

REVIEWS

FLUID RESUSCITATION IN THE PREHOSPITAL SETTING

Nicholas J Larson, BA, NREMT¹; Connor Yarbrough, BS¹; Pang Nhia Khang, BS¹; Frederick B Rogers, MD, MS, MA, FACS¹; Benoit Blondeau, MD, MBA, FACS¹; David J Dries, MD, MSE, FACS, MCCM*¹

Author Affiliations: 1. Department of Surgery, Regions Hospital, Saint Paul, MN, USA.

*Corresponding Author: david.j.dries@healthpartners.com

Recommended Citation: Larson, N.J., Yarbrough, C., Khang, P.N., Rogers, F.B., Blondeau, B., & Dries, D.J. (2025). Fluid resuscitation in the prehospital setting. *International Journal of Paramedicine*. (9), 43-62. <https://doi.org/10.56068/HBEA1061>. Retrieved from <https://internationaljournalofparamedicine.com/index.php/ijop/article/view/3188>

Keywords: lactated ringer's, blood, normal saline, hypertonic saline, hypotonic saline, intravenous dextrose, emergency medical services, EMS, paramedicine

Received: July 23, 2024

Revised: September 3, 2024

Accepted: September 29, 2024

Published: January 15, 2025

Funding: External funding was not used to support this work.

Declaration of Interests: None.

Disclosures: None.

Acknowledgements: The authors would like to thank Jennifer Feeken, MLIS for assistance with the literature review.

Copyright © 2025 by the National EMS Management Association and the authors. This work is licensed under Creative Commons Attribution-NoDerivatives 4.0 International. To view a copy of this license, visit <https://creativecommons.org/licenses/by-nd/4.0/>.

ABSTRACT

Emergency Medical Services benefit from an increased number of higher-level personnel (Advanced Emergency Medical Technicians and Paramedics) responding to all calls that are trained to obtain intravenous access. Current Prehospital Trauma Life Support guidelines recommend all trauma patients receive intravenous access, as long as it does not delay transport to definitive care and as such it is essential for EMS clinicians to be conversant with situations which may require fluid resuscitation. These situations are especially common in rural or austere environments as long transport times require EMS clinicians to maintain adequate hemodynamics until arrival at a trauma center for definitive care. Historically, crystalloid solutions have been the mainstay of fluid resuscitation with Normal Saline or Lactated Ringer's solution being preferred. Despite the recent shift in best practices from aggressive fluid resuscitation to delayed, or significantly scaled back, fluid resuscitation in most trauma settings, it is essential for EMS clinicians to understand when fluid resuscitation is indicated, or, more importantly, contraindicated. EMS clinicians must be comfortable with the various fluids available to them in the field. This review provides an overview of the most common crystalloid fluids and blood component therapies which may be used for resuscitation in the prehospital setting.

INTRODUCTION

Unintentional injury is the leading cause of death in Americans aged 1-44 years (CDC, 2023). Hemorrhage is the leading cause of preventable death, accounting for 35% of all prehospital deaths resulting from trauma and 1.5 million fatalities each year (Chambers et al., 2019; Knight et al., 2023). In these patients, fluid or blood administration allows restoration of lost intravascular volume, maintenance of organ perfusion and reduction in mortality (Ramesh et al., 2019). At the most basic level, Emergency Medical Technicians (EMTs) are trained to treat life threatening hemorrhage and provide prompt transport to a trauma center for definitive care. However, Emergency Medical Services (EMS), particularly in urban settings, benefit from personnel with advanced training to initiate intravenous (IV) fluids, thus allowing for fluid resuscitation, when appropriate, prior to arrival at a trauma center (Patterson et al., 2022).

Prehospital fluid resuscitation has taken root in the absence of strong clinical evidence. Hébert et al., (2023) conducted a meta-analysis and found weak evidence suggesting there is no mortality difference when comparing delayed versus immediate fluid resuscitation. As more randomized controlled trials are published, we expect to see a shift in standard EMS care from aggressive prehospital fluid resuscitation to delayed or significantly scaled back fluid resuscitation in most settings of trauma. Nevertheless, there are situations where prehospital fluid resuscitation is not only appropriate but necessary to provide optimal care to the injured patient. Current Prehospital Trauma Life Support (PHTLS) guidelines suggest traumatically injured patients to receive vascular access as long as it does not delay transfer to definitive care, emphasizing that transport is more important than immediate fluid administration in most cases (NAEMT, 2023). In low resource settings where transport time from injury to definitive care is greater than one hour, obtaining vascular access is essential and should be initiated concurrently with transport as resources allow. In situations with extended transport times, the benefits of having vascular access to initiate fluids or blood likely outweigh the risk associated with the few minute delay that may be required to obtain access (Ramesh et al., 2019). This paper is an introduction to the most common crystalloid fluids and blood components which may be used for resuscitation in the prehospital setting. In it, we provide an easy-to-follow table to determine the appropriate fluid to administer in each situation. A list of important terms relating to fluid resuscitation and their definitions can be found in Table 1.

PHYSIOLOGY

Total body water or the portion of body composition made up by water is responsible for 50% to 60% of total body weight in humans. Extracellular Fluids account for one third of total body water, and 20% of total body weight. Intracellular fluids account for two thirds

Term	Definition
Anion	Negatively charged ion
Balanced Crystalloid	Crystalloid solution such as Lactated Ringer's with sodium, potassium, and chloride concentration similar to the extracellular fluid
Buffered Crystalloid	Crystalloid solution that will have minimal impact on the acid/base balance
Cation	Positively charged ion
Crystalloid	Aqueous solution that consists of water and other solutes that can dissolve through a semipermeable membrane
Extracellular Fluid	Fluid that exists outside the cells
Hypertonic	Solution has more solute than the cell- causes water movement from the cell and cell shrinkage
Hypotonic	Solution has less solute concentration than the cell- water movement into the cell causing swelling
Intracellular Fluid	Fluid that exists within the cell
Interstitial Fluid	Fluid in the space adjacent to the cells
Isotonic	Solution and cell have same solute concentration- no net water movement
Osmolality	Concentration of dissolved particles in one kilogram (mass based)
Osmolarity	Concentration of dissolved particles in one liter (volume based)
Osmosis	Movement of fluid through a semipermeable membrane from a high to low solute concentration
Osmotic Pressure	Minimum pressure that must be applied to a solution to halt the flow of solvent particles through a semipermeable cellular membrane
Tonicity	The ability of a solution to make water move into or out of a cell

Table 1. Important terms.

of total body water and approximately 40% of total body weight. The distribution of fluids within the body is not uniform between the sexes. In the average lean female, 45% of body weight is due to solids and 55% is due to fluids. In the average lean male, 40% of body weight is due to solids and 60% is due to fluids. This difference is important clinically as fluid resuscitation requirements differ between the sexes (Larson et al., 2024).

Total body water is shared between two fluid compartments: intracellular fluid and extracellular fluid. Intracellular fluid (ICF) is defined as the fluid that exists within the cells, while the extracellular fluid (ECF) is defined as all fluid that exists outside the cells. The ECF is further subcategorized into plasma and interstitial fluid, or the fluid that exists in the space adjacent to cells. The main electrolytes found in the ICF are potassium, the primary cation, and phosphate, the primary anion. Within the ECF, the primary cation is sodium, and the primary anion is chloride. The regulation of these ion concentrations and gradients allows for many physiologic events to occur, and inappropriate composition within fluid compartments may cause a variety of problems (Larson et al., 2024).

Both intracellular and extracellular osmotic pressure result from composition of ions in each fluid space. Osmotic pressure is defined as the minimum pressure that must be applied to a solution to halt the flow of solvent particles through a semipermeable cellular membrane (osmosis). Osmosis is dependent on the concentration of solute particles in a solution. The concentration of solute particles shifts as water flows from areas of low solute concentration, typically sodium (low osmolality), to areas of high solute concentration (high osmolality) to achieve osmotic equilibrium (Larson et al., 2024). Osmotic equilibrium is measured by osmolarity which is the concentration of dissolved particles within the plasma. This is not to be confused with tonicity, or the ability of a solution to make water move into or out of a cell. The various fluids used for resuscitation are classified by their tonicity. Solutions that are hypotonic favor the movement of water out of the vasculature into the intracellular space while those that are hypertonic favor movement of water into the intravascular space. Isotonic solutions mimic the concentration of solute within the body resulting in a third of the fluid administered contributing to intravascular volume expansion. Given that the purpose of fluid resuscitation is to increase intravascular volume, only the latter two solutions are appropriate for fluid resuscitation (Barlow et al., 2020).

