Blood loss due to injuries in children and its effect on the cardiovascular system

Pérdida de sangre por traumatismos en niños y su efecto sobre el sistema cardiovascular

Israil Dzhabaevich Shavkhalov, Saratov State Medical University, 137 Bolshaya Sadovaya Str., Saratov, 410000, Russia.
israil.gunoevskiy@mail.ru https://orcid.org/0009-0003-6322-4351
Dyshni Muslimovic Aliev, Saratov State Medical University, 137 Bolshaya Sadovaya Str., Saratov, 410000, Russia.
alievdyshni999@mail.ru. https://orcid.org/0009-0002-0106-9918
Alima Ismailovna Tekeeva, Russian University of Medicin, 4 Dolgorukovskaya str., Moscow, 127006, Russia.
atekeeva1q@mail.ru https://orcid.org/0009-0009-8705-0919
Elizaveta Ilinichna Osintseva, Children's City Polyclinic of the Moscow, 2/1 Novoorlovskaya str., Moscow, 119633, Russia.
elizaveta.osintseva2017@ya.eu https://orcid.org/0009-0006-9373-6413
Sayd-Zayn Khamzatovich Gadaev, North Ossetian State Medical Academy, 40 Pushkinskaya str., Vladikavkaz, 362025, Russia.
sayd.zayn@mail.ru https://orcid.org/0009-0003-6243-5755
Magomed Alievich Abduev, North Ossetian State Medical Academy, 40 Pushkinskaya str., Vladikavkaz, 362025, Russia.
magomed.abduyev@bk.ru https://orcid.org/0009-0001-6542-4424
Umar Uvaysovich Abazov, North Ossetian State Medical Academy, 40 Pushkinskaya str., Vladikavkaz, 362025, Russia.
abasovumar095@gmail.com https://orcid.org/0009-0001-1668-2064
Received: 10/20/2024 Accepted: 01/19/2025 Published: 02/12/2025 DOI: http://doi.org/10.5281/zenodo.14861199

Abstract

Blood loss in children is one of the key causes of complications in traumatic injuries and requires a special approach in diagnosis and treatment. Due to the age-related anatomical and physiological features of the child's body, such as a smaller volume of circulating blood, a high metabolic rate and immaturity of compensatory mechanisms, even moderate blood loss can lead to severe hemodynamic disorders.

The paper examines the pathophysiological changes in the cardiovascular system in acute blood loss in children, including a decrease in blood pressure, tachycardia, impaired organ perfusion and the development of hypovolemic shock. Special attention is paid to the critical temporal aspects of the diagnosis and implementation of infusion-transfusion therapy.

The authors analyze modern approaches to the treatment of pediatric patients with an emphasis on the need for an individual approach. The principles of selection of infusion media, transfusion preparations and volumes, as well as the use of modern methods of hemodynamic monitoring are described. A special place is given to the prevention of hypoxia and multiple organ failure.

The presented data emphasize the importance of early detection of blood loss and timely therapy to prevent severe complications and improve the prognosis in children.

Keywords: blood loss, children, cardiovascular system, injuries, hypovolemia, infusion-transfusion therapy, pediatrics.

Resumen

La pérdida de sangre en los niños es una de las principales causas de complicaciones en las lesiones traumáticas y requiere un enfoque especial en el diagnóstico y el tratamiento. Debido a las características anatómicas y fisiológicas relacionadas con la edad del cuerpo del niño, como un menor volumen de sangre circulante, una alta tasa metabólica y la inmadurez de los mecanismos compensatorios, incluso una pérdida de sangre moderada puede provocar trastornos hemodinámicos graves.

El artículo examina los cambios fisiopatológicos en el sistema cardiovascular en la pérdida de sangre aguda en niños, incluida la disminución de la presión arterial, la taquicardia, la alteración de la perfusión orgánica y el desarrollo de shock hipovolémico. Se presta especial atención a los aspectos temporales críticos del diagnóstico y la implementación de la terapia de infusión-transfusión.

