Acute blood loss in children

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Hypovolaemia is the leading cause of circulatory failure in children. Effective fluid resuscitation is a mainstay of patient management and is dependent on accurate detection of blood loss or volume depletion. Calculation of blood volume in children is based on age, weight and clinical physiology and the estimation of the volume of blood lost requires interpretation of the history and orthostatic vital signs, especially heart rates. Administration of fluids following these calculations will also be discussed.

Introduction

The accurate and prompt assessment of children presenting to the hospital emergency department with haemorrhage is critical in determining the course of their clinical care and prognosis. In this setting, circulatory shock is a major cause of morbidity and mortality. [1] Hypovolaemia is the leading cause of circulatory failure in children. [2] Early and effective fluid resuscitation is a mainstay of patient management and is dependent on accurate detection of blood loss or volume depletion. While this is vital in hypovolaemic shock, it is preferable to detect changes in blood volume before clinical shock occurs. Here, methods for estimating children's blood volume, blood loss and methods for fluid resuscitation and maintenance will be discussed.

When referring to hypovolaemia it is important to distinguish between its respective components: volume depletion and dehydration. Volume depletion refers to a loss of volume from the extracellular space (intravascular and interstitial fluid). This can occur with diarrhoea, diuresis, gastrointestinal haemorrhage and vomiting. Dehydration describes a loss of intracellular water which elevates plasma sodium concentration and osmolality. [3]

Estimating fluid compartments

In adults, total body water comprises two thirds of body mass. Of this water, two thirds are in the intracellular space and one third is in the extracellular space.[4] Thus, a 70kg adult holds 45L of water with 30L of intracellular fluid and 15L of extracellular fluid. The extracellular fluid is further divided into 10L in the interstitial space and 5L intravascularly. Total blood volume circulating in the body is 7% of ideal body weight in adults. [5] There is a third space, also referred to as transcellular fluid. It is formed from the extracellular space and contains the cerebrospinal fluid, urine, fluid in the gut, fluid in ducts such as lymphatics and serous cavities.

Fluid distribution varies between age groups. Total body water of newborn infants is 75-80% of body weight, falling to 65-70% in one-to-twelve year olds and to adult levels of 55-60% after puberty. [6] Total blood volume (TBV) circulating is 7-9% in children, depending on age. [5] The following ranges can be used to estimate total blood volume in children: premature infants 89-105mL/kg, term newborns 82-86mL/kg and infants and preschool-aged children 73-82mL/kg. [7]

Estimating blood loss

Hypovolaemic shock

Hypovolaemic shock presents with tachypnoea, tachycardia, confusion, thready peripheral pulses, cool extremities, oliguria and hypotension. [8] It occurs as a result of loss of intravascular volume from blood, plasma (in burns or nephrotic syndrome), water and electrolytes (lost in diarrhoea, vomiting and diabetes). [8] Children

will initially compensate for shock by increasing heart rate to maintain cardiac output, and tachycardia is often the first measurable sign. [9] Uncompensated haemorrhagic shock leads to hypotension due to acute decrease in venous return [10] and thus in cardiac output. Depression of blood pressure reduces the carotid sinus baroreceptor inhibition of sympathetic activation to the cardiovascular system. This central compensatory mechanism leads to increased total peripheral vascular resistance, increased venous return and increased heart rate and contractility. [5,11] This range of sympathetic reflexes can maintain arterial pressure effectively for relatively large volume losses, even more so in infants and children in whom hypotension is a very late sign.

In addition to the sympathetic reflexes, compensatory mechanisms that restore blood volume include activation of the renin-angiotensin system and release of antidiuretic hormone. These cause arteriolar vasoconstriction as well as tubular sodium and chloride reabsorption which promote renal conservation of water and salt. [5] Finally, a shift of fluid from the interstitium to the intravascular space occurs which restores volume over a longer timeframe. [12]

Uncompensated hypovolaemic shock is a critical condition and evaluating acute blood loss prior to its onset can improve medical treatment. This can prove difficult since many clinical tests for blood loss are not well-proven or tested in large high-powered studies, particularly in paediatrics.