Cardiac output is highly sensitive to changes in fluid volume and is defined as the amount of blood pumped by the heart in a given time, usually measured in liters/minute. It is calculated by multiplying the heart rate and the stroke volume (amount of blood ejected with each heartbeat). A primary goal of fluid resuscitation is to increase the rapidly declining cardiac output of the hypovolemic injured patient to maintain organ perfusion (Casey et al., 2018).

A variety of fluids are used to support resuscitation physiology in the prehospital setting. The majority of these fluids are crystalloid solutions, which are defined as an aqueous solution that consists of water and other solutes, such as sodium, chloride, potassium, and glucose (Rudloff & Hopper, 2021). In the context of prehospital fluid resuscitation, the most common crystalloid solutions are Lactated Ringer's, Normal Saline, Hypotonic Saline, Hypertonic Saline, and intravenous dextrose.

BALANCED CRYSTALLOIDS: LACTATED RINGER'S

Lactated Ringer's (LR) is one of the most commonly utilized crystalloid solutions for fluid resuscitation. LR is considered a balanced crystalloid solution due to its relatively isotonic levels of sodium and chloride, as well as small amounts of potassium, calcium, and lactate that closely resemble the extracellular fluid in humans. Due to its sodium lactate content, LR is the most physiologically adaptive of the fluids offered to patients and has fewer adverse effects on the acid-base balance compared to other crystalloid resuscitation fluids in use (Semler & Kellum, 2019). As a result, LR serves as an effective solution for increasing overall perfusion in patients by quickly filling the vasculature, while protecting the acid/base balance through the conversion of lactate to bicarbonate by the liver. It should be noted that many of the following studies do not exclusively look at LR, instead they broadly study the effects of balanced crystalloids which include LR, isolyte, plasmalyte, etc. However, given that LR is the primary balanced crystalloid mentioned in PHTLS, it will be the focus of this section, although further randomized trials are needed to definitely compare if outcomes differ between the balanced crystalloid solutions. (Curran et al., 2021; NAEMT, 2023)

LR is commonly utilized in the treatment of sepsis. When a pathogen infects an individual, it has the potential to substantially decrease blood pressure secondary to septic shock. This is a result of an upregulation in both the pro and anti-inflammatory pathways leading to an unregulated release of cytokines, mediators, and other pathogen-related molecules thereby inducing vasodilation, vascular leakage, clot formation, and other effects cumulatively resulting in reduced organ perfusion and death (Jarczak et al., 2021). EMS clinicians can recognize septic patients by observation of relevant signs and symptoms, such as dyspnea, altered mental status (hypoperfusion of the brain), fever, weakness, pallor, and hypotension which is indicative of the inflammatory response in sepsis or hypoperfusion brought on by septic shock (Olander et al., 2019). These symptoms, coupled with a presumed or confirmed infection, should create a high level of suspicion for sepsis. Current guidelines from the Surviving Sepsis Campaign recommend that patients experiencing septic shock be infused with at least 30 mL/kg of a balanced crystalloid within the first three hours of resuscitation (Evans et al., 2021). In the prehospital setting, any hypotensive patient with a suspicion of sepsis should be treated as if in septic shock to capitalize on the resuscitative benefit of early fluid administration. Currently, LR is preferred over normal saline in these scenarios as lactate serves as a buffer to limit progression of metabolic acidosis commonly seen in sepsis, however the quality of evidence behind this recommendation is very low and subsequent studies have emphasized a need for further large randomized controlled trials to validate these claims. (Beran et al., 2022; Evans et al., 2021)

Another common use of LR is to treat patients diagnosed with acute pancreatitis (AP). AP is a condition where the pancreas rapidly becomes inflamed due to pancreatic enzymes normally released into the digestive tract causing injury to the pancreas. AP exacerbates metabolic acidosis which may produce further inflammation (Rumbus et al., 2018). Patients presenting with severe left upper quadrant abdominal pain, fever, nausea, vomiting, abdominal distension, or tachycardia and common risk factors such as heavy alcohol or drug use, gallstones, smoking, hypercalcemia, or renal disease should be treated with a high suspicion of AP (Sun et al., 2022). LR should be utilized to mitigate acidosis and inflammation. A systematic review and meta-analysis concluded that patients

who received LR to manage AP demonstrated significantly decreased odds of developing SIRS at 24-hours (pooled OR 0.38, 95% CI 0.15-0.98, $P = 0.05$) compared to patients who received normal saline. Patients in the LR group also demonstrated a trend of lower mortality although this did not reach statistical significance, prompting the authors to call for further randomized controlled trials to explore this potential association (Iqbal et al., 2018). It is important to understand the presentation and treatment of this disease as 10-30% of patients will develop recurrent AP that may require transport by EMS (Sun et al., 2022).

LR is also a commonly used fluid to manage hypovolemia secondary to hemorrhage. Protocols for determining solutions given in the prehospital setting vary regionally. Guidelines from the Eastern Association for the Surgery of Trauma (EAST), published in 2009, recommend that balanced crystalloid solutions should not be used for patients who are within 30 minutes of travel to the nearest hospital (Cotton et al., 2009). The more recent Western Trauma Association (WTA) guidelines recommend that crystalloids should function to manage hypovolemia and maintain a systolic blood pressure of 80 mmHg for non-Traumatic Brain Injury (TBI) patients with transport times < 20 minutes, or a systolic blood pressure of > 100 mmHg in cases of suspected TBI or transport times longer than 20 minutes (Sperry et al., 2019). The WTA guidelines promote permissive hypotension in these non-TBI patients, which is restricting the amount of fluid given to maintain blood pressure at a level that is lower than is typically found.

Permissive hypotension is designed to achieve a balance between organ perfusion and the volume requirement of the patient, as well as avoid any adverse effects introduced by early, high dose, crystalloid resuscitation such as dilutional coagulopathy (Kudo et al., 2017). The largest downfall of permissive hypotension is the increased risk of hypoperfusion to vital organs, and most research on permissive hypotension has been in cases of penetrating trauma, leaving the question of its generalization to all trauma patients. The benefit of permissive hypotension in penetrating trauma is likely because increasing intravascular volume through aggressive fluid resuscitation may worsen hemorrhage in these patients by increasing intravascular pressure which is associated with a dilution of coagulation factors and an exacerbation of hemorrhage by disrupting clots. In a prospective study of 598 adults with penetrating torso trauma, patients treated with permissive hypotension had a survival rate of 70% compared to a 62% survival rate in patients who received immediate fluid resuscitation (Bickell et al., 1994). It should be noted that permissive hypotension is contraindicated in patients with TBI as it may increase mortality by more than two-fold (Spaite et al., 2017) due to inadequate cerebral perfusion leading to secondary brain injury. The 10th edition of PHTLS recommends fluid/blood administration to maintain a systolic blood pressure of at least 110 mmHg in patients with CNS injury to prevent secondary brain injury. In patients with class III/IV hemorrhagic shock, blood/fluids should be titrated to maintain a systolic blood pressure of 80 to 90 mmHg, and it should be understood that large volume fluid resuscitation is not a substitute for adequate control of the source of hemorrhage (Henry, 2018; NAEMT, 2023).

The use of LR is also indicated for patients with severe burns. Following thermal injury, vascular permeability will increase resulting in edema at the site of injury due to a fluid shift from the vasculature into the interstitial and intracellular compartments. In severe cases of shock with increased vascular permeability, this fluid shift may result in deterioration of cardiac output secondary to reduced intravascular volume. In these instances,

fluid resuscitation should be initiated as soon as possible to prevent the patient from progressing into hypovolemic shock (Rogenes & Moylan, 1976). The benefit of LR for these patients is twofold. First, it will treat hypovolemia due to the leakage of fluid from the vasculature, and second, it will replenish the serum sodium levels which decrease from the fluid shift to the extravascular space. Advanced Burn Life Support (ABLS) guidelines (ABA, 2023) recommend that EMS clinicians infuse the patient with burns clearly covering >20% of the Total Body Surface Area (TBSA). LR is given at a rate of 125 mL per hour in patients 5 years or younger, 250 mL per hour for patients between the ages of 6 and 12, and 500 mL per hour for those 13 years of age and older.

There are, however, cases where LR is not recommended in the prehospital setting. LR should be avoided in patients receiving blood products due to the possibility of clot formation through reversible binding to the citrate anticoagulant found in blood products (Cull et al., 1991). Normal saline should be preferred to LR in TBI patients due to higher relative osmolarity (Table 2). A meta-analysis of eight randomized controlled trials showed that TBI patients given normal saline had significantly lower mortality rates compared to those who received a balanced crystalloid solution (either Plasma-Lyte or LR) (Dong et al., 2022).