Los autores analizan los enfoques modernos para el tratamiento de pacientes pediátricos con énfasis en la necesidad de un enfoque individual. Se describen los principios de selección de medios de infusión, preparaciones y volúmenes de transfusión, así como el uso de métodos modernos de monitorización hemodinámica. Se otorga un lugar especial a la prevención de la hipoxia y la insuficiencia orgánica múltiple. Los datos presentados destacan la importancia de la detección temprana de la pérdida de sangre y el tratamiento oportuno para prevenir complicaciones graves y mejorar el pronóstico en los niños.

Palabras clave: pérdida de sangre, niños, sistema cardiovascular, lesiones, hipovolemia, terapia de infusión-transfusión, pediatría.

Introduction

Blood loss due to injuries is one of the main causes of the development of critical conditions in children and requires special attention from medical personnel. Unlike adults, the child's body has a number of anatomical and physiological features that significantly affect the course of the pathological process and require an individualized approach to diagnosis and treatment[1]. Among these features, one can single out a smaller circulating blood volume (CBV), immaturity of the regulatory mechanisms of the cardiovascular system, increased tissue oxygen demand, as well as limited reserve capabilities of the body to compensate for hypovolemia.

Different types of injuries can cause bleeding of varying severity, due to the nature of the injuries and anatomical location. Damage to parenchymal organs such as the liver and spleen often leads to massive internal bleeding, which can be difficult to diagnose in the early stages. Given the high elasticity of the children's abdominal wall, clinical manifestations may be minimal until a critical condition develops.

Wounds that cause damage to blood vessels, internal organs, and soft tissues are accompanied by profuse external or internal bleeding. In such cases, the prognosis is determined by the speed of care and the replenishment of blood volume.

Fractures of large bones, such as the femur or pelvis, are often accompanied by significant blood loss. In children, due to the smaller volume of CBV, such injuries can quickly lead to hypovolemic shock. With TBI, the main threat is associated with intracranial pressure, ruptures of the vessels of the head can cause hemorrhages, worsening the general condition of the child.

Simultaneous damage to several anatomical areas, including a combination of fractures, injuries to the thoracic and abdominal organs, dramatically increases the risk of massive blood loss and requires an integrated treatment approach.

Even relatively small blood loss in children can lead to significant changes in hemodynamics, including a decrease in blood pressure, tachycardia, deterioration of peripheral perfusion and impaired oxygen delivery to vital organs. The rapid development of hypovolemic shock with significant blood loss makes timely detection and treatment of this condition critically important to prevent deaths.

The diagnosis of blood loss in children is complicated by the fact that the clinical manifestations may be hidden or develop gradually. For example, blood pressure

in children may remain stable in the early stages of hypovolemia due to compensatory mechanisms, which makes timely diagnosis difficult. However, when these mechanisms are depleted, the patient's condition may deteriorate dramatically.

Effective treatment of acute blood loss includes early diagnosis, replenishment of circulating blood volume and restoration of tissue perfusion. At the same time, the choice of infusion media, the use of blood components and hemodynamic monitoring should correspond to the age characteristics of the child. Additionally, prevention of complications such as hypoxia, acidosis, and multiple organ failure is important.

This study is aimed at analyzing the pathophysiological changes in blood loss in children, assessing the impact of these changes on the cardiovascular system, as well as considering modern approaches to the treatment of this condition.

Materials and methods

To collect data in the process of writing this paper, an analysis of case studies over the past few years has been conducted. In particular, a systematic review of scientific publications, textbooks, clinical guidelines and monographs on blood loss, traumatology and cardiovascular physiology in children was carried out. Modern research on methods of diagnosis and treatment of blood loss in children was also studied. The data obtained from various sources were summarized in order to identify the key features of the child's body that affect the course of traumatic blood loss. In addition, knowledge about the pathophysiological processes that occur during injuries and their relationship to the age-related features of the cardiovascular system has been synthesized.

Using classification and systematization methods, injuries sustained by children were classified according to their nature and severity and their effect on blood loss, as well as methods for diagnosing and treating blood loss in children, including infusion-transfusion therapy and hemodynamic monitoring.

