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Prehospital Trauma Compendium: Fluid Resuscitation in Trauma– a position statement and resource document of NAEMSP

Jason McMullan[a,*] 0000-0002-7656-7447, B Woods Curry[a], Dustin Calhoun[a], Frank Forde[b], J Jordan Gray[c], Thomas Lardaro[d] 0000-0002-4668-3842, Ashley Larrimore[e], Dustin LeBlanc[f], James Li[g], Sean Morgan[h], Matthew Neth[i], Woodrow Sams[j], John Lyng[k] 0000-0001-5191-5700

[a]Department of Emergency Medicine, University of Cincinnati, Cincinnati, OH
[b]Department of Emergency Medicine, University Hospitals Cleveland Medical Center, Cleveland, OH
[c]Department of Emergency Medicine, Dartmouth-Hitchcock Medical Center, Lebanon, NH
[d]Department of Emergency Medicine, Yale School of Medicine, New Haven, CT
[e]Department of Emergency Medicine, The Ohio State University Wexner Medical Center, Columbus, OH
[f]Department of Emergency Medicine, Medical University of South Carolina, Charleston, SC
[g]Department of Emergency Medicine, Washington University School of Medicine, St Louis, St Louis, MO
[h]Department of Emergency Medicine, University of Colorado School of Medicine, Aurora, CO
[i]Department of Emergency Medicine, Oregon Health & Science University, Portland, OR
[j]Department of Emergency Medicine, University of Michigan, Ann Arbor, MI
[k]Department of Emergency Medicine, North Memorial Health Level I Trauma Center, Robbinsdale, MN

***Corresponding Author**: Jason McMullan, [1]Department of Emergency Medicine, University of Cincinnati, Cincinnati, OH, Jason.McMullan@uc.edu

ABSTRACT

Fluid resuscitation choices in prehospital trauma care are limited, with most Emergency Medical Services (EMS) agencies only having access to crystalloids. Which solution to use, how much to administer, and judging the individual risks and benefits of giving or withholding fluids remains an area of uncertainty. To address the role of crystalloid fluids in prehospital trauma care, we reviewed the available relevant literature and developed recommendations to guide clinical care. The topic of prehospital blood product administration is covered elsewhere.

NAEMSP recommends:

- **Isotonic crystalloid solutions should be the preferred fluids for use in prehospital trauma management. Specific choice of isotonic crystalloid solutions may be driven by medication compatibility and other operational issues.**
- **Permissive hypotension is reasonable in patients without traumatic brain injury (TBI).**
- **Avoiding or correcting hypotension in polytrauma patients with TBI may be a higher priority than restricting fluid use.**
- **Large volume crystalloid resuscitation should be generally avoided.**
- **Developing processes to administer warmed intravenous (IV) fluids is reasonable.**
- **Risks of IV fluid use, or restriction, in trauma resuscitation should be weighed against possible benefits.**
- **Strategies to reduce the need for IV fluids should be considered.**
- **A standard trauma resuscitation curriculum for prehospital providers should be developed to improve evidence-based delivery of IV fluids in trauma.**

Keywords: fluid resuscitation, crystalloid, trauma

INTRODUCTION

Fluid resuscitation choices in prehospital trauma care are limited, with most Emergency Medical Services (EMS) agencies only having access to crystalloids. Which fluid to use, how much to administer, and judging the individual risks and benefits of giving or withholding fluids remains an area of uncertainty. To address the role of crystalloid fluids in prehospital trauma care, we reviewed the available relevant literature and developed recommendations to guide clinical care.

Prehospital transfusion is an area of active exploration. Operational challenges and a frequently constrained supply of blood for emergency care complicate the initiation of prehospital transfusion programs, and intravascular fluids will likely remain as an important component of prehospital trauma resuscitation, both as a vehicle for delivery of certain medications and to temporize/mitigate physiologic insults that occur secondary to traumatic injuries. Blood product administration is discussed in a separate position statement (1). Additionally, fluid management of entrapped or crushed patients likely requires alternative strategies to those discussed in this paper and is discussed in a companion paper to this manuscript (2).

METHODS

Content areas

Content areas were developed by the authors, in collaboration with the compendium editorial board, to cover the key decision points when deciding to administer intravenous (IV) fluids as part of comprehensive prehospital trauma care. This review is organized to inform several content areas:

1. Preferred fluid choice among IV fluids
2. Physiologic triggers for IV fluid resuscitation
3. Use of warmed IV fluids
4. Potential harms of IV fluid resuscitation
5. Educational strategies and gaps.