0.9% NORMAL SALINE

Normal saline (NS) is one of the primary fluids used in the prehospital setting alongside LR. NS is an isotonic solution with similar sodium and chloride composition to human plasma (Table 2). A common use for NS in the prehospital setting is in patients with TBI, with the severity of TBI categorized based on GCS score. About 10% of TBIs are severe (GCS scores between 3 and 8), another 10% moderate (GCS scores between 9 and 12), and the remaining 80% of TBIs are mild (GCS scores between 13 to 15) (Stiver & Manley, 2008). In the prehospital setting, the AVPU criteria (alert, verbal, pain [response], and unresponsive) is an attractive alternative to GCS that can be quickly done by even the most inexperienced EMS clinicians. While not as specific as GCS, AVPU does not specify eye, motor, and verbal scores, the AVPU criteria presents a similar ability to discriminate 48-

	Na+ (mmol/L)	Cl- (mmol/L)	K+ (mmol/L)	Ca ²⁺ (mmol/L)	Lactate (mmol/L)	Glucose (mmol/L)	pH	Osmolarity (calc, mOsm/L)	Tonicity
Plasma	140	100	4	5	1-2	0	7.35-7.45	275-290	N/A
0.45% NaCl	77	77	0	0	0	0	5.6	154	Hypotonic
0.9% NaCl	154	154	0	0	0	0	5.6	308	Isotonic
3% NaCl	513	513	0	0	0	0	5.8	1030	Hypertonic
Lactated Ringers	130	109	4	3	28	0	6.5	273	Isotonic
D5W	0	0	0	0	0	278	4.3	252	Clinically Hypotonic (due to rapid metabolism of dextrose)
D10W	0	0	0	0	0	556	4.3	505	Clinically Hypotonic (due to rapid metabolism of dextrose)
Plasma-Lyte A	140	98	5	0	0	0	7.4	294	Isotonic

Table 2. Characteristics of common fluids in the prehospital setting (Braun Medical, 2024.; Hospira, 2016; Singh et al., 2024; Pliakas, 2017; Hospira, 2009; Self et al., 2017; Baxter, n.d.).

hour mortality (AVPU: AUC 79.7% (95% CI 73.4–86.1), GCS: AUC 81.5% (95% CI 74.8–88.2)) while being significantly easier to use (Janagama et al., 2022). Table 3 shows an estimation of the GCS score associated with each AVPU criteria. In cases of TBI, NS is preferred over LR because of relatively higher osmolarity (Table 2). Administration of LR decreases plasma osmolarity resulting in cerebral edema and an increased ICP (Alvis-Miranda, Rubiano, et al., 2014). In TBI patients administered either NS or LR in the prehospital setting, LR was associated with increased mortality compared to NS (Alvis-Miranda, Castellar-Leones, et al., 2014; Zornow & Prough, 1995). Further, the addition of 5% dextrose (D5W) should be avoided due to the rapid metabolism of the dextrose resulting in what is essentially an accumulation of free water in the vasculature, increasing the ICP secondary to cerebral edema (Stiver & Manley, 2008).

Another use of NS in the prehospital setting is for crush injuries. A primary crush injury is a compression injury that causes reactive muscle or soft tissue swelling in the affected site. The cellular damage from mechanical compression causes release of intracellular contents resulting in an influx of fluid with associated swelling in the affected area. Crush injuries to the extremities may result in the development of compartment syndrome, where pressure builds in affected tissue, restricting blood flow, leading to ischemic tissue death. If crush injury affects the head, a neurological disturbance may occur due to the influx of fluid resulting in cerebral edema. Compartment injuries are most commonly encountered after natural disasters, such as earthquakes, or man-made disasters such as industrial accidents, or military conflicts where the patient may be pinned under a large volume of debris (Dimitriou, 2021). If left untreated without adequate fluid resuscitation, patients may develop a secondary injury, crush syndrome with muscle breakdown, also termed rhabdomyolysis, which is a series of metabolic changes associated with crush injury to affected skeletal muscle. This condition may cause renal failure from filtration of the released myoglobin (a protein found in muscle) by the kidneys. Clinical features of crush injuries may include traumatic asphyxia from the substantial increase in pressure within the chest and superior vena cava, hypovolemia, muscle paralysis, severe orthopedic injuries, tea colored urine due to myoglobin accumulation, sensory deficits, and myalgias (Long et al., 2023).

Initially, the patient with a crush injury may present with minimal symptoms, but it is important to be suspicious of evolving crush injuries. According to the National EMS Clinical Guidelines, a bolus of one liter of NS should be administered intravenously before the crushed body part is decompressed by first responders. After extrication of the affected patient, in adults 500 to 1000 mL/hr of NS should be administered during transfer to the nearest trauma center (NASEMSO, 2022). It is important to never give these patients LR as they often have high serum potassium levels due to the cellular damage in crushed tissues releasing potassium. Additional potassium contained in LR (Table 2) may result in new onset or worsening of hyperkalemia with cardiac rhythm changes (Rajasekaran et al., 2022).

The Association for the Advancement of Blood and Biotherapies (AABB) recommends that NS be the only solution used with blood components (Jorgenson, 2017). NS is also

TBI Severity	AVPU Score	Estimated GCS Score
Mild	Alert	15
Moderate	Verbal	12
Moderate	Pain	10
Severe	Unresponsive	5

Table 3. AVPU Scoring and its GCS Equivalent (Janagama et al., 2022).

the only fluid that should be administered for intravenous infusions and washing of red blood cells and platelets. The US Food and Drug Administration (FDA) has also certified a buffered crystalloid, Plasma-Lyte A, for usage with blood components (Table 2). However, Plasma-Lyte A is rarely utilized for this purpose due to cost and limited availability among EMS services compared to NS (Blumberg et al., 2018).

There are no absolute contraindications to the administration of NS in the prehospital setting and in most clinical situations administration of up to 1L of NS is unlikely to have adverse effects on patient hemodynamics but may help restore intravascular volume, increase end organ perfusion, and positively affect patient clinical status (Ley et al., 2011). Administration of >1L may negatively impact the acid/base balance by inducing hyperchloremic acidosis or contribute to dilutional coagulopathy (Cherkas, 2011), especially in those patients with reduced intravascular volume. When administering > 1L of NS, the benefits of restoring lost intravascular volume must be weighed against the risks described above, with consideration of a variety of factors such as time to definitive care, patient clinical status, patient ability to tolerate large volume fluid infusions, and so on.

HYPOTONIC SALINE

Hypotonic saline, most commonly 0.45% NaCl, contains half or less of the amount of sodium and chloride contained in NS (Table 2). As a result, infusion of Hypotonic Saline dilutes solute concentrations within circulating fluid, producing a net flow of fluid from the vasculature into the intracellular space. Therefore, this solution is most useful as a mechanism to replace fluids lost during states of cellular dehydration (Ernstmeier & Christman, 2021).

Dehydration may occur in patients via two mechanisms. The first mechanism is decreased fluid intake; the second mechanism is an increase in fluid loss. The most common signs and symptoms of dehydration seen by EMS are intense thirst, fatigue, dry mouth, lethargy, and headache (Shaheen et al., 2018). In these situations, obtaining an accurate history is most useful to determine if there is a high suspicion of dehydration. Hypotonic saline is an appropriate treatment for cellular dehydration due to stimulation of water movement to the intracellular space. EMS clinicians must be cautious of the amount of hypotonic saline administered as cerebral edema may arise from excess fluid transfer from the vascular compartment into the brain producing an elevated ICP secondary to cerebral edema (Tommasino, 2002).

Hypotonic fluids are contraindicated in patients who have experienced burns, hemorrhage, TBI, or have a history of heart failure, liver disease, or renal failure as hypotonic fluids may exacerbate hypovolemia in the vascular space by producing a net water flow from the vasculature into the intracellular space (Ernstmeier & Christman, 2021) which will elevate ICP due to cerebral edema.

HYPERTONIC SALINE

Another fluid used in the prehospital setting is hypertonic saline. This solution comes in many different sodium chloride concentrations, primarily 3%, 7.5%, and 23.4%. Hypertonic saline is a crystalloid solution composed of sodium and chloride at a higher concentration than plasma (Table 2). Its main function in the prehospital setting is to reduce elevated ICP (Fink, 2012).