Results

Blood loss in children is one of the leading causes of complications in traumatic injuries and poses a serious threat to life and health. Injuries accompanied by blood loss require immediate diagnosis and an individualized approach to treatment, which is associated with the unique anatomical and physiological characteristics of the child's body[2]. These features include lower circulating blood volume (CBV), increased metabolic rate, low functional reserve of the cardiovascular system, and immaturity of hypovolemia compensation mechanisms.

The authors of the tenth edition of the Advanced Trauma Life Support manual[3] presented criteria for a systemic response to assess the severity of blood loss in children (Table 1).

Table 1 Assessment of the severity of blood loss in pediatric patients

Severity of blood loss	Mild severity (less than 30% CBV)	Moderate severity (30-45% CBV)	Severe severity (more than 45% of CBV)
The cardiovascular system	Increased heart rate, weak, thready pulse in peripheral arteries, normal SAD and pulse pressure	Significant increase in heart rate, weak, thready pulse in the main arteries, absence of pulse in the peripheral arteries, decrease in pulse pressure	Tachycardia with transition to bradycardia, weak, thready pulse in the main arteries, absence of pulse in the peripheral arteries, decrease in SAD and pulse pressure (DBP is not detected!)
The central nervous system	Anxiety, agitation, disorientation	Lethargy, delayed response to pain	Coma
Skin	Cold, marbling, increased capillary filling time	Cyanosis, a significant increase in capillary filling time	Pale, cold
Diuresis	Low or very low	Oliguria	Anuria

The lower CBV in children compared to adults makes even moderate blood loss extremely dangerous. For example, the loss of 10% of the CBV in an adult may not cause significant changes in hemodynamics, whereas in a child this may already be accompanied by a decrease in blood pressure, tachycardia, and impaired organ perfusion. Taking into account the high metabolic activity of

tissues, the child's body is extremely sensitive to a decrease in oxygen delivery, which can lead to the rapid development of hypoxia[4].

The immaturity of compensatory mechanisms in children also plays a key role. In adults, the decrease in BCC is initially compensated by an increase in cardiac output, narrowing of peripheral vessels and redistribution of blood in favor of vital organs (brain, heart). In children, these mechanisms are not sufficiently developed, which limits their ability to maintain stable blood circulation during blood loss. As a result, the clinical manifestations of blood loss in children may be latent in the early stages, but with the depletion of compensatory capabilities, the condition quickly progresses to a critical one.

A particular threat is latent blood loss, which is characteristic of injuries to parenchymal organs (liver, spleen), abdominal injuries (intra-abdominal or intra-thoracic bleeding), as well as polytrauma. Given the anatomical elasticity of tissues in children, a significant amount of blood can accumulate in the abdominal or thoracic cavity, remaining unnoticed during the initial examination. This highlights the importance of using instrumental diagnostic methods such as ultrasound or computed tomography (CT) in addition to clinical examination[5].

Against the background of blood loss, a number of pathophysiological changes develop, especially in the cardiovascular system. The key factors are a decrease in the stroke volume of the heart, increased heart rate (tachycardia) and deterioration of peripheral perfusion. The progression of these changes without adequate treatment leads to hypovolemic shock, impaired oxygen metabolism and, eventually, multiple organ failure.

Effective treatment of blood loss in children requires an integrated approach. It is necessary to take into account age-specific features in the selection of infusion media, transfusion drugs and therapy volumes. At the same time, replenishing the volume of circulating blood is of paramount importance in order to restore adequate tissue perfusion[6]. Modern methods of infusion-transfusion therapy include the use of balanced crystalloids and colloids, as well as blood components (erythrocyte mass, freshly frozen plasma).

Timely detection of blood loss, monitoring of vital signs and adequate therapy can significantly reduce the risk of complications. However, it remains important to introduce new technologies, such as non-invasive hemodynamic monitoring, which can improve the diagnosis and treatment of blood loss in children.

Thus, blood loss due to injuries in children is a complex medical problem that requires an interdisciplinary approach involving pediatricians, traumatologists, and intensive care anesthesiologists. Only a comprehensive understanding of the pathophysiology, clinical manifestations, and therapeutic strategies can ensure effective treatment and prevent the development of severe complications.

