Review Article

Intravenous Fluid Management in Critically Ill Patients: Principles, Practices, and Evolving Paradigms

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Abstract:

IV fluid therapy constitutes a fundamental component within supportive care for critically ill patients. It is used essentially to replenish and maintain adequate intravascular volume so that tissue perfusion is adequate, in addition to rectifying electrolyte and acid-base imbalances. However, the administration of intravenous fluids requires a delicate balance between under-resuscitation and over-resuscitation. Under-resuscitation leads to hypoperfusion of organs, while over-resuscitation leads to fluid overload, tissue edema, and further deterioration of patient outcomes. Modern advances have shifted the focus from the traditional one-size-fits-all volume-centric approach to more targeted approaches adjoined to individual hemodynamic response, fluid responsiveness, and type of critical illness. The river of controversy continually flows between the use of crystalloids and colloids, and balanced and unbalanced solutions. Moreover, the recent trend is to adopt goal-directed fluid therapy, appropriate dynamic monitoring tools, and individualized protocols in intensive care.

This review article lays out a critical perspective into the contemporary understanding of intravenous fluid therapy in the critically ill. The article explores physiological basis of fluid administration, types of fluids used, indications, and limitations, as well as clinical strategies that steer fluid resuscitation, maintenance, and de-escalation.

Key words: Acid-base balance, Acute kidney injury, Colloids, Crystalloids, Fluid overload, Hemodynamic monitoring, Intensive care

Introduction:

Intravenous fluid therapy is one of the most commonly applied interventions in managing the critically ill. Since the dawn of resuscitation science, fluids have evolved as the primary management strategy for hypovolemia and shock. In the critical care setup, a timely and appropriate fluid administration is essentially life-saving, as it stabilizes patients in circulatory collapse from sepsis, trauma, or major surgery.[1-4] However, with the advancement of intensive care medicine has changed the understanding of the complicated interplay between fluids and organ function. The critically ill represent a heterogeneous group of patients concerning the degree of hemodynamic instability, organ dysfunction, and metabolic derangement. Hence, a flat "one-for-all" approach to fluid management is today being increasingly discouraged as a potential harm. [5,6] While initial aggressive fluid resuscitation is important in septic shock, fluid

excess accumulation or "fluid overload," as termed in common parlance, has always been found to be linked, independently, with worsening morbidity and mortality. This has led to the concept of fluid stewardship comprising resuscitation, optimization, stabilization, and de-escalation phases. A further point of fluid management, of course, is the type of fluid administered. The age-old chasm between crystalloids and colloids continues to evolve, especially in light of data questioning the safety of some synthetic colloids. [7]

The physiology and principles of IV fluid therapy:

A basis to start understanding fluid kinetics in critical illness is an appreciation of the various fluid compartments within the body and the physiological principles which govern fluid distribution between them. Approximately 60% of the human body is made up of water, distributed between the intracellular (ICF) and extracellular (ECF) compartments. The ECF is divided further into the interstitial and intravascular spaces. Under normal health conditions, homeostasis seeks to keep fluids in balance between these compartments through hydrostatic and oncotic pressures, depending on the integrity of the capillary membranes. [8-11]

In the critically ill patient, much of the homeostasis is lost. In cases of an inflammatory state such as sepsis or major trauma, capillary leak syndrome occurs: fluids and proteins extravasate through the capillary membrane into the interstitial compartment. This state deprives of an effective blood volume and favors edema with the resultant compromise of tissue oxygenation. Hence, IV fluid therapy should take into consideration the pathophysiological changes to restore perfusion without increasing serious third-spacing. [12]

Fluids are broadly segmented as crystalloids and colloids. Crystalloids are aqueous solutions of electrolytes capable of freely dispersing in the ECF, with about 20 to 25% of the volume remaining in the intravascular space after administration. Normal saline or 0.9% NaCl is the most conventional crystalloid solution; however, due to the concerns of hyperchloremic acidosis and renal impairment, balanced solutions such as lactated Ringer's and Plasma-Lyte are being used more frequently.

Colloids such as albumin, dextrans, or gelatins and synthetic starches contain larger molecules that are supposed to remain within the vasculature longer because of the oncotic pressure. Still, the clinical advantages of colloids over crystalloids remain controversial. Several studies demonstrated that there was no beneficent effect on mortality and that there could be harm with some colloids, especially hydroxyethyl starch, which has led to restrictions by authorities to their use.