Increased ICP is a potential consequence of TBI. Normal ICP is between 7 and 15 mmHg for adults, and increased ICP is associated with high mortality and poor neurological outcomes for affected patients (Canac et al., 2020; Smith, 2008). In the inpatient setting, when ICP rises in excess of 20 mmHg for longer than 5 minutes, hypertonic fluids should be started (Susanto & Riantri, 2022). In the prehospital setting, there is no way to definitively measure ICP without an intracranial monitor. However, there are clinical indicators that may raise suspicion of elevated ICP. These indicators include a GCS of 8 or less (unresponsive on AVPU criteria), absent pupillary response (unilateral or bilateral), hypertension (SBP \geq 160 mmHg), bradycardia ($<$ 60 bpm), decorticate or decerebrate posturing, and irregular respiration (NAEMT, 2023; Ter Avest et al., 2021) in conjunction with a suspected or confirmed TBI.

Hypertonic saline decreases ICP through two mechanisms. The first mechanism is through shrinking RBCs by producing a net flow of fluid to the extracellular space, allowing for greater venous drainage from the cranium, reducing cranial volume and ICP. The second mechanism is essential to ICP control in these patients. An increase of serum sodium concentration from administration of hypertonic saline results in an outflow of fluid from the brain to maintain osmotic equilibrium, subsequently reducing cerebral edema (Fink, 2012). Currently, there are no specific dose and concentration recommendations of hypertonic saline to reduce ICP in adults. Concentrations of hypertonic saline used for this purpose range from 3.0% to 23.4% at doses from 1.0 to 4.0 mL/kg (Shi et al., 2020). Rapid intermittent boluses of hypertonic saline present an alternative to the continuous infusions that have been traditionally used, while reducing the total amount of fluid administered and risk of electrolyte disturbances (Shi et al., 2020). There are no absolute contraindications for administration of hypertonic saline; however, care should be taken to avoid overshoot hyponatremia (serum sodium levels $>$ 145 mmol/L) (Qian, 2019).

INTRAVENOUS DEXTROSE

While not used for fluid resuscitation, intravenous dextrose in water is a common fluid used by EMS services to treat hypoglycemia, to dissolve IV medications, or to keep veins open (TKO/KVO) for future fluid administration. Intravenous dextrose in water is available in a variety of concentrations, most commonly 5%, 10%, 25%, and 50% (Pliakas, 2017). While it is an isotonic or hypertonic solution (depending on the concentration) in isolation, rapid metabolism of dextrose by the body increases free water in the vasculature making it a hypotonic solution not effective for fluid resuscitation (Saraghi, 2015). Further, the lack of electrolytes in IV dextrose (Table 2) makes large volume infusions impractical as any benefit provided would be offset by the resultant electrolyte abnormalities.

The most common use of IV dextrose by EMS clinicians is treatment of hypoglycemia in patients where administration of oral glucose is contraindicated. Clinically, a patient is hypoglycemic or meets reasonable suspicion for hypoglycemia when blood glucose levels are less than 60 mg/dL or the patient is a known diabetic presenting with altered mental status. When the patient is unconscious or unable to protect their airway, IV dextrose should be administered in stages until mental status improves or a maximal dose of dextrose is reached (25g in adults) (NASEMSO, 2022). Mental status change is the most important aspect of reassessment for these patients as the brain is the most sensitive or-

gan to changes in blood glucose levels. Dextrose 10% in water (D10W) is the preferred concentration for administration in urgent conditions. D10W may be administered to all patients regardless of age and does not carry the risk of local tissue damage from extravasation with water loss as seen with use of dextrose 50% in water (D50W).

However, should D10W not be available, the amount of dextrose in each IV concentration should be known to prevent hyperglycemia secondary to excess dextrose administration (Table 4). All patients requiring IV dextrose should be transported to the nearest hospital for evaluation.

Maximum adult dose of dextrose	Fluid type	Amount of fluid to be administered (mL)
25g	Dextrose 50%	50mL
25g	Dextrose 25%	100mL
25g	Dextrose 10%	250mL

Table 4. Maximum adult IV dextrose volumes (National Model EMS Clinical Guidelines, 2022).

Less common uses for IV dextrose in the prehospital setting are as a drug diluent and mechanism to maintain vein patency. Dextrose 5% in water (D5W) is a common drug diluent for the administration of various medications in the prehospital setting. Due to its lack of electrolytes, D5W can be particularly useful in patients where electrolyte disturbances are a concern. D5W may also be used to maintain vein patency at a “TKO” rate of 30mL/hr (NAEMT, 2023) which allows EMS clinicians to have constant venous access to patients where vein collapse might be a concern, allowing for the prompt administration of fluids.

Intravenous dextrose is contraindicated if the patient is hyperglycemic, as the additional dextrose given could exacerbate symptoms of hyperglycemia, or if the patient has an elevated ICP. Intravenous dextrose should be avoided in the setting of elevated ICP as it is essentially free water (hypotonic) and will produce cerebral edema, further elevating ICP.

DELETERIOUS EFFECTS OF CRYSTALLOIDS

In recent years there has been a growing understanding that aggressive crystalloid fluid resuscitation may have a deleterious effect on patients. In a retrospective study of 970 adult trauma patients, those who received five or more liters of crystalloids during resuscitation within the first 24 hours post-injury were 2.55 times more likely to die compared to those who received less than five liters of crystalloids (OR 2.55, 95% CI [1.38-4.72], $p=0.0029$). Further, five or more liters of crystalloid administered was associated with a significant increase in days on the ventilator (RR 2.31, 95% CI [1.81-2.96], $p<0.0001$) (D. G. Jones et al., 2018). A retrospective study of 3,137 trauma patients at a Level I trauma center from 2000-2008 investigated the effects of crystalloid infusions in elderly (70 years of age) and non-elderly (< 70 years of age) populations (Ley et al., 2011). The results showed that infusion of at least 1.5 liters of crystalloid was associated with significantly higher mortality rates in both elderly (OR 2.89, 95% CI [1.13-7.49], $p=0.027$) and non-elderly patients (OR 2.09, 95% CI [1.31-3.33], $p=0.002$), while those who received less than one liter of crystalloid did not have a significant increase in mortality. In the elderly population, infusion of three or more liters of a crystalloid solution was associated with a mortality 8.61 times that of patients receiving less than three liters of crystalloid (OR 8.61, 95% CI [1.55-47.75], $p=0.014$).

Large volume crystalloid infusions result in increased mortality as they may increase the rate of hemorrhage, dilute clotting factors, reduce the oxygen carrying capacity of the blood through hemodilution, and contribute to an increase in cellular edema and interstitial fluid at the microvascular level. LR is known to escalate the expression of inflammatory genes and increase expression of neutrophil adhesion molecules. In patients suffering from hemorrhagic shock, high dose crystalloid use has been shown to cause negative effects such as reduction in cardiac function, gastric dysmotility, pulmonary complications, and coagulopathy (Alam et al., 2004; Gump et al., 1968; Jaskille et al., 2004; D. G. Jones et al., 2018; Ley et al., 2011). Further, only 30% of the crystalloid infused will remain in the vasculature, resulting in a resuscitation requirement three times that of the estimated blood loss (EBL) (Kaur et al., 2011). As a result, ATLS and PHTLS guidelines have emphasized using limited crystalloid resuscitation to avoid the deleterious effects of crystalloids described above (Harada et al., 2017; NAEMT, 2023).

BLOOD COMPONENT THERAPY

In cases of hemorrhage, resuscitation with blood component therapy has been traditionally used in hospitals and by EMS services. Blood component therapy is the administration of the individual components of blood (plasma/platelets/red blood cells) separately. The Prospective Observational Multicenter Major Trauma Transfusion (PROMMTT) study (Holcomb et al., 2013) showed that a high plasma to RBC ratio and a high platelet to RBC ratio were independently associated with a lower 6-hour mortality with resuscitation. In other words, infusing a higher ratio of plasma/platelets to RBCs was associated with lower 6-hour mortality. Within the first 6 hours, patients who received a ratio <1:2 plasma or platelets to RBC had a 3 to 4 times greater mortality than patients who received a ratio of 1:1 of plasma or platelets to RBC. The Pragmatic Randomized Optimal Platelet and Plasma Ratios (PROPPR) trial (Holcomb et al., 2015) took the above approach a step further, investigating the safety and efficacy of a 1:1:1 transfusion ratio of components (plasma/platelets/red blood cells) compared to a ratio of 1:1:2 transfusion ratio for trauma patients. In 680 trauma patients who were expected to require large blood component transfusions, there was no appreciable difference in overall mortality at 24 hours or 30 days between the groups. Nonetheless, the 1:1:1 ratio group's hemostasis rate was higher and exsanguination in the first 24 hours after admission was significantly decreased, making the 1:1:1 ratio the standard for blood component therapy after trauma.