In case of individual traumatic injuries, massive bleeding may occur in children[7]. Accordingly, if there is a suspicion that the child has received such injuries, the specialist should immediately take measures to stop the bleeding in order to eliminate the threat to the patient's life. The most dangerous injuries for children, accompanied by massive bleeding, are shown in Table 2.

Table 2 The most dangerous injuries for children, accompanied by massive bleeding

Type of injury	Injury description	Localization	Risk of bleeding	Features
Fractures of long bones	Fractures of the hip, shoulder, and lower leg can damage large vessels, especially in the hip and pelvis.	Hip, Shoulder, shin, pelvis	High	It can lead to significant blood loss due to damage to large vessels such as the femoral artery.
Traumatic brain injuries (TBI)	Head injuries can lead to rupture of cerebral vessels, which causes intracranial hemorrhages.	Head, brain	Medium - high (depending on the severity of the injury)	Increased intracranial pressure, possible development of hemorrhage and compression of the brain.
Blunt abdominal injuries	Damage to parenchymal organs (liver, spleen) causes internal bleeding, which is difficult to diagnose in the early stages.	Abdomen (liver, spleen, kidneys)	High	They can lead to hidden bleeding, and early diagnosis by ultrasound or CT is necessary.
Penetration wounds	Penetration into tissues and organs can damage blood vessels, causing external or internal bleeding.	Body (chest, abdomen, limbs)	Very high	Direct damage to blood vessels and organs; rapid deterioration of the condition, requires immediate intervention.
Fractures of the pelvic bones	Pelvic fractures are often accompanied by damage to large vessels and internal organs, which leads to massive bleeding.	Pelvis	Very high	Given the location of large vessels such as the internal and external iliac arteries, blood loss can be catastrophic.
Chest wounds	Chest wounds can damage blood vessels and lungs, causing hemopneumothorax and massive bleeding.	Chest (pleura, lungs)	Medium – high	With damage to the lungs and large vessels, acute bleeding develops rapidly.
Polytrauma	Combined injuries (damage to several organs and tissues at the same time) are often accompanied by massive blood loss, which requires emergency intervention.	The entire body surface	Very high	Simultaneous damage to several anatomical areas, which significantly increases the amount of blood loss.

The risks of blood loss in children depend on the type of injury, its location, the degree of damage to blood vessels and internal organs, as well as the age of the child, which has certain anatomical and physiological characteristics. With fractures of long bones, especially in the hip and pelvis, there is a risk of damage to large vessels such as the femoral artery. Even relatively moderate blood loss can lead to the rapid development of hypovolemia in children, since their circulating blood volume is significantly less than in adults[8], this increases the likelihood of shock, hemodynamic disorders, and the need for emergency surgery.

Traumatic brain injuries can lead to rupture of cerebral vessels, which causes intracranial hemorrhages. In this case, blood loss may be hidden, and clinical manifestations may not appear immediately, which makes diagnosis difficult. In the case of massive bleeding in the brain, increased intracranial pressure may occur, which worsens the patient's condition and requires immediate intervention to eliminate hematomas or control bleeding.

Abdominal injuries, especially damage to organs such as the liver and spleen, can cause profuse internal bleeding. It can be latent, especially in the early stages, and requires high-quality imaging for diagnosis, such as ultrasound or computed tomography. Blood loss from these injuries can be significant, which leads to a rapid deterioration of the child's condition. It is important to remember that blood loss from such organs can be progressive and last even after the initial assessment[9].

Penetration wounds, such as knife or gunshot wounds, can damage blood vessels and internal organs, causing external and internal bleeding. Such injuries are particularly dangerous because the damage can be extensive, and blood loss often requires immediate surgery to stop the bleeding. The risks associated with penetration wounds include not only blood loss, but also the development of infections, as well as possible damage to vital organs such as the heart, lungs, and liver.

Fractures of the pelvic bones are often accompanied by damage to large vessels, such as the internal iliac arteries. This leads to massive internal bleeding, which can be difficult to diagnose in the context of primary diagnosis. Blood loss from such injuries can quickly cause hypovolemic shock, especially in young children with limited compensatory abilities[10]. The need for emergency surgery to stop bleeding often occurs at the earliest stages of treatment.