Fluid Therapy in Critical Illness: Clinical Phases:

Modern fluid management adheres to a methodical, phase-based approach that gradually adapts to the patient's physiological requirements. Known as the "ROSD" model, these stages—Resuscitation, Optimisation, Stabilisation, and De-escalation—offer a flexible framework for directing fluid therapy in patients who are in critical condition. (Fig 1) In patients with potentially fatal hypovolemia, such as those in septic or hemorrhagic shock, rapid volume expansion is essential to restoring perfusion during the resuscitation phase. [13-15] Here, isotonic crystalloids are usually given in rapid boluses according to haemodynamic and clinical criteria. Within the first three hours of sepsis-induced hypotension or lactate elevation, the Surviving Sepsis Campaign advises administering a 30-mL/kg crystalloid bolus.

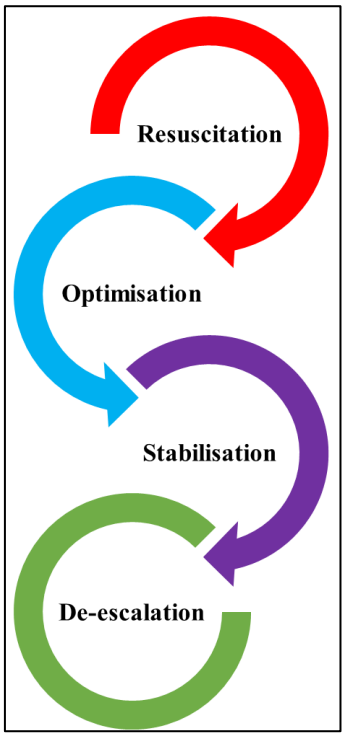

Fig 1: ROSD model for fluid resuscitation for a critically ill patient

Fluids are generally divided into crystalloids and colloids. Crystalloids are aqueous solutions of electrolytes that distribute freely in the ECF, with basically only 20–25% remaining intravascularly after administration. Normal saline (0.9% NaCl) is the most commonly used crystalloid solution but concerns on hyperchloremic acidosis and renal impairment have fostered increased utilization of balanced solutions such as lactated Ringer's and Plasma-Lyte. Colloids, including albumin, dextrans, gelatins, and synthetic starches, contain larger molecules that theoretically would remain in the vasculature longer by virtue of oncotic pressure. The clinical benefits of colloids over crystalloids remain controversial; multiple studies have shown no clear mortality benefit and some potential harms of certain colloids, especially hydroxyethyl starch, which has consequently been restricted in use by regulatory authorities. [16]

Clinical phases of fluid therapy in critical illness:

Currently, fluid therapy is perceived to be administered in phases according to the physiological needs of the patient at any particular time in that course of the patient being treated. These phases of treatment—Resuscitation, Optimization, Stabilization, and De-escalation—are collectively known as the "ROSD" Model fluid management. This model allows physicians to provide more dynamic therapy aimed at the critically ill patient. (Fig 1)

In the resuscitation phase, it is a matter of utmost urgency to administer rapid volume expansion to reverse compromised perfusion in a state of life-threatening hypovolemia such as seen in septic or hemorrhagic shock. Typically, large volumes of isotonic crystalloid boluses are given in such situations depending on clinical and hemodynamic grounds. The Surviving Sepsis

Campaign recommends an initial bolus of 30 mL/kg of crystalloids within the first three hours of hypotension due to sepsis or elevation of lactate. However, this generalized recommendation has undergone challenge, particularly in patients with heart failure or renal impairment who might be adversely affected by fluid overload.