Search strategy

We performed a structured search of the literature using guidance developed for the National Association of EMS Physicians (NAEMSP) Trauma Compendium (3) for prehospital trauma related publications: "injury"[Title/Abstract] OR "injuries"[Title/Abstract] OR "trauma*"[Title/Abstract] OR "wound*"[Title/Abstract] OR "Advanced Trauma Life Support Care"[MeSH Terms] OR "Wounds and Injuries"[MeSH Terms]; "Emergency Medical Dispatch"[MeSH Terms] OR "Emergency Medical Service Communication Systems"[MeSH Terms] OR "Emergency Medical Technicians"[MeSH Terms] OR "Transportation of Patients"[MeSH Terms] OR "air medical"[Title/Abstract] OR "air medicine"[Title/Abstract] OR "aeromedical"[Title/Abstract] OR "aero-medical"[Title/Abstract] OR "aeromedicine"[Title/Abstract] OR "aero-medicine"[Title/Abstract] OR "ambulance*"[Title/Abstract] OR "emergency medical service*"[Title/Abstract] OR "emergency medical technician*"[Title/Abstract] OR "emergency services"[Title/Abstract] OR "ems"[Title/Abstract] OR "emt"[Title/Abstract] OR "field triage"[Title/Abstract] OR "first responder*"[Title/Abstract] OR "paramedic*"[Title/Abstract] OR "prehospital"[Title/Abstract] OR "pre-hospital"[Title/Abstract].

Search terms for crystalloid or colloid solutions were added: "crystalloid solutions"[MeSH Terms] OR "crystalloid"[Title/Abstract] OR "saline"[Title/Abstract] OR "ringers"[Title/Abstract] OR "fluid"[Title/Abstract]; “colloids”[MeSH Terms}.

We searched PubMed on 19 October 2022 for articles published from inception through that date. Articles were screened using EndNote, which was used to eliminate duplicates.

Screening of publications

All authors contributed to article identification and screening. One author performed the search, removal of duplicates, and title-based screen. Content sections were assigned to pairs of authors, who performed abstract and manuscript reviews and selected relevant papers. A secondary search supplemented the structured PubMed strategy and was based on each author’s familiarity with the subject matter and review of the references of reviewed manuscripts. Non-English and non-human articles were excluded during title and abstract screening. Articles were included if they provided relevant information for prehospital application.

Summarizing evidence

Author pairs suggested key findings of their respective content areas. One author created the evidence table (Table 1), which describes the content area(s) and key findings of included manuscripts grouped by content areas. All authors reviewed, edited, and approved the final version of the manuscript.

RESULTS

Literature review

As described in Figure 1, we first identified roughly 1.9 million trauma related articles, 100,000 EMS related articles, and 650,000 articles regarding crystalloids. Combining these three searches identified 885 unique articles; 39 additional articles were identified by substituting colloid terms for crystalloid terms. This combined search formed the basis for title screening. After reviewing 181 abstracts, 67 manuscripts underwent full review. Twenty-six additional manuscripts were identified through the secondary search, and 68 papers form the basis of this position statement. Table 1 describes the content area(s) and key findings of included manuscripts.

DISCUSSION

Preferred IV fluid choice.

- **Isotonic crystalloid solutions should be the preferred fluids for use in prehospital trauma management. The specific choice of isotonic crystalloid solutions may be driven by medication compatibility and other operational issues.**

Intravenous fluids can be classified into two categories related to their respective impact on oncotic pressures: crystalloids and colloids. Previous investigations evaluated colloids as a preferred resuscitation fluid because of more durable intravascular volume expansion, while critics consider colloids impractical for the field setting (4). Severely injured trauma patients receiving >1L synthetic colloid fluids prior to hospital arrival had increased risk of renal failure and need for dialysis, while those receiving any prehospital colloids had an increased risk of multi-organ system failure; there was no association with in-hospital mortality (5). A randomized trial of hypovolemic intensive care unit (ICU) patients resuscitated with crystalloid vs any type of colloid found no difference in rates of dialysis or 28-day mortality; however, the number of trauma patients enrolled in this study represented less than 3% of the total (6).

Tonicity is another factor characterizing crystalloid fluids. The two nearly isotonic solutions commonly encountered in EMS are 0.9% normal saline (nonbuffered) and Ringer's lactate (buffered); other buffered isotonic solutions, like Plasma-Lyte, are gaining popularity. It should be noted that 0.9% normal saline is relatively hypertonic compared to serum osmolarity but should not be confused with 'hypertonic' saline which is typically administered in at least 3% concentrations (4). Hypertonic saline offers no benefit compared to isotonic fluids for many studied outcomes, including organ failure (7), survival to hospital discharge (7), 28-day mortality (8), or in patients with concomitant hemorrhagic shock and traumatic brain injury (TBI) (9).