Chest injuries, including wounds that can damage the lungs and blood vessels, cause hemopneumorex and internal bleeding. These injuries can lead to rapid loss of a significant amount of blood, which requires immediate intervention. Chest wounds can lead to respiratory disorders, a drop in blood pressure, and acute disorders of cardiovascular function, which makes blood loss especially dangerous for children[11].

Polytrauma involving damage to several organs and tissues at the same time significantly increases the risk of blood loss. Such injuries are often accompanied by extensive damage to blood vessels and internal organs, which can lead to significant blood loss, circulatory disorders and oxygen deficiency. In such cases, surgical intervention is important to stabilize the patient's condition, stop bleeding and restore normal hemodynamic condition.

The risk of blood loss in children directly depends on age, since the anatomical and physiological features of the body change with the growth and development of the child[12]. A smaller volume of circulating blood, immaturity of compensatory mechanisms, and differences in the ability to maintain normal blood pressure levels during blood loss make children more vulnerable than adults to the effects of traumatic blood loss.

For newborns and infants (0-2 years old), the volume of circulating blood is approximately 80-90 ml/kg of body weight, which is significantly less than in older children and adults. Their compensatory mechanisms, such as increased heart rate or vasoconstriction, are still poorly developed. The loss of only 5-10% of blood volume can lead to serious hemodynamic disorders such as tachycardia, hypotension, and microcirculation disorders[13]. For this reason, even moderate blood loss can be life-threatening, and emergency care is required to restore blood volume and maintain blood pressure.

In children of preschool and primary school age (3-7 years old), the volume of circulating blood is 75-80 ml/kg of body weight. Compensatory mechanisms are starting to work more effectively, but the child is still vulnerable, and the loss of 10-15% of blood volume can cause hemodynamic disorders. It is important to quickly restore the volume of circulating blood and support the cardiovascular system in order to prevent deterioration of the condition.

In schoolchildren (8-12 years old), the volume of circulating blood is about 75 ml/kg of body weight, which is close to the values in adolescents. At this age, the compensatory mechanisms are already sufficiently developed, and the body is able to tolerate moderate blood loss. However, the loss of more than 15% of blood volume can cause serious problems with the cardiovascular system, such as tachycardia and a decrease in blood pressure. Treatment in such cases will include both infusion therapy and monitoring of heart and vascular function[14].

For adolescents (13-18 years old), the volume of circulating blood is about 70-75 ml/kg of body weight, which corresponds to the level of adults. Their compensatory mechanisms are almost fully developed, and the body is able to effectively cope with blood loss of up to 20%. However, with more significant blood loss (more than 20-25% of the circulating blood volume), hypovolemic shock may occur, which requires emergency medical care and

restoration of blood circulation through blood transfusion and other intensive care methods[15].

Discussion

Acute blood loss in children causes complex pathophysiological changes in the cardiovascular system associated with a decrease in the volume of circulating blood. These changes can progress rapidly, leading to hypovolemic shock if timely measures are not taken. Let's consider the main pathophysiological changes that occur during acute blood loss in children, as well as critical aspects of diagnosis and infusion-transfusion therapy.

Blood loss reduces the total volume of circulating blood, which leads to insufficient perfusion of tissues and organs[16]. In children, due to their anatomical and physiological characteristics, this process occurs faster than in adults, since their blood volume is relatively small. As a result of a decrease in blood volume, the cardiovascular system tries to compensate for the deficit by increasing cardiac output, vasoconstriction, and increased heart rate. However, in the later stages of blood loss, there is a sharp decrease in blood pressure, which indicates a deterioration in the function of the cardiovascular system. This condition requires immediate intervention to prevent the development of hypovolemic shock[17].

One of the first compensatory mechanisms of the body is tachycardia, an increase in heart rate aimed at maintaining adequate cardiac output. Tachycardia can reach high levels, which is an attempt by the body to compensate for the loss of blood volume[18]. However, with increasing blood loss, tachycardia loses its effectiveness, and bradycardia and depression of cardiac activity may develop against the background of further deterioration of hemodynamics.