WHOLE BLOOD

Recently, there has been a push to have whole blood (WB), or blood that has not been separated into its components (plasma/platelets/red blood cells) as the mainstay for resuscitation. Compared to component therapy, studies show that WB reduces morbidity and mortality with less overall volume given (Jones et al., 2021). In 2020, Hanna et al. examined 8,494 patients who received transfusions of WB or component therapy, finding that WB was associated with reduced 24-hour mortality rates (17% vs. 25%; $p = 0.002$) and was independently associated with lower 24-hour mortality on regression analysis (OR 0.78, 95% CI [0.59-0.89], $p=0.006$). The WB group also had a significantly shorter hospital length of stay (9 days vs. 15 days; $p = 0.011$) (Hanna et al., 2020). Patients also benefit from WB transfusion due to a natural supply of coagulation factors, such as fibrinogen, fibronectin, and factors V, VII, VIII, and XIII. In contrast to WB, using component therapy for resuscitation requires the administration of plasma, cryoprecipitate, and packed RBCs

to provide the needed clotting factors. This requires clinicians using component therapy to strike a balance between hemostasis and the patient's fluid volume status. WB also carries less risk of infection and transfusion reactions due to recipient exposure to donor products (Jones et al., 2021).

There are two primary factors that must be considered before administering blood in the prehospital setting. First, are local laws and scope of practice determined by the governing agency for local EMS. While prehospital blood is carried by helicopter EMS services (HEMS) in all 50 states, as of August 2023 only 112 ground EMS agencies may administer blood (Holcomb et al., 2023). A second management issue is clinical need. While prehospital blood administration decreases mortality, it is essential that the decision to transfuse blood does not prolong the time to definitive care (Yazer et al., 2022). Patients who will benefit from blood transfusion are those with symptomatic bleeding, regardless of cause. Relevant symptoms include tachycardia, hypotension, and skin that is pale, cool, and clammy. In order of preference, if available, whole blood is preferred for resuscitation, followed by component therapy (plasma/platelets/red blood cells) in a 1:1:1 ratio, plasma and red blood cells in a 1:1 ratio, and finally plasma alone or red blood cells alone (Ravi & Puri, 2017).

Prehospital Trauma Life Support 10th edition recommends blood administration in the following situations of uncontrolled hemorrhage or CNS injury (Table 5). In situations of class I/II hemorrhagic shock where hemodynamics are relatively unchanged, vascular access should be obtained and kept patent through administration of fluid at a TKO/KVO rate of 30mL/hr. At this stage further fluid resuscitation is unnecessary. When a patient progresses to class III/IV hemorrhagic shock characterized by a heart rate >120 bpm with decreased blood pressure and increasing cognitive decline, blood should be administered, if available, in order of preference described above, or fluids should be initiated to maintain a systolic blood pressure of 80-90 mmHg (MAP of 60-65 mmHg). In situations of CNS injury, blood or fluids should be initiated to maintain a systolic blood pressure of at least 110 mmHg. It is important to maintain higher pressures in patients with CNS injuries to prevent secondary brain injury resulting from hypoperfusion (NAEMT, 2023; Spaite et al., 2017).

Injury type	Heart Rate (bpm)	Blood Pressure	CNS	Blood Loss	Fluids/Blood
Class I hemorrhagic shock*	<100	Normal	Slightly anxious	<15%	IV fluid at TKO/KVO rate of 30mL/hr
Class II hemorrhagic shock*	>100	Normal	Moderately anxious	15%-30%	IV fluid at TKO/KVO rate of 30mL/hr
Class III hemorrhagic shock*	>120	Decreased	Confused	30%-40%	Titrate fluid or add blood§ to maintain SBP 80-90 mmHg (MAP 60-65 mmHg)
Class IV hemorrhagic shock*	>140	Decreased	Lethargic	>40%	Titrate fluid or add blood§ to maintain SBP 80-90 mmHg (MAP 60-65 mmHg)
CNS Injury	<60	Increased	GCS<8, Unresponsive on AVPU criteria	N/A	Titrate fluid or add blood§ to maintain SBP 110 mmHg
*Management is for uncontrolled hemorrhage					
§In order of preference: 1) whole blood, 2) 1:1:1 blood component therapy, 3) 1:1 plasma/red blood cells, 4) plasma alone, 5) red blood cells alone, 6) NS/LR					

Table 5. Managing fluid resuscitation for uncontrolled hemorrhage or CNS injury (Prehospital Trauma Life Support, 2023; Ravi & Puri, 2017; Ter Avest et al., 2021).

CURRENT INNOVATIONS/FUTURE DIRECTIONS

It is well established that whole blood (WB) administration improves outcomes in those patients requiring large volume infusions due to hemorrhage, and while best practices within hospitals are shifting towards preferential administration of WB, the majority of ground EMS agencies do not carry any blood products (Hanna et al., 2020; Holcomb et al., 2023). Lessons can be learned from Maryland's prehospital low titer O + WB program (Levy et al., 2024), where they state sourcing their blood was the major barrier to implementation, with the program costing between \$46,250 and \$69,375 annually. On a large scale, greater integration of EMS into the local trauma systems may allow for a shared burden between EMS agencies and trauma centers both financially and logistically through storage and distribution of blood products. Future research may benefit from comparing hospital costs between those treated with prehospital WB and those who were not to provide financial incentive for trauma centers to get involved in prehospital WB programs. Current research conducted at a single center has established less red blood cell transfusion requirements for those given prehospital WB which may translate to lower cost, although this was not analyzed in the study (Guyette et al., 2022).

Another direction for future research is balanced crystalloids. Currently, LR serves as a common balanced crystalloid utilized both in-hospital and in the prehospital setting. However, a variety of balanced crystalloids exist, and minimal research has been done comparing the outcomes between them. Curran et al. (2021) conducted a systematic review and meta-analysis comparing outcomes between various balanced crystalloids and called for more randomized controlled trials studying these differences as the level of evidence currently in the literature is low. Beyond the different physiologic effects of these solutions, analysis comparing hospital outcomes and subsequent financial cost to the patient would be invariably useful to limit the physical and financial burden of medical care costs in the United States. Finally, on a national scale, EMS programs would benefit from a greater focus on evidence-based research by incorporating it into the training and continuing education requirements for all provider levels. Establishing performance improvement initiatives between EMS agencies and trauma centers may provide clinicians with the skills, infrastructure, and culture that promotes scholarly practice to ensure patients receive the highest quality of evidence-based care.

CONCLUSIONS

Lactated Ringer's will most commonly be used in those patients in class III or IV hemorrhagic shock as a mechanism to replace lost intravascular volume as a temporizing measure before blood products can be given. Further, in patients showing signs of infection (dyspnea, fever, pallor, hypotension) LR should be administered to capitalize on the resuscitation benefits seen with early fluid administration in patients in septic shock. Finally, in those patients presenting with recurrent acute pancreatitis, prehospital LR administration is indicated. Normal saline will most commonly be used in those patients with TBI to maintain adequate cerebral perfusion, or in crush injuries to compensate for the fluid shift intracellularly. Hypotonic saline will be used almost exclusively to treat intracellular dehydration, and hypertonic saline will be used almost exclusively to lower elevated ICP. Intravenous dextrose is not utilized for fluid resuscitation but will be used to treat the common problem of hypoglycemia in those patients where oral glucose is contraindicated. Blood products should be preferentially administered to those patients

with symptomatic bleeding (class III/IV hemorrhagic shock) or in those patients with CNS injury to maintain adequate cerebral perfusion. Whole blood is preferred, as it has been shown to have lower mortality rates when compared to component therapy. Should whole blood not be available, the order of preference for fluid administration in these situations are 1:1:1 blood component therapy, 1:1 plasma/red blood cells, plasma alone, red blood cells alone, or NS/LR (Hanna et al., 2020; Ravi & Puri, 2017) . Table 6 contains a summary of the most common prehospital fluids and their indications.

It is essential for EMS clinicians to understand the indications, and limitations of, fluid resuscitation in the prehospital setting. Fluid resuscitation should be used sparingly, and the best treatment for these patients is prompt transfer to definitive care. However, in low resource settings where transfer to definitive care may be significantly delayed, it is the responsibility of the clinician to be conversant with the most common fluids available to them in the field.