In contrast to resuscitation, optimization tries to achieve adequate oxygenation and perfusion of tissues in an attempt to avoid fluid accumulation that might be unnecessary. This would put the patient on a more cautious lookout with the use of fluid responsiveness dynamic parameters such as the passive leg raise test, stroke volume variation, or pulse pressure variation in patients that are mechanically ventilated. [17,18]

Advanced hemodynamic monitoring options include esophageal Doppler, thermodilution-based methods, or non-invasive cardiac output monitors that may augment clinical judgment. At the stabilization stage, the patient has been relatively stabilized in terms of hemodynamics. In this portion, the objective changes from correction to maintenance-that is, permitting only sufficient perfusion of organs with the least amount of intervention. Fluids are judiciously titrated for maintenance purposes while attention is paid to electrolyte and metabolic balance. Avoid administering fluids just for the sake of it when there are no ongoing losses. Finally, the so-called de-escalation phase involves actively removing fluids through diuretic use or renal replacement therapies if fluid overload has been confirmed as an issue. Many studies highlight how persistent positive fluid balance harbors poor prognosis in ICU patients. Protocol-based fluid de-escalation, whenever feasible, seems to shorten ICU stay, improve oxygenation, and allow renal recovery. The overall success depends upon the patient and treatment factors as depicted in fig no 2.

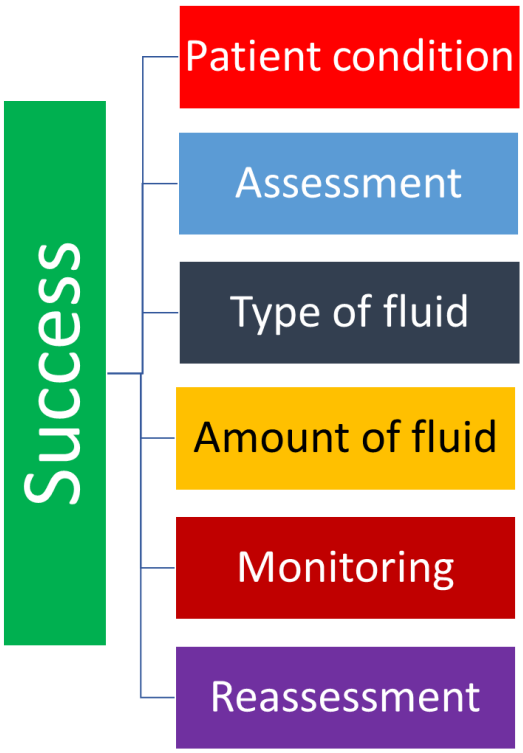

Fig 2: The flow chart shows how the fluid resuscitation of critical ill patient can be successful

Types of Fluids: Indications, Benefits, and Hazards:

The decision between crystalloids and colloids, and balanced and unbalanced fluids, is crucial in fluid therapy. Crystalloids are usually first-line because they are cost-effective and safe. Of these, normal saline was the standard for several decades, but its high chloride load can cause metabolic acidosis, reduced renal perfusion, and augmented risk of AKI. Balanced fluids like Ringer's lactate, Hartmann's solution, and Plasma-Lyte are closer in composition to plasma and are linked with less risk of hyperchloremic acidosis and renal impairment.

Colloids—specifically albumin—have a theoretical benefit in intravascular volume maintenance with the use of lesser amounts of fluid. The ALBIOS trial looked at albumin use in septic shock and demonstrated no difference in mortality to crystalloids, but indicated hemodynamic advantages perhaps. Synthetic colloids such as hydroxyethyl starch (HES) have lost popularity with evidence of higher risk of renal damage and death, particularly in septic patients, demonstrated by the CHEST and 6S trials. Gelatins and dextrans are also limited because of adverse effects like coagulopathy and anaphylaxis.

Monitoring methods and fluid responsiveness:

Clinical indicators like blood pressure, heart rate, capillary refill, and urine output are still useful but often are not adequate in themselves to direct fluid treatment. Dynamic tests—that can pick up on alterations with an increase in fluid load—are better predictors of volume responsiveness. Methods include: Passive Leg Raise (PLR): A reversible "autotransfusion" procedure that simulates a fluid bolus. An increase in stroke volume or cardiac output indicates fluid responsiveness. Pulse Pressure Variation (PPV) and Stroke Volume Variation (SVV): Reliable in sedated, mechanically ventilated patients with controlled tidal volumes. Increased variability indicates preload responsiveness. Echocardiography: Bedside ultrasound offers real-time information about cardiac filling, contractility, and volume status. Invasive monitoring: Equipment like PiCCO and LiDCO provides continuous cardiac output and preload indices. No parameter is alone adequate; a multimodal approach is generally required to accurately inform fluid decisions.