With a decrease in blood volume, and hence a decrease in blood pressure, there is a violation of perfusion of vital organs such as the heart, brain and kidneys. This can lead to oxygen starvation of cells and tissue damage. Organs with high metabolic activity, such as the brain and heart, are particularly vulnerable. Poor renal perfusion can lead to acute renal failure, and decreased brain perfusion can lead to neurological disorders.

If acute blood loss is not compensated, hypovolemic shock develops, which is characterized not only by a decrease in blood pressure, but also by a violation of microcirculation, which leads to insufficient oxygen delivery to tissues and organs[19]. Shock can be divided into several stages: compensated, decompensated, and terminal. In the terminal stage, without timely therapy, organ failure may develop and the patient may die.

Early diagnosis of acute blood loss is crucial for successful treatment. Signs of hypovolemia may include tachycardia, decreased blood pressure, pallor of the skin, delayed capillary filling, hypotension, decreased diuresis, and other symptoms. It is very important to quickly assess the degree of blood loss (mild, moderate, severe), which determines the choice of treatment methods. Methods such as monitoring of central venous pressure, ultrasound examination of organs, and blood tests, including hemoglobin levels and hematocrit, are used to diagnose an acute condition[20].

The basis for the treatment of acute blood loss is infusion therapy, aimed at restoring the volume of circulating blood. Crystalloid and colloidal solutions are used to quickly replenish the volume of circulating liquid. Crystalloids (for example, saline solution or Ringer's solution) are administered in the first stages of treatment, and colloidal solutions (albumin, dextrans) are used to improve blood volume maintenance in subsequent stages. It is important to monitor the patient's condition during infusion therapy to avoid overloading the blood circulation.

In case of severe blood loss, when the volume of circulating blood is significantly reduced, transfusion of blood or its components (erythrocyte mass, platelet mass, freshly frozen plasma) is necessary. The erythrocyte mass restores blood volume and improves oxygen capacity, platelets help with clotting disorders, and plasma restores the level of proteins and blood clotting factors[21].

An important component of treatment is constant monitoring of blood pressure, cardiac output, blood oxygen saturation, and diuresis. Lowering blood pressure below a critical level requires the immediate administration of drugs to increase vascular tone and stabilize cardiovascular function.

Modern approaches to the treatment of blood loss in children are based on multicomponent therapy, which requires careful individualization. When developing a treatment strategy, an important aspect is to take into account the characteristics of the child's age, weight, condition, degree of blood loss and the presence of concomitant diseases. The most important components of treatment are infusion therapy, transfusion therapy, hemodynamic monitoring and maintenance of physiological functions.

Individualization of therapy is crucial for effective treatment and prevention of complications with blood loss. Therapy should take into account several factors:

– the age and body weight of the child. Infants and low-weight children have significantly less circulating blood volume than older children and adults, so approaches to infusion therapy and transfusion treatment should take into account the weight and age of the child to accurately calculate the required volume of fluids and drugs.;

- the degree of blood loss. Depending on how large the blood loss is (mild, moderate, severe), different treatment approaches are selected. Moderate blood loss (up to 30% of the circulating blood volume) requires the administration of crystalloid solutions, while severe loss (more than 30%) may require not only volumetric infusion, but also transfusion of blood components.;

-the presence of concomitant diseases. In children with cardiovascular diseases, blood clotting disorders, or chronic conditions (such as anemia), treatment approaches may require more gentle and thoughtful tactics. In such cases, infusion therapy and transfusion should be strictly dosed[22].

In the treatment of acute blood loss, crystalloid solutions (e.g. saline, Ringer's solution, isotonic sodium chloride solution) are used for initial infusion therapy. Such solutions help to replenish the volume of fluid in the body and improve microcirculation. It is important to remember that they do not contain proteins and cells, so they do not restore blood volume, but only compensate for fluid deficiency[23].

Colloidal solutions (for example, albumin, dextran, hydroxyethyl starch) are used for longer-term restoration of circulating blood volume and improvement of colloidal osmotic pressure, which helps to retain fluid in the vascular bed. Colloids can be used for more severe blood loss (more than 20-30%) and if necessary, rapid recovery of blood volume.