Drug	Indications	Contraindications
IV dextrose	<ul style="list-style-type: none"> • Blood glucose levels < 60 mg/dL • Altered mental status in a known diabetic • Use as a drug diluent • TKO rate to maintain vascular access 	<ul style="list-style-type: none"> • Head trauma (Increased ICP) • Hyperglycemia
Lactated Ringers	<ul style="list-style-type: none"> • Signs of infection (dyspnea, fever, pallor, hypotension) • Class III/IV hemorrhagic shock • Patient describes recurrent acute pancreatitis (upper abdominal/back pain) 	<ul style="list-style-type: none"> • Infusion of blood products • Suspected brain injury • Crush injury
Normal Saline	<ul style="list-style-type: none"> • Traumatic Brain Injury (TBI) • Crush Injury/Crush Syndrome 	<ul style="list-style-type: none"> • No absolute contraindications
Hypotonic Saline	<ul style="list-style-type: none"> • Dehydration 	<ul style="list-style-type: none"> • Suspected brain injury • Severe burns • History of heart failure, liver disease, or renal failure
Hypertonic Saline	<ul style="list-style-type: none"> • Increased Intracranial Pressure (ICP) 	<ul style="list-style-type: none"> • No absolute contraindications
Whole Blood or Component Therapy	<ul style="list-style-type: none"> • Symptomatic bleeding • Tachycardia, hypotension, skin that is pale; cool; diaphoretic • Class III/IV hemorrhagic shock • CNS injury 	<ul style="list-style-type: none"> • Administered as protocol allows

Table 6. Common prehospital fluids and their indications.

REFERENCES

ABA. (2023). Advanced burn life support course manual. *American Burn Association*. <https://ameriburn.org/wp-content/uploads/2019/08/2018-abls-providermanual.pdf>

Alam, H. B., Stanton, K., Koustova, E., Burris, D., Rich, N., & Rhee, P. (2004). Effect of different resuscitation strategies on neutrophil activation in a swine model of hemorrhagic shock. *Resuscitation*, 60(1), 91–99. <https://doi.org/10.1016/j.resuscitation.2003.08.006>

Alvis-Miranda, H. R., Castellar-Leones, S. M., & Moscote-Salazar, L. R. (2014). Intravenous fluid therapy in traumatic brain injury and decompressive craniectomy. *Bulletin of emergency and trauma*, 2(1), 3–14. <https://pmc.ncbi.nlm.nih.gov/articles/PMC4771253/>

- Alvis-Miranda, H. R., Rubiano, A. M. R., Puyana, J. C., Alcalá-Cerra, G., & Moscote-Salazar, L. R. (2014). Fluid therapy in neurotrauma: Basic and clinical concepts. *Reviews in Health Care*, 5(1), 7–22. <https://doi.org/10.7175/rhc.v5i1.636>
- Barlow, A., Barlow, B., Tang, N., Shah, B. M., & King, A. E. (2020). Intravenous fluid management in critically ill adults: A review. *Critical Care Nurse*, 40(6), e17–e27. <https://doi.org/10.4037/ccn2020337>
- Baxter. (n.d.). *Plasma-Lyte 148 (An electrolyte solution) injection/ Plasma-Lyte A (An electrolyte solution) injection*. https://www.baxter.ca/sites/g/files/ebysai1431/files/2018-11/Plasma-Lyte_EN.pdf
- Beran, A., Altorok, N., Srouf, O., Malhas, S.-E., Khokher, W., Mhanna, M., Ayes, H., Aladamat, N., Abuhelwa, Z., Srouf, K., Mahmood, A., Altorok, N., Taleb, M., & Assaly, R. (2022). Balanced crystalloids versus normal saline in adults with sepsis: A comprehensive systematic review and meta-analysis. *Journal of Clinical Medicine*, 11(7), Article 7. <https://doi.org/10.3390/jcm11071971>
- Bickell, W. H., Wall, M. J., Pepe, P. E., Martin, R. R., Ginger, V. F., Allen, M. K., & Mattox, K. L. (1994). Immediate versus delayed fluid resuscitation for hypotensive patients with penetrating torso injuries. *The New England Journal of Medicine*, 331(17), 1105–1109. <https://doi.org/10.1056/NEJM199410273311701>
- Blumberg, N., Cholette, J. M., Pietropaoli, A. P., Phipps, R., Spinelli, S. L., Eaton, M. P., Noronha, S. A., Seghatchian, J., Heal, J. M., & Refaai, M. A. (2018). 0.9% NaCl (normal saline) – Perhaps not so normal after all? *Transfusion and Apheresis Science*, 57(1), 127–131. <https://doi.org/10.1016/j.transci.2018.02.021>
- Braun Medical. (2024). Sodium chloride injection, solution. *B. Braun Medical, Inc.* <https://dailymed.nlm.nih.gov/dailymed/fda/fdadrugxsl.cfm?setid=f2475fa3-ab1d-4b81-8127-b58cd0790a54&type=display>
- Canac, N., Jaleddini, K., Thorpe, S. G., Thibeault, C. M., & Hamilton, R. B. (2020). Review: Pathophysiology of intracranial hypertension and noninvasive intracranial pressure monitoring. *Fluids and Barriers of the CNS*, 17(1), 40. <https://doi.org/10.1186/s12987-020-00201-8>
- Casey, J. D., Brown, R. M., & Semler, M. W. (2018). Resuscitation fluids. *Current Opinion in Critical Care*, 24(6), 512–518. <https://doi.org/10.1097/MCC.0000000000000551>
- CDC. (2023). Injuries and violence are leading causes of death. *Centers for Disease Control Injury Center*. <https://www.cdc.gov/injury/wisqars/animated-leading-causes.html>
- Chambers, J. A., Seastedt, K., Krell, R., Caterson, E., Levy, M., & Turner, N. (2019). Stop the bleed: A U.S. military installation's model for implementation of a rapid hemorrhage control program. *Military Medicine*, 184(3–4), 67–71. <https://doi.org/10.1093/milmed/usy185>
- Cherkas D. (2011). Traumatic hemorrhagic shock: advances in fluid management. *Emergency medicine practice*, 13(11), 1–20. <https://pubmed.ncbi.nlm.nih.gov/22164397/>
- Cotton, B. A., Jerome, R., Collier, B. R., Khetarpal, S., Holevar, M., Tucker, B., Kurek, S., Mowery, N. T., Shah, K., Bromberg, W., Gunter, O. L., & Riordan, W. P. (2009). Guidelines for prehospital fluid resuscitation in the injured patient. *Journal of Trauma: Injury, Infection & Critical Care*, 67(2), 389–402. <https://doi.org/10.1097/ta.0b013e3181a8b26f>
- Cull, D. L., Lally, K. P., & Murphy, K. D. (1991). Compatibility of packed erythrocytes and Ringer's lactate solution. *Surgery, gynecology & obstetrics*, 173(1), 9–12. <https://pubmed.ncbi.nlm.nih.gov/1866680/>