The combination of hypertonic solutions and colloids, such as 7.5% saline with 6% dextran, offers no benefit to isotonic crystalloids (8, 10-14) and may worsen coagulopathy (15). Prehospital evidence directly comparing isotonic fluids is limited. A secondary analysis of subjects enrolled in a prospective observational prehospital trial showed increased all-cause mortality in those with TBI who received lactated ringers vs. normal saline, but there were no differences among those without TBI (16). The 2018 Solutions and Major Adverse Renal Events Trial (SMART) study enrolled over 15,000 critically ill patients to be resuscitated with either normal saline or lactated ringer's/Plasma-Lyte. This revealed a 1.1% reduction in adverse outcome in favor of the buffered solutions in the composite outcome of death from any cause, new renal-replacement therapy, or persistent renal dysfunction (17). The concurrent Saline against Lactated Ringer's or Plasma-Lyte in the Emergency Department (SALT-ED) trial studied similar outcomes in noncritically ill patients. This found no difference in hospital-free days (days alive after discharge before day 28) between treatment with buffered crystalloids and treatment with saline (18).

The potential benefit of buffered solutions is thought to be related to a decreased risk of iatrogenic hyperchloremic metabolic acidosis and resulting coagulopathy. However, this benefit does come with the caveat that more medications are compatible with 0.9% normal saline for concurrent administration due to its relatively few constituent parts and the absence of minerals that could precipitate in solution or interfere with blood chelating agents.

Physiologic triggers for IV fluid resuscitation.

- **Permissive hypotension is reasonable in patients without TBI.**
- **Avoiding or correcting hypotension in polytrauma patients with TBI may be a higher priority than restricting fluid use.**
- **Large volume crystalloid resuscitation should be generally avoided.**

Permissive hypotension. There is a lack of standardization regarding specific hemodynamic triggers to give IV fluids. Thirty years ago, uncontrolled hemorrhage was observed in half of patients with a systolic blood pressure (SBP) <90mmHg (19). Little has changed, as many resources still suggest using a mean arterial blood pressure (MAP) of 50 mmHg or a SPB of 70 mmHg to 90 mmHg to guide resuscitation (20, 21), with infusion boluses of 100 mL to 200 mL at a time, while monitoring MAP/SBP responses (22). Many authors counter, however, that defining hypotension at higher blood pressures (BP) is more appropriate, especially in the elderly (23-25).

Permissive hypotension is the practice of maintaining a BP lower than standard physiological levels in a patient suffering hemorrhagic blood loss secondary to trauma. The goal of this process is to maintain adequate vasoconstriction, organ perfusion, and prevent an undesired coagulopathy during initial fluid resuscitation. Increasing preload and cardiac output, and therefore MAP, by infusing fluids or blood can result in a decrease in peripheral vasoconstriction resulting in additional blood loss as well as potentially causing hydrostatic damage to already injured vessels. Aggressive fluid resuscitation with the goal of arbitrarily increasing MAP can also lead to clot destabilization through mechanical displacement leading to rebleeding. In general, IV fluids are used to achieve or maintain physiologic targets such as mental status or presence of distal pulses (22, 26). Permissive hypotension strategies confer mortality benefits after trauma but prior to definitive hemorrhage control (27). Severely burned patients have unique fluid needs (28) and permissive hypotension is not described in this population.

Impact of mechanism of injury/Injury-type. Different injuries may require different physiological goals for resuscitation. Penetrating trauma may require lower MAPs to prevent the propagation of injury, while patients experiencing TBI may require higher MAPs to facilitate increased cerebral perfusion pressures (CPP) (29). As summarized in the prologue of this compendium, current prehospital TBI guidelines recommend a SBP of 110 mmHg in adults, or above the 75th percentile of age-appropriate BP in pediatrics, while acknowledging that no data exists for any specific cut-off value (30).

Impact of methods used to detect and monitor for hypotension. Automated BP measurements may be unreliable, especially in hypotensive patients (31). Future markers and methods, such as ultrasound measurement of inferior vena cava diameter response to fluid administration, serial biomarkers including lactate, and beat to beat measurements of electrocardiogram (ECG) waveforms or cardiac output may provide more objective resuscitation endpoints (32). However, this suggested use of prehospital point of care ultrasound and other technologies need further evaluation prior to any recommendation or widespread implementation.

Volume of IV fluids for trauma resuscitation. No specific ideal volume for IV fluid resuscitation has been established. Several registry-based studies show no differences in outcomes based on the volume of IV fluid administered (33-35). Targeted resuscitations result in smaller volumes of administered crystalloid and are associated with improved outcomes and survival (21, 36, 37). Conversely, large volume (>2L) crystalloid resuscitation is frequently associated with complications, including coagulopathy, increased transfusion requirements (38), and mortality (39). Worse outcomes have also been observed when IV fluids are given to patients without hypotension (40, 41).

Use of warmed IV fluids.

- **Developing processes to minimize the use of non-warmed IV fluids is reasonable.**

Hypothermia in trauma patients is associated with worsened outcomes. Use of warmed IV fluids is only one component of overall body temperature management strategies, and the relative impact of IV fluids on body temperature is largely guided by the second law of thermodynamics and intrinsic thermoregulatory physiology. When considering the role of prehospital IV fluids in body temperature regulation, two distinct scenarios exist: preventing the development of hypothermia in initially normothermic patients and attempting to actively warm a hypothermic trauma patient. The former role in heat loss prevention is likely of greater importance in the prehospital setting, as the latter, active rewarming of hypothermic patients using warmed IV fluids, would require prohibitively large (and probably harmful) volumes of IV fluid (42, 43).