In case of severe blood loss and a decrease in hemoglobin or hematocrit (usually after a loss of more than 30% of blood volume), transfusion of blood components is indicated. The erythrocyte mass is necessary to restore the oxygen capacity of the blood. Platelet mass is used for blood clotting disorders, in the case of thrombocytopenia[24]. Plasma is used to restore the level of proteins and coagulation factors, which is especially important in cases of severe hemostasis.

The selection of blood components should be based on the child's blood tests, as well as the degree of blood loss and the clinical situation. In some cases, when standard methods are ineffective, solutions containing artificial oxygen carriers (for example, hemoglobin solutions) can be used, which help improve oxygen delivery to tissues.

One of the most important aspects of the treatment of acute blood loss is constant monitoring of the patient's condition[25]. Modern methods of hemodynamic monitoring make it possible to accurately assess the effectiveness of therapy and adjust it in a timely manner. It is important to regularly measure blood pressure to assess the effectiveness of restoring blood volume and cardiovascular function. In case of low blood pressure, it is necessary to promptly intervene with the help of drugs that increase vascular tone.

Measuring central venous pressure helps to assess the volume of circulating blood and the state of venous return. This is an important indicator for monitoring the effectiveness of infusion therapy and preventing cardiac overload. Measuring oxygen saturation using pulse oximetry provides information about blood oxygen capacity and organ perfusion. At low oxygen saturation values, correction of respiratory function is required, which may include the use of oxygen therapy.

Capnography allows you to evaluate the effectiveness of breathing and ventilation. Measuring the level of carbon dioxide in exhaled air can help monitor the function of the respiratory system and identify respiratory disorders associated with hypovolemia and oxygen starvation of tissues[26]. The use of ultrasound, in particular, to assess the condition of organs and blood vessels, makes it possible to identify changes in blood circulation, including an assessment of cardiac output and heart function, as well as an assessment of the condition of the liver, kidneys and other organs at risk of blood loss.

Modern approaches to the treatment of blood loss in children require a comprehensive and individualized approach. The selection of infusion solutions and transfusion preparations, as well as constant monitoring of hemodynamics, make it possible to effectively restore the volume of circulating blood and maintain vital organ functions[27]. All these measures are aimed at stabilizing the patient's condition as soon as possible and preventing the development of severe complications such as hypovolemic shock and organ failure.

Prevention of hypoxia and multiple organ failure in acute blood loss in children is an important task in therapy, as these conditions significantly worsen the prognosis and can lead to irreversible organ damage. In conditions of significant blood loss, the child's body is susceptible to many dangers, including tissue hypoxia and multiple organ failure[28]. Prevention of these conditions requires an integrated approach, including measures to restore the volume of circulating blood, maintain normal tissue oxygenation and maintain the function of vital organs.

Hypoxia, that is, a lack of oxygen in the tissues, is one of the first and most dangerous complications of acute blood loss. Disruption of oxygen delivery to tissues can cause their damage and deterioration of organ function, which further leads to multiple organ failure.

One of the most important ways to prevent hypoxia is the early restoration of circulating blood volume using infusion therapy (crystalloids, colloids) and transfusion therapy (erythrocyte mass, plasma). With this, a normal blood volume is restored, which improves oxygen delivery to tissues and organs.

In hypoxia, it is important to ensure adequate tissue oxygenation. For this purpose, oxygen therapy is used, which can include both oxygen through a mask and invasive methods (for example, endotracheal intubation and artificial ventilation) in cases of severe respiratory disorders. Such methods help to ensure sufficient oxygen

saturation of the blood and minimize oxygen deficiency in the tissues[29].

Regular monitoring of blood oxygen levels using pulse oximetry and capnography helps to detect the deterioration of oxygenation in a timely manner, which allows doctors to adjust treatment and enhance oxygen support in case of deterioration.

If hypoxia is caused not only by blood loss, but also by a malfunction of the respiratory or cardiovascular systems (for example, with hypotension), it is necessary to correct these conditions with vasoconstrictor drugs, as well as drugs that support cardiac activity (for example, aminophilin or dobutamine).

Prevention of multiple organ failure should be aimed at maintaining the normal functioning of vital organs and tissues such as the heart, kidneys, liver and brain (Fig. 1).