Guidelines and evidence-based recommendations:

In the last two decades, various clinical trials and professional societies have given useful recommendations regarding fluid management in the ICU. The Surviving Sepsis Campaign (SSC) guidelines recommend early fluid resuscitation with crystalloids with a minimum of 30 mL/kg within the initial three hours of septic shock. But at the same time, these guidelines emphasize a reassessment of fluid responsiveness and hemodynamic status during this initial resuscitation period. Likewise, the National Institute for Health and Care Excellence (NICE) advocates the use of a restrictive strategy for fluid therapy in critically ill patients, with particular focus on avoiding overload. The European Society of Intensive Care Medicine (ESICM) advocates for the use of balanced crystalloids as first-line treatment and against synthetic colloids because of their risk profile.

Landmark trials like the SPLIT, SMART, and SALTED trials have shaped practice by revealing the renal safety profile of balanced crystalloids. The SMART trial, for instance, compared saline to balanced crystalloids and detected a major decrease in major adverse kidney events at 30 days with balanced solutions. In trauma management, European guidelines for the treatment

of major trauma bleeding and coagulopathy and recommendations from the Advanced Trauma Life Support program suggest restricted application of crystalloids and promote early transfusion approaches and use of blood products. Damage control resuscitation and permissive hypotension and are key to avoiding the harmful consequences of fluid overload.

Fluid overload and its consequences:

Excessive fluid retention has been independently linked with poor outcomes in patients from heterogeneous ICU populations. The Fluid and Catheter Treatment Trial (FACTT) among ARDS patients demonstrated that conservative fluid management resulted in better oxygenation and reduced ventilator days without affecting renal function. Fluid overload may compromise pulmonary gas exchange, extend mechanical ventilation, rise intra-abdominal pressure, delay wound healing, and cause organ dysfunction.

Identification of fluid overload signs, for example, weight increase, increased central venous pressure, imaging evidence of pulmonary edema, and reduced urine output, is important. Treatment options involve restriction of fluid, diuretics (ideally loop diuretics), and ultrafiltration in extreme situations. Cumulative fluid balance monitoring at the bedside is an accessible practical tool that must inform continuing management.

Short description of condition-specific fluid strategies:

Sepsis and septic shock:

Fluid resuscitation in sepsis is a management cornerstone. Early Goal-Directed Therapy (EGDT), previously revolutionary, has been moderated by studies such as ProCESS, ARISE, and ProMISe, revealing that protocolized fluid and vasopressor treatment did not enhance outcomes over conventional care. A more tailored approach is now promoted, with careful respect for fluid responsiveness, lactate clearance, and organ perfusion. Balanced crystalloids are often used in sepsis with lower risk of AKI.

Trauma and hemorrhagic shock:

Control of bleeding in trauma is urgent. Fluid resuscitation has to be balanced so that it does not create dilutional coagulopathy or exacerbate bleeding. The peri-spmetic hypotension concept—of keeping a less-than-normal systolic blood pressure until the bleeding is under control—is reasonable in some trauma situations, particularly in penetrating trauma. Whole blood and component therapy are given priority in massive hemorrhage protocols, with crystalloids being used as adjuncts.

Acute kidney injury (AKI):

The evolution or aggravation of AKI has a close relationship with fluid therapy. Both fluid overload and hypovolemia can lead to renal damage. Avoidance of nephrotoxic colloids (such as HES), using balanced crystalloids, and renal replacement therapy early if needed are main strategies. Post-resuscitation conservative fluid management could promote renal recovery.

Cardiac conditions:

In cardiogenic shock or heart failure patients, fluid resuscitation should be undertaken with extreme care. Over-resuscitation may lead to pulmonary edema as well as worsen cardiac output. Monitoring of hemodynamics—especially invasive monitoring and echocardiography—is crucial. Such patients might be more helped by vasopressor or inotrope support than by vigorous fluid loading.

Postoperative patients:
Fluid management in the surgical ICU is dependent on the type of surgery and intraoperative course. Enhanced Recovery After Surgery (ERAS) protocols recommend minimal perioperative fluid excess and early restoration of enteral hydration. Fluid therapy in the postoperative period should include maintenance for ongoing, insensible, and renal losses. Elimination of unnecessary maintenance fluids and early mobilization are also recommended.