There are no specific evidence-based guidelines for managing hypothermia in trauma patients although there have been proposed goal-directed algorithms that include warmed IV fluids (44). There is not a clear consensus on a target temperature. Advanced Trauma Life Support (ATLS) guidelines recommend heating blood or crystalloid to 39°C (102°F) before infusion; Trauma Combat Casualty Care (TCCC) guidelines recommend using a battery-powered warming device to deliver fluids at 38°C to prevent hypothermia (45).

IV fluids and iatrogenic thermal injuries. In healthy adults, a 2L bolus of room temperature (21°C) crystalloid decreases body temperature by only 0.3°C (42); a similar amount of fluid given to military combat casualties also had minimal impact on core temperature (46). Room temperature is not the same as ambient temperature, as prehospital fluids may acclimate to lower ambient temperatures, especially in cold environments (47).

Even mild hypothermia has been associated with higher morbidity and mortality in trauma, including increased fluid and transfusion requirements (48, 49). In one prospective study of severely injured trauma patients, an infusion fluid temperature below 21°C was a risk factor for hypothermia at hospital arrival (OR 1.17) (50).

Our literature search did not reveal evidence of an upper temperature limit for crystalloid infusions. In one operating room study examining patients undergoing burn debridement, investigators used a modified fluid warmer to infuse saline heated to 60°C through a central venous line. A thermocouple was attached at the connection of the central line catheter. The average temperature of infused fluid was 54°C +/- 1-2°C. Core temperatures had an insignificant increase during the procedure without evidence of hemolysis or coagulopathy (51).

IV fluid temperature management strategies. Although various improvised methods of warming fluids have been described (hand warmers, MRE [meal ready to eat] heaters, heating blankets, vehicle windshield defroster, heated storage, etc.), commercial battery-powered warming devices have been shown to be more reliable at achieving near or supra- physiologic temperatures (43, 52). These devices have been adopted for use by the military and many civilian EMS programs.

In one randomized in-vitro study, the performance of various commercial fluid-warming devices was variable, but all provided superior warming performance compared to control (53). However, at higher flow rates and lower input temperatures, some battery-powered warming devices are unable to warm the transfused fluid appropriately (54).

Several factors that may limit a device's ability to deliver fluids at the target temperature including limited heat transfer capability of materials, the surface area of the heat exchange mechanism, and heat loss through IV tubing after it leaves the warmer (53, 55). Size, complexity, portability, device weight, battery life, and ruggedness for environmental conditions are other considerations for use in prehospital settings.

Insulating the IV tubing to prevent heat loss between the bag and distal end of the administration set using a cotton conforming bandage and reflective emergency blankets results in a mean of 3.5°C fluid temperature decrease compared to 5.3°C in the control group (53).

If clinically indicated, a simple infrared thermometer can be used to monitor the temperature of infusion fluids (50).

Potential harms associated with IV fluid resuscitation decisions.

- **Risks of IV fluid use, or restriction, in trauma resuscitation should be weighed against possible benefits.**
- **Strategies to reduce the need for IV fluids should be considered.**

The administration of saline solutions is associated with hyperchloremic acidosis potentially impairing the clotting cascade and exacerbating post-trauma bleeding. Intravascular volume expansion with balanced fluids (e.g., lactated Ringer's, Plasma-Lyte) appear more effective at maintaining an optimal acid-base status (56). Conversely, balanced crystalloid solutions have less tonicity than normal saline and are associated with increased mortality in patients with TBI (15). Use of any IV fluid may contribute to a dilutional coagulopathy, and the amount of crystalloid received is an independent predictor of trauma-induced coagulopathy (57). However, confounding by indication may complicate interpretation of any observational study, and observed coagulopathy may be a marker of injury severity instead of iatrogenic injury (58-60).

Potential harms of withholding IV fluids in trauma patients. While evidence suggests a fluid restrictive approach in hypotensive trauma patients may be optimal (20, 37), select patients may be harmed by this strategy. In the Prospective Observational Multicenter Massive Transfusion Study of 1200 patients at 10 trauma centers, receiving fluid resuscitation prior to arrival was associated with increased survival (36). Severe organ hypoperfusion may result if no fluids are given, when compared to hypotensive or normotensive resuscitation strategies (61).

Current prehospital TBI guidelines suggest a minimum SBP target of ≥110 mmHg in adults (30), with recent evidence suggesting that hypotension has a dose and duration-response effect (62). This higher

BP target is thought to prevent secondary brain injury by improving cerebral perfusion. Additionally, it is recommended that patients with acute spinal cord injuries require higher BP goals (MAP ≥ 85 mmHg) to improve spinal cord perfusion (63). Prehospital treatment of hypotension in these cases should be treated with isotonic crystalloids (30).