- Curran, J. D., Major, P., Tang, K., Bagshaw, S. M., Dionne, J. C., Menon, K., & Rochweg, B. (2021). Comparison of balanced crystalloid solutions: A systematic review and meta-analysis of randomized controlled trials. *Critical Care Explorations*, 3(5), e0398. <https://doi.org/10.1097/CCE.0000000000000398>
- Dimitriou, N. (2021). Basics of trauma management: Crush injuries. *Emergency Medicine, Trauma and Disaster Management*, 299–309. https://doi.org/10.1007/978-3-030-34116-9_22
- Dong, W.-H., Yan, W.-Q., Song, X., Zhou, W.-Q., & Chen, Z. (2022). Fluid resuscitation with balanced crystalloids versus normal saline in critically ill patients: A systematic review and meta-analysis. *Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine*, 30(1). <https://doi.org/10.1186/s13049-022-01015-3>
- Ernstmeyer, & Christman. (2021, July 27). Intravenous Solutions. *Medicine LibreTexts*. [https://med.libretexts.org/Bookshelves/Nursing/Nursing_Fundamentals_\(Open-RN\)/15%3A_Fluids_and_Electrolytes/15.03%3A_Intravenous_Solutions](https://med.libretexts.org/Bookshelves/Nursing/Nursing_Fundamentals_(Open-RN)/15%3A_Fluids_and_Electrolytes/15.03%3A_Intravenous_Solutions)
- Evans, L., Rhodes, A., Alhazzani, W., Antonelli, M., Coopersmith, C. M., French, C., Machado, F. R., McIntyre, L., Ostermann, M., Prescott, H. C., Schorr, C., Simpson, S., Wiersinga, W. J., Alshamsi, F., Angus, D. C., Arabi, Y., Azevedo, L., Beale, R., Beilman, G., ... Levy, M. (2021). Surviving sepsis campaign: International guidelines for management of sepsis and septic shock 2021. *Critical Care Medicine*, 49(11), e1063. <https://doi.org/10.1097/CCM.0000000000005337>
- Fink, M. E. (2012). Osmotherapy for intracranial hypertension: Mannitol versus hypertonic saline. *Continuum*, 18(3), 640–654. <https://doi.org/10.1212/01.CON.0000415432.84147.1e>
- Gump, F. E., Butler, H., & Kinney, J. M. (1968). Oxygen transport and consumption during acute hemodilution. *Annals of surgery*, 168(1), 54–60. <https://doi.org/10.1097/00000658-196807000-00006>
- Guyette, F. X., Zenati, M., Triulzi, D. J., Yazer, M. H., Skroczyk, H., Early, B. J., Adams, P. W., Brown, J. B., Alarcon, L., Neal, M. D., Forsythe, R. M., Zuckerbraun, B. S., Peitzman, A. B., Billiar, T. R., & Sperry, J. L. (2022). Prehospital low titer group O whole blood is feasible and safe: Results of a prospective randomized pilot trial. *Journal of Trauma and Acute Care Surgery*, 92(5), 839–847. <https://doi.org/10.1097/ta.0000000000003551>
- Hanna, K., Bible, L., Chehab, M., Asmar, S., Douglas, M., Ditillo, M., Castanon, L., Tang, A., & Joseph, B. (2020). Nationwide analysis of whole blood hemostatic resuscitation in civilian trauma. *The Journal of Trauma and Acute Care Surgery*, 89(2), 329–335. <https://doi.org/10.1097/TA.0000000000002753>
- Harada, M. Y., Ko, A., Barmparas, G., Smith, E. J. T., Patel, B. K., Dhillon, N. K., Thomsen, G. M., & Ley, E. J. (2017). 10-Year trend in crystalloid resuscitation: Reduced volume and lower mortality. *International Journal of Surgery*, 38, 78–82. <https://doi.org/10.1016/j.ijssu.2016.12.073>
- Hébert, S., Kohtakangas, E., Campbell, A., & Ohle, R. (2023). The efficacy of prehospital IV fluid management in severely injured adult trauma patients: A systematic review and meta-analysis. *Canadian Journal of Emergency Medicine*, 25(3), 200–208. <https://doi.org/10.1007/s43678-023-00447-9>
- Henry, S. (2018). *ATLS advanced trauma life support 10th edition student course manual*. ACS American College of Surgeons.

- Holcomb, J. B., Bank, E. A., Leppeke, S. N., Mendelsohn Stone, L., Krohmer, J., Schaefer, R., Homer, M. J., Flanagan, C., & Skillman, B. (2023, August 9). *Prehospital Blood Transfusion Initiative Coalition*. Presented to the National EMS Advisory Council.
- Holcomb, J. B., del Junco, D. J., Fox, E. E., Wade, C. E., Cohen, M. J., Schreiber, M. A., Alarcon, L. H., Bai, Y., Brasel, K. J., Bulger, E. M., Cotton, B. A., Matijevic, N., Muskat, P., Myers, J. G., Phelan, H. A., White, C. E., Zhang, J., Rahbar, M. H., & PROMMTT Study Group. (2013). The prospective, observational, multicenter, major trauma transfusion (PROMMTT) study: Comparative effectiveness of a time-varying treatment with competing risks. *JAMA Surgery, 148*(2), 127–136. <https://doi.org/10.1001/2013.jamasurg.387>
- Holcomb, J. B., Tilley, B. C., Baraniuk, S., Fox, E. E., Wade, C. E., Podbielski, J. M., del Junco, D. J., Brasel, K. J., Bulger, E. M., Callcut, R. A., Cohen, M. J., Cotton, B. A., Fabian, T. C., Inaba, K., Kerby, J. D., Muskat, P., O’Keefe, T., Rizoli, S., Robinson, B. R. H., ... PROPPR Study Group. (2015). Transfusion of plasma, platelets, and red blood cells in a 1:1:1 vs a 1:1:2 ratio and mortality in patients with severe trauma: The PROPPR randomized clinical trial. *JAMA, 313*(5), 471–482. <https://doi.org/10.1001/jama.2015.12>
- Hospira. (2009). 0.45% Sodium Chloride irrigation, USP. *Hospira, Inc.* <https://labeling.pfizer.com/ShowLabeling.aspx?id=4616>
- Hospira. (2016). Dextrose monohydrate injection, solution. *Hospira, Inc.* <https://labeling.pfizer.com/ShowLabeling.aspx?id=4420>
- Iqbal, U., Anwar, H., & Scribani, M. (2018). Ringer’s lactate versus normal saline in acute pancreatitis: A systematic review and meta-analysis. *Journal of Digestive Diseases, 19*(6), 335–341. <https://doi.org/10.1111/1751-2980.12606>
- Janagama, S. R., Newberry, J. A., Kohn, M. A., Rao, G. V. R., Strehlow, M. C., & Mahadevan, S. V. (2022). Is AVPU comparable to GCS in critical prehospital decisions? - A cross-sectional study. *The American Journal of Emergency Medicine, 59*, 106–110. <https://doi.org/10.1016/j.ajem.2022.06.042>
- Jarczack, D., Kluge, S., & Nierhaus, A. (2021). Sepsis—Pathophysiology and therapeutic concepts. *Frontiers in Medicine, 8*, 628302. <https://doi.org/10.3389/fmed.2021.628302>
- Jaskille, A., Alam, H. B., Rhee, P., Hanes, W., Kirkpatrick, J. R., & Koustova, E. (2004). D-Lactate Increases Pulmonary Apoptosis by Restricting Phosphorylation of Bad and eNOS in a Rat Model of Hemorrhagic Shock. *The Journal of Trauma: Injury, Infection, and Critical Care, 57*(2), 262–270. <https://doi.org/10.1097/01.ta.0000133841.95455.73>
- Jones, A. R., Miller, J. L., Jansen, J. O., & Wang, H. E. (2021). Whole blood for resuscitation of traumatic hemorrhagic shock in adults. *Advanced Emergency Nursing Journal, 43*(4), 344–354. <https://doi.org/10.1097/TME.0000000000000376>
- Jones, D. G., Nantais, J., Rezende-Neto, J. B., Yazdani, S., Vegas, P., & Rizoli, S. (2018). Crystalloid resuscitation in trauma patients: Deleterious effect of 5L or more in the first 24h. *BMC Surgery, 18*, 93. <https://doi.org/10.1186/s12893-018-0427-y>
- Jorgenson, M. (2017). *Administration of Blood Components*. In M. Fung, A. Eder, S. Spitalnik, & C. Westhoff (Eds.), *Technical Manual* (19th ed.). Association for the Advancement of Blood and Biotherapies.
- Kaur, P., Basu, S., Kaur, G., & Kaur, R. (2011). Transfusion protocol in trauma. *Journal of Emergencies, Trauma, and Shock, 4*(1), 103–108. <https://doi.org/10.4103/0974-2700.76844>
- Knight, C. D., Bebarta, V., Meledeo, M. A., Ross, E., Wu, X., Bynum, J., Schauer, S., Getz, T., & April, M. (2023). A narrative review of prehospital hemorrhagic shock treatment with non-blood product medications. *Transfusion, 63*(S3). Portico. <https://doi.org/10.1111/trf.17324>