Emerging concepts and future directions:
A number of novel trends are also remodelling ICU fluid management. Fluid stewardship is one of those developments, a practice similar to antimicrobial stewardship, where fluid use is closely monitored, justified, and tailored to the individual. The concept is to have fluids treated like pharmacologic agents with indications, contraindications, doses, and side effects. The use of individualized fluid therapy—driven by genomics, biomarkers, and real-time analytics—is another topic that is exciting. Although still in the nascent stage, this has the potential to individualize fluid therapy based on patient-specific responses and disease phenotypes. Artificial intelligence (AI) and machine learning are also being adopted within ICU care. Machine learning using predictive algorithms to analyze hemodynamic trends, lab results, and ventilator settings can be used to help clinicians predict fluid requirements, detect responders, and prevent complications. Decision-support systems with AI could soon become a part of managing fluid therapy with accuracy.
Hemodynamic coherence is a more recent one highlighting the fact that macro-circulatory goals (such as MAP and CVP) do not always portend micro-circulatory perfusion. Measures measuring sublingual microcirculation or tissue oxygen saturation are potentially superior endpoints to use to direct fluid therapy in some situations. [5] Lastly, the addition of point-of-care ultrasonography (POCUS) has transformed bedside evaluation. With swift, reproducible, and non-invasive assessment of cardiac function, IVC responsiveness, lung edema, and volume status, POCUS is now a routine tool in most ICUs for fluid management guidance.

Challenges in practice:
In spite of such advances, fluid therapy is still plagued with difficulty. Inter-patient heterogeneity, dynamic and changing clinical circumstances, and limitations in the monitoring technologies render decision-making difficult. Fluid therapy is much like a "trial-and-error" process where early responses need to be repeatedly re-evaluated. Further, availability issues, unavailability of sophisticated monitoring, and differences in experience in POCUS or hemodynamic interpretation might restrict optimal practice in most environments.
Additionally, the understanding of cumulative fluid balance can be challenging owing to inaccuracy in fluid input/output charting, undocumented insensible losses, and variability in vascular permeability. Defining optimal and reproducible endpoints for fluid resuscitation is elusive in most conditions. Ethical issues also arise in end-of-life care. [1] Deciding when to withhold fluids in dying patients, weighing comfort against physiologic needs, and reconciling fluid decisions with patient or family wishes demand careful, multidisciplinary consideration.

Future directions in iv fluid administration in critical illness:

The intravenous fluid management of critically ill patients is on the cusp of change with advances through innovation, integration, and individualization. As evidence builds, critical care moves away from universal protocols to more patient-tailored, evidence-based approaches recognizing the individuality and heterogeneity of fluid requirements across different clinical scenarios.

Integration of precision medicine:
Precision medicine—shaping treatment to a person's genetic, environmental, and lifestyle variables—is slowly starting to gain its position in fluid therapy. Pharmacogenetics and genomic profiling could, in the future, assist in the identification of patients at increased risk for fluid overload, capillary leak, or fluid-refractory shock. These findings may direct not only the volume but also the type of fluid given, making therapy more effective and targeted.

Artificial intelligence–driven decision support:
With the burst of ICU data from monitors, ventilators, and electronic health records, AI can transform fluid management. Future systems will incorporate predictive algorithms continuously monitoring patient trajectory, proposing fluid adjustments in real time on the basis of minute-to-minute trends in vital signs, urine output, laboratory tests, and imaging findings. These systems will function as clinical co-pilots, assisting but not supplanting human decision-making.

Advanced microcirculatory monitoring:
Subsequent fluid management might transfer its interest away from maintaining macrocirculatory targets (e.g., MAP, CVP) and toward optimal microcirculatory and cellular perfusion. Technologies that can assess minimal perfusion deficits on the tissue level, like near-infrared spectroscopy (NIRS) or video-capillaroscopy, will become able to redefine endpoints of fluid resuscitation. Integration of these devices into clinical routine will increase the accuracy of therapy and prevent under- or over-resuscitation.

Tailored goal-directed therapy protocols:
Goal-directed fluid therapy (GDFT) will increasingly be personalized. In its current form, GDFT is based on population-derived goals (e.g., SVV, CO), but in the future, it will probably take into account patient-specific hemodynamic baselines, disease phenotypes, and reaction to past interventions. Automated algorithms adjusting GDFT according to the changing physiology of a patient will allow for a closed-loop system of fluid management.