Techniques for measuring acute hypovolaemia

The clinical assessment of hypovolaemic shock in children can be difficult. Studies looking at objective measures are largely adult-based and volume depletion and physiological responses to hypovolaemia can be quite different in children. Large reviews of clinical studies in hypovolaemia have summarised evidence for the variety of clinical signs of blood or fluid loss. The most useful signs are severe postural dizziness or postural pulse increase of 30 beats per minute or more. Supine hypotension and tachycardia, which are frequently absent, carry a high specificity when present. Dry mucous membranes and a dry axilla have a low sensitivity but reliably high specificity. [19]

If the child is lucid or has a guardian present, often the simplest method of gauging blood and fluid loss is by enquiring about the mechanism and history of the injury. Additionally, whether the child was restrained and how, whether there was any loss of consciousness and whether the wound was weeping or gushing can assist the clinician in initial volume estimates. Other helpful questions include: when did s/he last keep something down? How many wet nappies has s/he had in the last

24 hours (infants aged up to 12 months will empty their bladder on average once an hour, decreasing to about ten times per day at three years) [13-15] and what was his/her weight at the last baby check?

Capillary refill

As a quick, easily obtained and non-invasive test, the capillary refill test on the sternum has gained popularity in clinical practice as part of the Trauma Score. It is generally advised that a refill time of two seconds or more is abnormal, despite a paucity of evidence. In the paediatric setting, Schriger and Baraff [16] tested healthy participants between two weeks and twelve years of age and demonstrated an upper limit of normal of 1.9 seconds, which confirms the accepted normal value. [17] Despite this, it is worth noting that in experiments on adults the sensitivity of the capillary refill test in patients with a history of hypovolaemia and abnormal orthostatic vital signs is 26%, and 46% in ED patients with frank hypotension. [18]

Fluid resuscitation

The first step in treatment of hypovolaemia and hypovolaemic shock is adequate fluid resuscitation with either a crystalloid or a colloid solution. [20] As previously mentioned, the emergency criteria for volume administration include orthostatic tachycardia, reduced urine output, hypotension and metabolic acidosis. These signs can be very late and initial resuscitation can easily be based on history alone.

The differences between crystalloid and colloid lie in their effects on the Starling equation, which describes fluid movement between intravascular and interstitial spaces. Starling stated that the rate of fluid movement into or out of a capillary depends on the net hydrostatic pressure minus the net colloid osmotic pressure. [21] While colloids are widely used in Europe for volume replacement, crystalloids are popular in the United States. [22] The merits of either are disputed [23,24] and will be discussed below.

Crystalloids can be considered in two groups: those that contain electrolytes in similar concentration to plasma (isotonic) and those that contain lower concentrations or no electrolytes (hypotonic) but contain glucose so that their osmolality matches that of plasma (see Table 1). Only isotonic crystalloids are used in the initial management of haemorrhagic shock. On administration they are redistributed into various body fluid compartments. After fifteen to thirty minutes only 25-30% of volume remains in the intravascular compartment. [4] This is particularly true of 5% glucose, of which less than 10% remains in the intravascular compartment after the glucose is metabolised. Hypertonic saline solution can range from 1.8% NaCl to 7.5% NaCl, the latter of which can expand intravascular volume by up to 1.5 litres in boluses of 250mL.

Table 1. *The relative compositions of crystalloid solutions. Glucose-containing solutions are used to treat dehydration as a result of water loss.*

Crystalloid	Na^+	K^+	Ca^{2+}	Cl^-	HCO_3^-	pH	Osmolality
Harmtmann's (isotonic)	131	5	4	112*	29	6.5	281
0.9% NaCl	154			154*		5.5	300
4% glucose + 0.18% NaCl	31			31		4.5	284
5% glucose						4.1	278
Hypertonic saline (1.8-7.5% NaCl)	Expand intravascular volume						

** Greater than plasma concentrations.*

Colloid solutions are made up of high molecular weight particles derived from gelatin (Haemaccel®, Gelofusine®), protein (albumin) or starch (HAES-steril®) and are rarely used in the initial emergency management of haemorrhagic shock. Colloids can be given in a similar volume to the estimated deficit (Table 2). [4] While albumin persists in the body for 20 days, its duration of action within the intravascular compartment varies from less than two hours to more than a day. Gelatins produce an intravascular volume expansion effect almost equivalent to albumin, with a duration of three to four hours. [22] There is no limit to volume which can be administered, provided haemoglobin levels are maintained.

