIIa: recombinant factor VIIa.			

Table 2. Platelet transfusion thresholds for pediatric patients according to clinical indications [73,76].

Indication	Platelet threshold ($x10^9$/L)	Notes
Active bleeding	Depends on clinical context	Individualized based on severity and cause
Afebrile stable patient without bleeding	<10	Routine prophylaxis recommended to prevent spontaneous bleeding
Febrile, unstable, or sepsis	<20	Higher threshold due to increased bleeding risk
Prior to lumbar puncture	<50	Consider a higher threshold if technical difficulty or coagulopathy exists
Prior to major surgery	75-100	May be increased to ≥$100x10^9$/L for surgery at critical sites (central nervous system including eyes) or high-risk procedures
Non-tunneled central venous catheter insertion	<20	
Tunneled central venous catheter insertion	<50	
Bleeding during extracorporeal membrane oxygenation or during surgery	50-100	

Platelet dysfunction with active bleeding and/or need for invasive procedure	Not applicable	Platelet transfusion is based on function, not count alone
Hypoproliferative thrombocytopenia (no bleeding, stable)	10	May be increased to 15-20x10^{9}/L for hematopoietic stem cell transplantation