- Kudo, D., Yoshida, Y., & Kushimoto, S. (2017). Permissive hypotension/hypotensive resuscitation and restricted/controlled resuscitation in patients with severe trauma. *Journal of Intensive Care*, 5(1), 11. <https://doi.org/10.1186/s40560-016-0202-z>
- Larson, N. J., Rogers, F. B., Feeken, J. L., Blondeau, B., & Dries, D. J. (2024). Electrolyte disorders: Causes, diagnosis, and initial care-Part 1. *Air Medical Journal*, 43(2), 80–83. <https://doi.org/10.1016/j.amj.2024.01.001>
- Levy, M. J., Garfinkel, E. M., May, R., Cohn, E., Tillett, Z., Wend, C., Sikorksi, R. A., Troncoso, R., Jenkins, J. L., Chizmar, T. P., & Margolis, A. M. (2024). Implementation of a prehospital whole blood program: Lessons learned. *Journal of the American College of Emergency Physicians Open*, 5(2), e13142. <https://doi.org/10.1002/emp2.13142>
- Ley, E. J., Clond, M. A., Srour, M. K., Barnajian, M., Mirocha, J., Margulies, D. R., & Salim, A. (2011). Emergency department crystalloid resuscitation of 1.5 L or more is associated with increased mortality in elderly and nonelderly trauma patients. *The Journal of Trauma*, 70(2), 398–400. <https://doi.org/10.1097/TA.0b013e318208f99b>
- Long, B., Liang, S. Y., & Gottlieb, M. (2023). Crush injury and syndrome: A review for emergency clinicians. *The American Journal of Emergency Medicine*, 69, 180–187. <https://doi.org/10.1016/j.ajem.2023.04.029>
- NAEMT. (2023). *Prehospital Trauma Life Support* (10th ed.). National Association of Emergency Medical Technicians.
- NASEMSO. (2022). National Model EMS Clinical Guidelines. *National Association of State EMS Officials*. https://nasemso.org/content.aspx?page_id=22&club_id=157064&module_id=701974
- Olander, A., Andersson, H., Sundler, A. J., Bremer, A., Ljungström, L., & Andersson Hagihara, M. (2019). Prehospital characteristics among patients with sepsis: A comparison between patients with or without adverse outcome. *BMC Emergency Medicine*, 19(1), 43. <https://doi.org/10.1186/s12873-019-0255-0>
- Patterson, D., Nudell, N., Garberson, L., & Andrilla, H. (2022). Prehospital emergency medical services personnel: Comparing rural and urban professional experience and provision of evidence-based care. *Rural Health Research Gateway*. <https://www.rural-healthresearch.org/publications/1496>
- Pliakas, J. (2017). *EMS Pharmacology Reference Guide*. Rhode Island Department of Health. <https://health.ri.gov/publications/guides/EMSParmacologyReference.pdf>
- Qian, Q. (2019). Hyponatremia. *Clinical Journal of the American Society of Nephrology*, 14(3), 432–434. <https://doi.org/10.2215/cjn.12141018>
- Rajasekaran, A., Bade, N., Cutter, G. R., Rizk, D. V., & Zarjou, A. (2022). Lactated Ringer's solution and risk of hyperkalemia in patients with reduced kidney function. *The American Journal of the Medical Sciences*, 364(4), 433–443. <https://doi.org/10.1016/j.amjms.2022.04.024>
- Ramesh, G. H., Uma, J. C., & Farhath, S. (2019). Fluid resuscitation in trauma: What are the best strategies and fluids? *International Journal of Emergency Medicine*, 12(1), 38. <https://doi.org/10.1186/s12245-019-0253-8>
- Ravi, P. R., & Puri, B. (2017). Fluid resuscitation in haemorrhagic shock in combat casualties. *Disaster and Military Medicine*, 3, 2. <https://doi.org/10.1186/s40696-017-0030-2>
- Rogenes, P. R., & Moylan, J. A. (1976). Restoring fluid balance in the patient with severe burns. *The American Journal of Nursing*, 76(12), 1953–1957. <https://doi.org/10.2307/3424042>

- Rudloff, E., & Hopper, K. (2021). Crystalloid and colloid compositions and their impact. *Frontiers in Veterinary Science*, 8, 639848. <https://doi.org/10.3389/fvets.2021.639848>
- Rumbus, Z., Toth, E., Poto, L., Vincze, A., Veres, G., Czako, L., Olah, E., Marta, K., Miko, A., Rakonczay, Z., Balla, Z., Kaszaki, J., Foldesi, I., Maleth, J., Hegyi, P., & Garami, A. (2018). Bidirectional relationship between reduced blood pH and acute pancreatitis: A translational study of their noxious combination. *Frontiers in Physiology*, 9, 1360. <https://doi.org/10.3389/fphys.2018.01360>
- Saraghi, M. (2015). Intraoperative fluids and fluid management for ambulatory dental sedation and general anesthesia. *Anesthesia Progress*, 62(4), 168–177. <https://doi.org/10.2344/0003-3006-62.4.168>
- Self, W. H., Semler, M. W., Wanderer, J. P., Ehrenfeld, J. M., Byrne, D. W., Wang, L., Atchison, L., Felbinger, M., Jones, I. D., Russ, S., Shaw, A. D., Bernard, G. R., & Rice, T. W. (2017). Saline versus balanced crystalloids for intravenous fluid therapy in the emergency department: Study protocol for a cluster-randomized, multiple-crossover trial. *Trials*, 18, 178. <https://doi.org/10.1186/s13063-017-1923-6>
- Semler, M. W., & Kellum, J. A. (2019). Balanced crystalloid solutions. *American Journal of Respiratory and Critical Care Medicine*, 199(8), 952–960. <https://doi.org/10.1164/rcm.201809-1677CI>
- Shaheen, N. A., Alqahtani, A. A., Assiri, H., Alkhodair, R., & Hussein, M. A. (2018). Public knowledge of dehydration and fluid intake practices: Variation by participants' characteristics. *BMC Public Health*, 18(1), 1346. <https://doi.org/10.1186/s12889-018-6252-5>
- Shi, J., Tan, L., Ye, J., & Hu, L. (2020). Hypertonic saline and mannitol in patients with traumatic brain injury: A systematic and meta-analysis. *Medicine*, 99(35), e21655. <https://doi.org/10.1097/MD.00000000000021655>
- Singh, S., Kerndt, C. C., & Davis, D. (2024). Ringer's Lactate. In *StatPearls*. StatPearls Publishing. <http://www.ncbi.nlm.nih.gov/books/NBK500033>
- Smith, M. (2008). Monitoring intracranial pressure in traumatic brain injury. *Anesthesia and Analgesia*, 106(1), 240–248. <https://doi.org/10.1213/01.ane.0000297296.52006.8e>
- Spaite, D. W., Hu, C., Bobrow, B. J., Chikani, V., Barnhart, B., Gaither, J. B., Denninghoff, K. R., Adelson, P. D., Keim, S. M., Viscusi, C., Mullins, T., & Sherrill, D. (2017). The impact of combined prehospital hypotension and hypoxia on mortality in major traumatic brain injury. *Annals of Emergency Medicine*, 69(1), 62–72. <https://doi.org/10.1016/j.annemergmed.2016.08.007>
- Sperry, J. L., Martin, M. J., Moore, E. E., Sava, J. A., Ciesla, D., Rizzo, A. G., Brown, C., Brasel, K., Kozar, R., Vercruyse, G., & Inaba, K. (2019). Prehospital resuscitation in adult patients following injury: A Western Trauma Association critical decisions algorithm. *The Journal of Trauma and Acute Care Surgery*, 87(5), 1228–1231. <https://doi.org/10.1097/TA.0000000000002488>
- Stiver, S. I., & Manley, G. T. (2008). Prehospital management of traumatic brain injury. *Neurosurgical Focus*, 25(4), E5. <https://doi.org/10.3171/FOC.2008.25.10.E5>
- Sun, Y., Jin, J., Zhu, A., Hu, H., Lu, Y., Zeng, Y., & Jing, D. (2022). Risk factors for recurrent pancreatitis after first episode of acute pancreatitis. *International Journal of General Medicine*, 15, 1319–1328. <https://doi.org/10.2147/IJGM.S344863>
- Susanto, M., & Riantri, I. (2022). Optimal dose and concentration of hypertonic saline in traumatic brain injury: A systematic review. *Medeniyet Medical Journal*, 37(2), 203–211. <https://doi.org/10.4274/MMJ.galenos.2022.75725>

- ter Avest, E., Taylor, S., Wilson, M., & Lyon, R. L. (2020). Prehospital clinical signs are a poor predictor of raised intracranial pressure following traumatic brain injury. *Emergency Medicine Journal*, 38(1), 21–26. <https://doi.org/10.1136/emered-2020-209635>
- Tommasino, C. (2002). Fluids and the neurosurgical patient. *Anesthesiology Clinics of North America*, 20(2), 329–346. [https://doi.org/10.1016/S0889-8537\(01\)00013-X](https://doi.org/10.1016/S0889-8537(01)00013-X)
- Yazer, M. H., Spinella, P. C., Bank, E. A., Cannon, J. W., Dunbar, N. M., Holcomb, J. B., Jackson, B. P., Jenkins, D., Levy, M., Pepe, P. E., Sperry, J. L., Stubbs, J. R., & Winckler, C. J. (2022). THOR-AABB working party recommendations for a prehospital blood product transfusion program. *Prehospital Emergency Care*, 26(6), 863–875. <https://doi.org/10.1080/10903127.2021.1995089>
- Zornow, M. H., & Prough, D. S. (1995). Fluid management in patients with traumatic brain injury. *New Horizons (Baltimore, Md.)*, 3(3), 488–498. <https://europepmc.org/article/med/7496759>