Creating Safer, Smarter Fluids:
Biochemists and pharmacologists are formulating next-generation IV solutions—solutions that not only replace volume loss but also modulate the immune system, stabilize the endothelium, or deliver therapeutic agents. These include cytokine-enriched fluids containing anti-inflammatory cytokines, oxygen carriers, or antioxidants. These "intelligent fluids" would have the potential to deliver two advantages: hemodynamic support and cellular protection.

Remote monitoring and telecritical care applications:

With advances in wearable sensors and remote connectivity, fluid monitoring can potentially be taken outside the ICU. Post-ICU step-down or home-based recipients of critical care could have their hydration status and fluid balance monitored remotely. Tele-ICU platforms may incorporate AI and wearable technology to provide continuity of care and timely fluid intervention.

Global standardization and adaptability:
Whereas fluid management is evolving in affluent settings, gaps persist worldwide. The future will have to be directed at unifying fluid protocols, developing scalable and flexible guidelines that will be effective in both resource-rich and poor settings. Cost-effective diagnostic technology, low-tech monitoring approaches, and modular training programs will be fundamental in making the improvements equitable.

Educational reforms and simulation-based training:
As fluid management is increasingly complex, the call for better education increases. Training in the future will involve simulation-based learning, virtual reality modules, and interactive AI tutors to educate on dynamic fluid assessment, POCUS interpretation, and predicting fluid responsiveness. Equipping clinicians with ability to use advanced technologies safely and effectively will become crucial.

Ethical and palliative considerations:
Future practice will need to deal with the ethical aspects of fluid therapy, particularly in the end stages of life. Ongoing trials of patient-centered outcomes, quality of life measurements, and family-reported outcomes will dictate guidelines for escalation, maintenance, or withholding of fluids, specifically in terminal or non-recoverable illness.

Real-world data and learning health systems:
Last but not least, the future of fluid management will be informed by real-world data captured from a wide range of ICUs. Learning health systems will update fluid protocols continuously based on the learnings from large, multicenter databases. These dynamic frameworks will make fluid management approaches up-to-date, evidence-based, and agile to address evolving clinical realities.

Conclusion:
Intravenous fluid administration is still a pillar of intensive care practice, but it is now acknowledged as a sophisticated and powerful intervention and no longer a harmless practice. IV fluids are pharmacological drugs with strong physiological actions, and their abuse can cause serious adverse effects, particularly in patients who are critically ill and whose conditions are unstable and unpredictable. Contemporary fluid therapy follows a step-wise approach, synchronizing therapy with the patient's developing requirements—from resuscitation to stabilization and eventual weaning. Fluid choice, whether crystalloids or colloids, balanced or unbalanced, has to be judicious, with crystalloids, and especially balanced solutions, as the basis for most therapy, with the use of colloids such as albumin being limited to special indications, and synthetic colloids being avoided as much as possible on safety grounds. Dynamic fluid responsiveness can be optimally monitored with bedside ultrasound and more

sophisticated hemodynamic monitoring to facilitate timely, individualized decision-making. Individualized care based on the patient's personal physiological profile, disease state, and reaction to previous treatment is replacing strict protocols. Technologies like artificial intelligence and microcirculatory monitoring are also improving fluid stewardship precision. In spite of these improvements, practical use is still tricky, requiring constant watchfulness, repeated re-evaluation, and extensive interaction among medical practitioners. Above all, successful fluid therapy in the ICU is all about attaining the fine equipoise between under-treatment and over-treatment where each drop is as much a measure of quantity as of its effect on patient outcomes.