Prompt transport with scene times under ten minutes is encouraged, especially when surgical management is likely (e.g., major hemorrhage, penetrating trauma, thoracoabdominal trauma) (64). In these cases, delaying IV access and fluid administration is reasonable. However, in situations where extrication or transport times are prolonged and surgical hemostasis is delayed, prehospital IV fluid administration may be needed to maintain perfusion. Prolonged field care for patients with entrapment or crush injury may also require more aggressive use of normal saline, as further discussed in a companion paper to this manuscript (2).

Strategies to reduce the need for IV fluid resuscitation. Hemorrhage control is an essential component of trauma resuscitation. EMS clinicians should be highly trained in the components of non-surgical bleeding control including tourniquet application, wound packing, and pressure dressings. The prehospital roles of fracture immobilization and pelvic binder application in hemorrhage control are discussed in companion papers to this manuscript.

Prehospital administration of tranexamic acid, discussed further elsewhere in the compendium, has been shown to lead to clot stabilization (65). Tranexamic acid serves as an anti-fibrinolytic agent and has been shown to decrease mortality as well as the need for massive transfusion (66). Clot stabilization may prevent mechanical displacement of clot and subsequent rebleeding caused by aggressive fluid administration. However, this has not been studied.

Pediatric considerations. Pediatric-specific literature is sparse. Similar associations between high-volume fluid resuscitation and worsened outcomes have been observed (58, 67), but these studies suffer the same limitations and potential biases as adult-focused literature discussed previously.

Gaps in EMS clinician education and training.

- **A standard trauma resuscitation curriculum for prehospital providers should be developed to improve evidence-based delivery of IV fluids in trauma.**

The 2021 National Emergency Medical Services Education Standards state that both Advanced Emergency Medical Technicians and Paramedics should understand the pathophysiology, assessment, and management, including fluid administration, of patients in shock and peri-arrest states. Most prehospital trauma resuscitation research focuses on how EMS clinician care can impact the clinical outcomes of critically injured patients. Studies are needed to direct how to best train EMS clinicians to attain and maintain competency in management of trauma patients in shock or peri-arrest states, including appropriate use of IV fluids.

There is no standard initial or continuing education prehospital trauma resuscitation course. Review of common prehospital trauma courses, including Prehospital Trauma Life Support, International Trauma Life Support, the Committee for Tactical Emergency Casualty Care and TCCC (29) guidelines, and paramedic course textbooks revealed several common themes. All discuss the need for hemorrhage control, resuscitation with blood products, IV fluid options, permissive hypotension, and physiologic markers of perfusion. However, while numeric BP goals have changed in recent years, these sources fail to sufficiently emphasize the superiority of physiologic indicators of perfusion over any SBP goal. Additionally, while the association between intravenous fluids and the “trauma triad of death” (hypothermia, coagulopathy, and acidosis) is well known, this concept is inadequately relayed, and the spectrum of the risks and benefits surrounding the use of crystalloid fluids in trauma remains poorly absorbed by the learner.

Even when guidelines are updated to reflect new knowledge, clinical uptake is slow (68-70). Unsurprisingly, state-level EMS protocols are highly variable in recommendations on when to give IV fluids, how much to give, and what type is preferred (71).

CONCLUSIONS

Use of prehospital IV fluids in trauma should be focused on individual patients, as universal large volume resuscitations and universal withholding of fluids may be harmful. Resuscitation should target mental status and signs of perfusion instead of arbitrary BP values. Warmed fluids can be considered as part of an overall temperature-management strategy. Significant evidence gaps exist in determining best practices for pediatric patients, and standardizing educational curricula may improve prehospital provider understanding of the nuance of IV fluid resuscitation in trauma.

EXTERNAL REVIEW: this document was created solely by NAEMSP and was not subject to review by external parties.

UPDATING PROCEDURE: Pursuant to NAEMSP Standards & Clinical Practices Committee procedures and practices, this position statement and resource document will be reviewed and updated five years after its publication. Applicable NAEMSP review and revision practices that are current as of the time of the review will be followed. At a minimum the review process should include a search and synthesis of any new and relevant evidence that is published since the printing of this document.

IMPLEMENTATION GUIDANCE: EMS agencies should review current clinical guidelines for alignment with these recommendations. Operational considerations may impact the feasibility of implementation, such as balancing the costs of fluid warming technologies with the relative risks posed to individual patients.

EVALUATION: Quality improvement/quality assurance programs should monitor for deviations from recommendations, such as use of large volumes of IV fluids in patients without traumatic brain injury, or use of non-warmed fluids in cold environments (if available).