Figure 1. Measures for the prevention of multiple organ failure

Prevention of multiple organ failure	Maintaining adequate blood pressure and cardiac output
	Organ function monitoring and early intervention
	Correction of coagulopathy and maintenance of normal hemostasis
	Monitoring of electrolyte levels and acid-base balance
	Prevention of sepsis and infections
	Maintaining adequate blood pressure and cardiac output

Maintaining normal blood pressure and cardiac output is crucial to prevent multiple organ failure. This is achieved through infusion therapy, as well as the administration of vasoconstrictor drugs (for example, norepinephrine, dopamine) to maintain vascular tone and normalize blood pressure.

For the prevention of multiple organ failure, constant monitoring of vital organs is necessary, including:

– monitoring of diuresis and creatinine levels for early detection of renal failure;

– regular check of transaminase and bilirubin levels to diagnose liver dysfunction;

– monitoring the state of the central nervous system using the Glasgow Scale and other indicators.

Early detection of disorders in these organs allows you to start treatment at an earlier stage, preventing the development of organ failure.

Multiple organ failure is often accompanied by impaired blood clotting. For the prevention of hemostasis disorders, drugs are used to normalize the coagulation system (for example, freshly frozen plasma or platelet mass). It is also important to monitor the level of fibrinogen and other markers of hemostasis for the prevention of DIC syndrome.

Acid-base balance disorders and electrolyte disturbances can cause organ dysfunction, especially of the heart and kidneys. Regular monitoring and correction of electrolyte levels (sodium, potassium, calcium, magnesium) and blood pH helps to prevent organ damage and improve the patient's condition.

One of the factors contributing to multiple organ failure may be the development of infection or sepsis. Timely administration of antibacterial therapy, as well as compliance with strict hygiene standards during invasive procedures, minimizes the risk of infectious complications.

It can be concluded that the prevention of hypoxia and multiple organ failure in acute blood loss in children requires an integrated approach and consideration of the characteristics of the child's body. Effective restoration of blood volume, adequate oxygen therapy, monitoring of organ function, maintenance of hemodynamics and correction of metabolic disorders play a crucial role in preventing complications. It is also important to follow an individual approach, taking into account age, body weight, degree of blood loss and concomitant diseases, in order to maintain physiological functions as effectively as possible and prevent severe consequences.

Conclusions

Acute blood loss is one of the main causes of severe complications of traumatic injuries in children. Due to the anatomical and physiological features of the child's body, such as a smaller volume of circulating blood and insufficient maturity of compensatory mechanisms, even moderate blood loss can quickly lead to serious hemodynamic disorders, hypovolemic shock and multiple organ failure.

With acute blood loss in children, significant pathophysiological changes occur, including a decrease in blood pressure, tachycardia, impaired organ perfusion, and the development of hypovolemic shock. These changes require rapid intervention, as they can lead to irreversible damage to organs and systems, especially in the long-term absence of adequate treatment.

Early diagnosis of blood loss and initiation of therapy in the first minutes are critical to prevent serious complications. Signs of blood loss, such as tachycardia, decreased blood pressure, decreased diuresis, and changes in consciousness, should alert doctors and require immediate intervention. Timely infusion and transfusion

therapy can prevent the development of hypovolemic shock, organ failure and improve the prognosis.

A key aspect of the treatment of blood loss in children is an individual approach that takes into account the age, body weight, health status of the child and the degree of blood loss. This allows you to accurately select the volume and composition of infusion solutions, as well as the required amount of transfusion preparations. Individualization of therapy also includes adjusting drug dosages and careful monitoring of the patient's condition during treatment.

Modern methods of hemodynamic monitoring, such as ultrasound diagnostics, impedance cardiography and other innovative technologies, open up new opportunities for more accurate assessment of the patient's condition and real-time treatment adjustments, which allows doctors to respond faster to changes in the condition and prevent severe consequences for the child's health.

To further improve the diagnosis and treatment of blood loss in children, it is necessary to develop new biomarkers for the early detection of even moderate forms of blood loss, as well as to develop more effective and safe methods for restoring circulating blood volume. It is important to continue to study the genetic aspects that can influence the body's response to blood loss, and to investigate the long-term effects of trauma and intensive care on the child's health.

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