References:

1. Vincent JL. Fluid management in the critically ill. Kidney Int. 2019 Jul;96(1):52-57.
2. Lewis SR, Pritchard MW, Evans DJ, Butler AR, Alderson P, Smith AF, Roberts I. Colloids versus crystalloids for fluid resuscitation in critically ill people. Cochrane Database Syst Rev. 2018 Aug 3;8(8):CD000567.
3. Perel P, Roberts I. Colloids versus crystalloids for fluid resuscitation in critically ill patients. Cochrane Database Syst Rev. 2011 Mar 16;(3):CD000567.
4. Liu C, Mao Z, Hu P, Hu X, Kang H, Hu J, Yang Z, Ma P, Zhou F. Fluid resuscitation in critically ill patients: a systematic review and network meta-analysis. Ther Clin Risk Manag. 2018 Sep 12;14:1701-1709.
5. Haase N, Perner A, Hennings LI, Siegemund M, Lauridsen B, Wetterslev M, Wetterslev J. Hydroxyethyl starch 130/0.38-0.45 versus crystalloid or albumin in patients with sepsis: systematic review with meta-analysis and trial sequential analysis. BMJ. 2013 Feb 15;346:f839.
6. Zarychanski R, Abou-Setta AM, Turgeon AF, Houston BL, McIntyre L, Marshall JC, Fergusson DA. Association of hydroxyethyl starch administration with mortality and acute kidney injury in critically ill patients requiring volume resuscitation: a systematic review and meta-analysis. JAMA. 2013 Feb 20;309(7):678-88.
7. Arabi YM, Belley-Cote E, Carsetti A, De Backer D, Donadello K, Juffermans NP, Hammond N, Laake JH, Liu D, Maitland K, Messina A, Møller MH, Poole D, Mac Sweeney R, Vincent JL, Zampieri FG, AlShamsi F; European Society of Intensive Care Medicine. European Society of Intensive Care Medicine clinical practice guideline on fluid therapy in adult critically ill patients. Part 1: the choice of resuscitation fluids. Intensive Care Med. 2024 Jun;50(6):813-831
8. Finfer S, Liu B, Taylor C, Bellomo R, Billot L, Cook D, Du B, McArthur C, Myburgh J; SAFE TRIPS Investigators. Resuscitation fluid use in critically ill adults: an international cross-sectional study in 391 intensive care units. Crit Care. 2010;14(5):R185.
9. Bunn F, Trivedi D, Ashraf S. Colloid solutions for fluid resuscitation. Cochrane Database Syst Rev. 2008;17:CD001319.
10. The SAFE Study Investigators. Saline or albumin for fluid resuscitation in patients with traumatic brain injury. N Engl J Med. 2007;357:874–884.
11. Rivers E, Nguyen B, Havstad S, Ressler J, Muzzin A, Knoblich B, Peterson E, Tomlanovich M. Early Goal-Directed Therapy Collaborative Group. Early goal-

directed therapy in the treatment of severe sepsis and septic shock. N Engl J Med. 2001;345:1368–1377.
12. Casey JD, Brown RM, Semler MW. Resuscitation fluids. Curr Opin Crit Care. 2018 Dec;24(6):512-518.
13. Schortgen F, Tabra Osorio C, Carpentier D, Henry M, Beuret P, et al; Save Useless Fluids For Intensive Resuscitation (SUFFIR) Study Group, Reseau European de Recherche en Ventilation Artificielle (REVA) Network. Fluid Intake in Critically Ill Patients: The "Save Useless Fluids For Intensive Resuscitation" Multicenter Prospective Cohort Study. Crit Care Med. 2024 Feb 1;52(2):258-267.
14. Zampieri FG, Bagshaw SM, Semler MW. Fluid Therapy for Critically Ill Adults With Sepsis: A Review. JAMA. 2023 Jun 13;329(22):1967-1980.
15. van Haren F. Personalised fluid resuscitation in the ICU: still a fluid concept? Crit Care. 2017 Dec 28;21(Suppl 3):313.
16. Malbrain ML, Marik PE, Witters I, Cordemans C, Kirkpatrick AW, Roberts DJ, Van Regenmortel N. Fluid overload, de-resuscitation, and outcomes in critically ill or injured patients: a systematic review with suggestions for clinical practice. Anaesthesiol Intensive Ther. 2014 Nov-Dec;46(5):361-80.
17. Dong WH, Yan WQ, Song X, Zhou WQ, Chen Z. Fluid resuscitation with balanced crystalloids versus normal saline in critically ill patients: a systematic review and meta-analysis. Scand J Trauma Resusc Emerg Med. 2022 Apr 18;30(1):28.
18. Frazee E, Kashani K. Fluid Management for Critically Ill Patients: A Review of the Current State of Fluid Therapy in the Intensive Care Unit. Kidney Dis (Basel). 2016 Jun;2(2):64-71.

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