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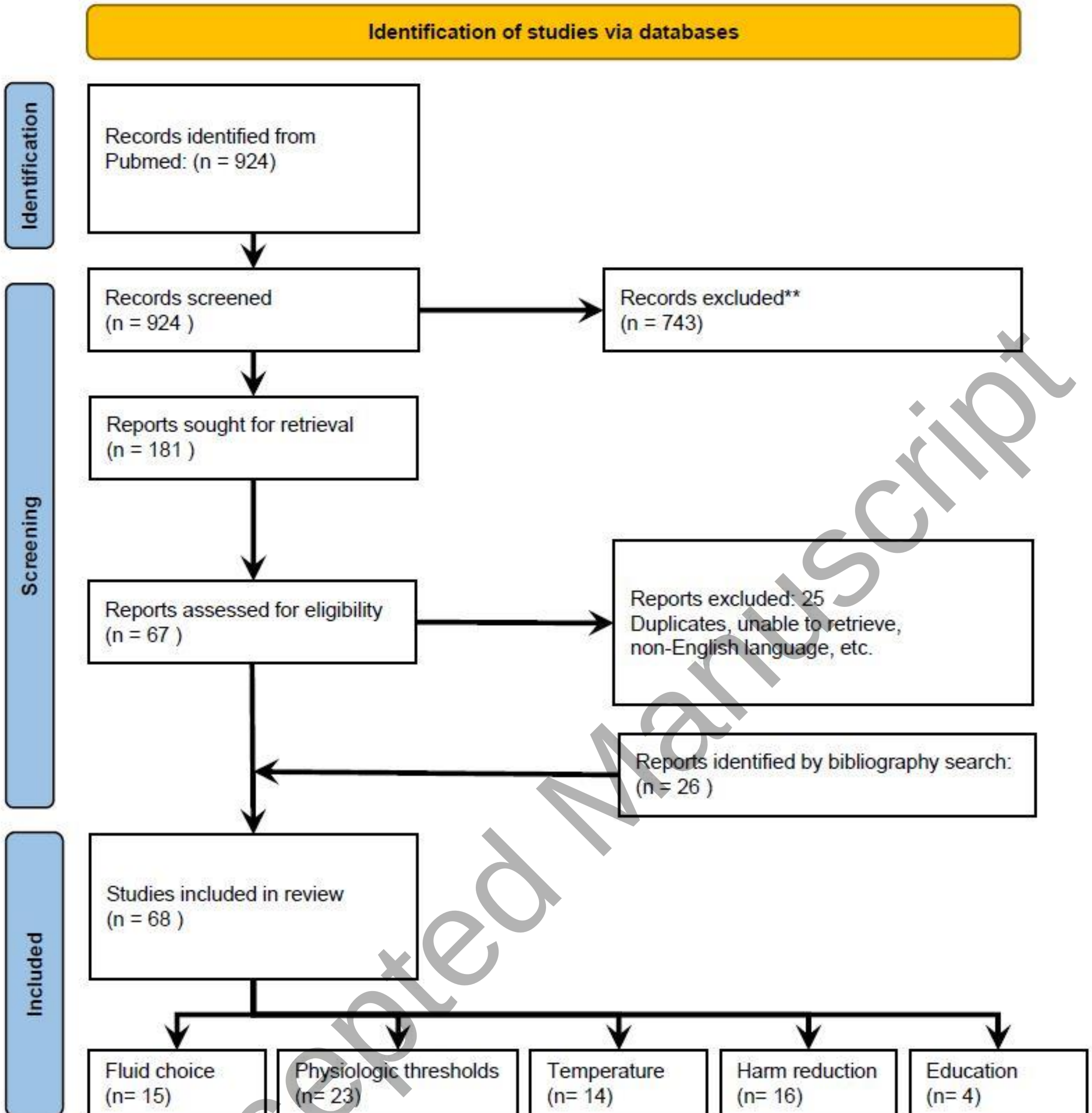

Figure 1: Literature search flow diagram.

Table 1: Evidence table.

Author/Year	Content Area(s)	Article Type	Findings or Description
Myburgh 2013	1	Review	Overview of history and physiology of fluid resuscitation, types of fluids, and dose of fluids for acutely ill patients
Hilbert-Carius 2018	1	Registry	Synthetic colloid use associated with increased risk of multiple organ failure and, at volumes >1L, increased risk of renal failure and need for dialysis
Annane 2013	1	Multi-center RCT	No difference in 28-day mortality in ICU patients with hypovolemic shock treated with colloids vs. crystalloids
Blanchard 2017	1	Systematic review and meta-analysis	No difference in survival to hospital discharge in hypotensive prehospital patients treated with hypertonic vs. isotonic fluids
Bulger 2011	1	Multi-center RCT	No difference in 28-day mortality in prehospital patients with hypovolemic shock treated with hypertonic saline, hypertonic saline with dextran, or normal saline
Cooper 2004	1	Single-center RCT	No difference in 6-month neurologic function in hypotensive prehospital patients with severe TBI treated with a bolus of hypertonic saline (or lactated ringers) in addition to standard fluid resuscitation
Mattox 1991	1	Multi-center RCT	No difference in survival in hypotensive prehospital trauma patients treated with hypertonic saline with dextran vs. isotonic crystalloids.
Vassar 1993	1	Multi-center RCT	No overall difference in survival in hypotensive prehospital trauma patients treated with lactated ringers, hypertonic saline, or wither of two hypertonic saline with dextran solutions. In subgroup analysis, patients with low GCS treated with hypertonic saline had improved outcomes.