Table 2. *The relative compositions of colloid solutions.*

Colloid	Avg MW	Na^+	K^+	Ca^{2+}	Cl^-	HCO_3^-	pH	Osmolality
Haemaccel	35	145	5	6.2	145		7.3	350
Gelofusine	35	154	0.4	0.4	125		7.4	465
Albumin	69	130-160	2		120		6.7-7.3	270-300
Starch	140-400	154			154		5.5	310

Unfortunately, colloids have been associated with a variety of adverse effects including anaphylactic reactions, risks of infection with albumin, and interference with accuracy of laboratory investigations. [25,26]

Evidence for their use

While physiological explanations for colloid superiority over crystalloids have been postulated, evidence does not support their superiority. [27] In a randomised controlled trial, So and colleagues [28] found isotonic saline to be as effective as 5% albumin in treating hypotension in preterm neonates. In older children, there are limited numbers of large randomised controlled trials on fluid management of acute blood loss. Paediatric care is largely based on the results of adult trials, where the evidence supports both solutions. Velanovich [29] conducted a meta-analysis in adults and found a 5.7% relative difference in mortality in favour of crystalloids. When data was pooled into studies using trauma or non-trauma patients, the overall treatment effect was better in crystalloids and colloids respectively. In comparison, a recent SAFE Study in Australia and New Zealand compared 4% albumin to isotonic saline for intravascular fluid resuscitation in 7,000 adult intensive care patients. The relative mortality risk for patients receiving albumin compared to saline was 0.99 (95% CI, 0.91-1.09), indicating similar survival for both treatments. [30]

Paediatric data in other forms of shock confirm the lack of supportive evidence for added benefit to resuscitation with either crystalloid or colloid solutions. Two trials in dengue shock syndrome demonstrated no clear benefits between dextran 70, 3% gelatin, Hartmann's solution and isotonic saline in pulse pressure recovery time or "any complication" of fluid therapy, although six children had allergic reactions after colloids. [31] The second study in moderately severe shock comparing Hartmann's solution, dextran 70 and 6% hydroxyethyl starch found a slightly increased risk of requirement for rescue colloid in Hartmann's solution. [32] As crystalloids are significantly cheaper and show no demonstrable benefit, the clinically rational approach to resuscitation following blood loss is resuscitation with a crystalloid solution.

Finally, blood and blood components can be used in fluid resuscitation and are a mainstay of acute blood loss therapy. Packed red blood cells are used in preference to whole blood because they consist of red cell concentrate with saline, adenine and mannitol which improves red cell survival and flow. Additionally, each unit contains the same red cell mass as one unit of whole blood at around half the volume and twice the haematocrit (50-70%) and raises an adult haemoglobin by 10g/L. [4,5] Transfusion of packed red blood cells is indicated for improving oxygen-carrying capacity and increasing blood volume. The decision to transfuse is based on responsiveness to two 20mL/kg boluses of crystalloid and is indicated to maintain appropriate end-organ perfusion. In the context of trauma and acute blood loss, haemoglobin levels are not used as a guide for when to use blood.

Fresh frozen plasma (FFP) is extracted from donated blood and one unit

(200-250mL) is from a single donation. [4] It contains normal levels of clotting factors and is used to correct clotting factor abnormalities which can occur secondary to large transfusion and dilution of a patient's own factors, especially Factor VIII and fibrinogen. Cryoprecipitate is formed from thawed FFP, which is centrifuged to remove plasma and hence contains high concentrations of FVIII and fibrinogen in a small volume. This reduced volume (15mL) allows more rapid replacement of these factors than a single unit of FFP (200mL), while reducing the risk of volume overload, which is important in a small-volume patient. [33]

Volume and rate of administration

Children have a larger surface area-to-volume ratio than adults and assuming a healthy cardiovascular system can tolerate larger volumes per kilogram of weight. [34] Current World Health Organisation guidelines instruct two boluses of 20mL/kg of Hartmann's solution or normal saline in hypovolaemic shock. They recommend a third bolus if no improvement (defined as "warmer hands, pulse slows and capillary return faster") before infusing 20mL/kg blood over 30 minutes. This differs from standard paediatric practice in developed countries that follow Australian Resuscitation Council and Australian Paediatric Life Support guidelines to deliver two boluses followed by blood transfusion.

There is scant evidence in children with hypovolaemia not due to septic shock about optimal volume to be used and the velocity of fluid delivery. Efficacy of fluid resuscitation depends on the compliance of the interstitial space, existing microvascular pressures and the permeability of the microvascular barrier. [20] The best two indicators of correct fluid intake are urine output and osmolarity. [35]

Conclusion

Acute blood loss in children can be a critical presentation in emergency departments. The management of these patients and prevention of their progression to hypovolaemic shock involves three major processes: the calculation of their blood volume, which depends on age and weight and clinical acumen; estimation of the volume of blood lost using a clinical history; and orthostatic vital signs, especially heart rate and administration of fluids. The differences in paediatric physiology demand extra attention and require different approaches in medical care.

Conflict of interest

None declared.

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