Bulger 2008	1	Single-center RCT	No difference in 28-days survival without acute respiratory distress syndrome in hypotensive prehospital trauma patients treated with lactated ringers vs. hypertonic saline with dextran.
Wu 2017	1	Systematic review and meta-analysis	No mortality difference in hemorrhagic shock patients treated with hypertonic saline, hypertonic saline with dextran, or isotonic crystalloids.
de Crecenzo 2017	1	Systematic review and meta-analysis	No mortality difference in hypotensive prehospital trauma patients treated with hypertonic saline, hypertonic saline with dextran, or isotonic crystalloids.
Delano 2015	1	Subgroup analysis of a prospective observational trial	Treatment of hypotensive prehospital trauma patients with hypertonic solutions, with or without dextran, is associated with hypocoagulability and hyperfibrinolysis
Rowell 2016	1	Subgroup analysis of a prospective observational trial	No mortality in trauma patients without head injury receiving prehospital lactated ringers vs. normal saline. Increased mortality in trauma patients with head injury that received lactated ringers compared to normal saline.
Semler 2018	1	Multi-center pragmatic, cluster-randomized, multiple cross-over trial	ICU patients treated with lactated ringers or Plasma-Lyte, compared to normal saline, had decreased risk of the composite outcome of death, new dialysis, or persistent renal dysfunction.
Self 2018	1	Single-center pragmatic, cluster-randomized, multiple cross-over trial	No difference in hospital-free days in ED patients admitted to a non-ICU hospital level of care treated with lactated ringers or Plasma-Lyte, compared to normal saline.
Lechleuthner 1994	2	Retrospective review with CART methodology	Prehospital systolic blood pressure most sensitive marker associated with uncontrolled hemorrhage, but not reliable in patients with TBI

Bickell 1994	2, 4	Non-randomized prospective trial	Patients with penetrating wounds to the torso who did not receive any IV fluids prior to the operating room had increased survival compared to those who received fluids.
Schreiber 2015	2	Multi-center RCT pilot	Trigger for IV fluid was no radial pulse or systolic blood pressure <70 mmHg (vs. all patients receive fluid). Resuscitation end-points were radial pulse or SBP>70mmHg vs. SBP>110mmHg.
Sperry 2019	2	Guidelines	Western Trauma Association critical decision algorithm for prehospital resuscitation
Edwards 2010	2	Registry	Blood pressure thresholds associated with improved survival increase with age, up to systolic blood pressure >140mmHg in elderly trauma patients without TBI.
Eastridge 2007	2	Registry	Mortality increases with systolic blood pressure <110 mmHg.
Bridges 2015	2	Registry	Similar outcomes in patients <55 years-old, compared to older patients, undergoing "damage control laparotomy."
Cotton 2009	2	Guidelines	Eastern Association for the Surgery of Trauma guidelines for prehospital fluid resuscitation
Tran 2018	2	Systematic review and meta-analysis	Permissive hypotension has improved survival and reduced blood loss and transfusion requirements.
Leclerc 2021	2	Guideline comparison	Compares fluid resuscitation needs calculated using a simplified WHO burn formula and the Galveston formula
Deaton 2021	2	Guidelines	Trauma Combat Casualty Care guidelines on fluid resuscitation
Lulla 2023	2, 4	Guidelines	Brain Trauma Foundation prehospital TBI guidelines
Davis 2003	2	Retrospective review	Automated blood pressure measurements are higher than manual blood pressure measurements, especially in hypotensive patients.
Doucet 2020	2	Multi-center prospective cohort	Ultrasound measurements of the IVC predicts 24-hour IV fluid

			requirements in "major" trauma patients
Bores 2018	2	Registry supplemented by chart review	No difference in mortality of penetrating trauma patients associated with use, or non-use, of prehospital fluids.
Dula 2002	2	Matched-pairs case-control	No difference in mortality of hypotensive blunt trauma patients associated with use, or non-use, of prehospital fluids.
Zitek 2021	2	Registry supplemented by chart review	No association with mortality or transfusion requirements in trauma patients with tachycardia or hypotension stratified by volume of IV fluids received
Hampton 2013	2, 4	Prospective observational	Improved mortality and worsened coagulation profiles were seen in trauma patients who received prehospital IV fluids compared to those who did not receive fluids.
Albreiki 2018	2, 4	Systematic review	Permissive hypotension strategies are associated with improved mortality.
Geeraedts 2015	2	Retrospective chart review	Receiving >1L of prehospital IV fluids is associated with increased transfusion need in hypotensive trauma patients.
Ley 2011	2	Retrospective review	Receiving <1L of IV fluids in the ED is not associated with increased mortality. Increasing volumes of fluid are associated with increased risk of mortality, especially in the elderly.
Sung 2022	2	Registry	Prehospital fluid administration is associated with increased mortality and poorer functional outcomes in trauma patients.
Brown 2013	2	Subgroup analysis of a multi-center prospective observational trial	Receiving >500mL of prehospital crystalloid was associated with increased mortality and coagulopathy in severely injured trauma patients without hypotension. There were no differences in outcomes in hypotensive patients.

Barthel 2012	3	Statistical modeling	Very large volumes of warm IV fluids would be needed to actively war, hypothermic patients if no other warming methods were used.
Lyng 2021	3	Benchtop	Placing bags of fluid on a vehicle's defroster vents increased temperature by 13C.
Haverkamp 2018	3	Review	Review of prehospital strategies to rewarm hypothermic patients, including methods to warm IV fluids.
CoTCCC 2022	3	Guidelines	Tactical Combat Casualty Care guidelines including use of IV fluid warmers
Farkash 2002	3	Registry	No association between prehospital IV fluid administration and body temperature or coagulopathy.
Joslin 2014	3	Prospective observational	Ambient temperature is associated with temperature of prehospital IV fluids.
Wang 2005	3	Registry	Hypothermia at ED arrival was associated with mortality in trauma patients.
Bukur 2012	3	Registry	Prehospital hypothermia is associated with increased transfusion requirements, development of acute respiratory distress syndrome, and mortality
Lapostalle 2006	3	Benchtop	Infrared thermometers reliable measure the temperature of IV bags
Gore 1997	3	Observational	Infusion of 1.1L of 50C IV fluids during burn debridement did not increase core body temperature and appeared safe.
Milligan 2016	3	Benchtop	Evaluation of several improvised and commercially available blood warming techniques.
Weatherall 2019	3	Benchtop	Evaluation of several commercially available blood warmers.
Lehavi 2018	3	Benchtop	Evaluation of several battery-operated fluid warmers
Singleton 2017	3	Benchtop	Evaluation of temperature change between IV bag and end of tubing using a fluid warming device.

Young 2014	4	Single-center RCT	In severely injured trauma patients, use of Plasma-Lyte improved acid-base status and resulted in less hyperchloremia than use of normal saline.
David 2017	4	Registry	Receiving >1L of prehospital IV fluids is associated with increased transfusion need and coagulopathy.
Garwe 2016	4	Retrospective cohort	There may be bias and confounding in trials that find associations between prehospital IV fluid administration and outcomes in pediatric trauma patients.
Floccard 2012	4	Prospective observational	Coagulopathy frequently occurs early after trauma and before administration of prehospital fluids.
Kutcher 2015	4	Registry	Injury severity, temperature, and acidosis are associated with coagulopathy after trauma, and coagulopathy is independently associated with worsened outcomes.
Schmidt 2012	4	Murine randomized trial	Hypotensive resuscitation decreases bleeding while maintaining organ perfusion, while non-use of fluids is associated with decreased organ perfusion.
Spaite 2017	4	Registry	Observed linear association between degree of hypotension and risk of mortality in TBI patients, with no distinct inflection-point or threshold seen.
Bernhard 2005	4	Review	General review of prehospital management of spinal cord injury
Waalwijk 2022	4	Observational	Prolonged transport time intervals are associated with increased mortality in moderately and severely injured trauma patients.
Stein 2018	4	Prospective multi-center observational	Prehospital TXA administration is associated with clot stabilization
CRASH-2 2010	4	Multi-center RCT	TXA reduces mortality in trauma patients with, or at risk of, significant hemorrhage

Polites 2020	4	Prospective multi-center observational	In pediatric trauma patients with an elevated shock index, receiving multiple crystalloid boluses was associated with increased transfusion needs and longer ICU and hospital stay.
Clarke 2021	5	Registry	Practice patterns in tactical combat casualty care had not meaningfully changed five years after guidelines encouraged blood products over crystalloids.
Driessen 2016	5	Registry	The volume of prehospital fluids given to trauma patients decreased from 2002 to 2012, as did the proportion requiring massive transfusion.
Yaghoubian 2007	5	Registry	Guidelines for restricting prehospital IV fluids are not represented in clinical care.
Dadoo 2017	5	Comparison of state protocols	EMS protocols covering prehospital IV fluids in trauma patients are variable.

Content areas are (1) preferred fluid choice among intravenous fluids, (2) physiologic triggers for intravenous fluid resuscitation, (3) use of warmed intravenous fluids, (4) potential harms of intravenous fluid resuscitation, and (5) educational strategies and gaps.