

A nursing-led sepsis response team guiding resuscitation with point-of-care ultrasound: A review and model for improving bundle compliance while individualizing sepsis care

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Abstract

A dysregulated host response to infection resulting in life-threatening organ dysfunction defines the onset of sepsis. Unfortunately, sepsis is common, costly, and deadly. The Surviving Sepsis Campaign publishes regularly updated, evidence-informed, detection, and treatment guidelines culminating in time-sensitive care “bundles.” The goal of these bundles is to expedite sepsis recognition because it is widely held that early treatment is life-saving. Hospitals are mandated to publicly report their bundle compliance, and this will soon be tied to hospital reimbursement. For these reasons, hospitals are creating sepsis emergency response teams which are a form of a rapid response team consisting of dedicated medical professionals who evaluate patients with suspected sepsis and initiate therapy when appropriate. Evidence to date support sepsis emergency response teams as a mechanism to improve bundle compliance, and potentially, patient outcome. Nevertheless, some elements of bundled sepsis care are controversial (e.g., intravenous fluid administration) as some argue that mandated treatment precludes personalized care. Herein, we briefly describe general sepsis emergency response team structure, review evidence supporting sepsis emergency response teams to improve bundle compliance and patient outcome and report our unique experience incorporating point of care ultrasound—to guide intravenous fluid—into a nursing-led sepsis team. We propose that our sepsis emergency response team approach allays concern that sepsis care is either bundled or personalized. Instead, incorporating point of care ultrasound into a nursing-led sepsis emergency response team increases bundle compliance *and* individualizes care.

Keywords

Severe sepsis, septic shock, point-of-care ultrasound, wearable technology, sepsis response team, nursing-led, fluid resuscitation, review

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Introduction

Sepsis is life-threatening organ dysfunction due to a dysregulated host response to infection.¹ Though the nomenclature has changed in recent years, herein “sepsis” refers to infection associated with organ dysfunction, similar to the former definition of “severe sepsis.” Sepsis and septic shock are common, highly mortal conditions.² Indeed, there were between 300 and 1000 cases of sepsis per 100,000 people in the United States (US) in the first decade of the 21st century, and that number is increasing³; in-hospital mortality for sepsis ranges between 20% and 40%.^{4–6} From a global perspective, approximately 1-in-5 deaths are attributed to sepsis.⁷

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Table 1. Basic SERT components.

SERT component	Description
“Central nervous system” or administrative	Plans, obtains resources, educates, implements, and structures the SERT. This often begins by identifying, supporting and empowering local SERT champions
“Afferent limb”	Like a sensory nerve obtaining environmental data. This part of the SERT searches for and detects patients with sepsis or septic shock. The afferent limb uses clinical signs and symptoms that are, ideally, both sensitive and specific for identifying sepsis. Traditionally, early recognition of sepsis belonged to bedside clinicians. ²² Increasingly, the afferent limb is supplemented by electronic medical records that scan patient data for early warning. ^{27,28}
“Efferent limb”	Includes mobile resources (personnel with defined competencies and specialized equipment) that arrive quickly, assess, and intervene early
“Quality assurance” or feedback	By measuring and monitoring intended SERT outcomes, adjustments can be made, iteratively, for process improvements to the afferent and efferent elements. This final SERT component is often part of the aforementioned “administrative” arm. ²²

SERT: sepsis emergency response team.

Additionally, sepsis is costly. In the United States in 2013, sepsis care cost approximately \$23 billion⁸; unsurprisingly, sepsis is associated with a 75% longer inpatient stay.⁹ Thus, it is widely accepted that prompt recognition and treatment of sepsis is imperative to reduce its human and financial burden.^{10–12}

Therapy for sepsis and septic shock continues to evolve. Since Rivers and colleagues published the landmark Early Goal Directed Therapy (EGDT) protocol in 2001,¹³ the Surviving Sepsis Campaign (SSC) has published numerous guidelines on sepsis and septic shock management.¹⁴ As a result of the 2012 SSC update, the New York State Department of Health (NYSDOH) mandated that all hospitals in New York State follow evidence-based protocols for identifying and treating sepsis and septic shock.¹⁰ The protocols included a 3-h bundle consisting of: (1) blood cultures before antibiotics, (2) serum lactate level, and (3) broad-spectrum antibiotics, all completed within 3 h. Furthermore, these protocols also required a 6-h bundle that includes an intravenous (IV) bolus of 30 mL/kg of body weight of crystalloid in patients with hypotension or a serum lactate level of 4.0 mmol or more.¹⁵ The 6-h bundle also included vasopressors for refractory hypotension, and repeat serum lactate within 6 h of protocol initiation. Despite mixed evidence regarding efficacy of these bundles,^{6,11} (especially with respect to IV fluid resuscitation),¹⁰ the SSC has recently mandated 1-h completion of the aforementioned.^{16–19} Furthermore, bundle compliance must be reported publicly by all hospitals in the United States and will be tied to reimbursement beginning in 2026 as a part of the Centers for Medicare and Medicaid Services (CMS) value-based care initiative. Given the clinical and financial importance of recognizing and treating sepsis expeditiously, interest in sepsis emergency response teams (SERTs) is growing. A SERT is similar to rapid or pulmonary embolism response team (i.e., RRT, PERT), however, focused on identifying and treating sepsis and septic shock.^{20,21}

Over the last 2 decades, observational studies on the efficacy of SERTs have been published and reviewed. These

studies often showed that SERT implementation associates with reduced sepsis mortality and, almost ubiquitously, increases guideline or bundle compliance. As outlined by both Funk et al.²² as well as Bloos,²⁰ a SERT is characterized by its organization, trigger, response (including personnel and equipment) and quality improvement mechanism. Using this framework as a point-of-departure, we review and summarize basic elements of a SERT, give an overview of previously reported SERT investigations and describe our unique experience led by nurses trained in point-of-care ultrasound (POCUS).²³ We argue that nurses using POCUS can improve bundle compliance *and* individualize IV fluid therapy early in the care of sepsis and septic shock.

A brief overview of sepsis response team structure

Early identification of patients with sepsis and septic shock by a “sepsis emergency response team” (SERT) is believed to improve outcomes.^{20–22,24} A SERT is defined as a form of a rapid response team (RRT) consisting of dedicated medical professionals who clinically evaluate patients suspected to have sepsis and initiate therapy when appropriate.²¹ Fundamentally, for a SERT to be successful it should contain four basic parts^{22,25,26} (Table 1).

Afferent arm

Although an exhaustive review of SERT triggers is beyond the scope of this manuscript, a brief explanation is warranted. Both Bloos and Uffen and colleagues have provided up-to-date overviews on SERT alerts.^{20,21} Usually, the goal of a screening tool is to be overly sensitive (i.e., minimize false negatives) while accepting diminished specificity (i.e., tolerate more false positives). The downside to decreased specificity is that too many false positive alerts can cause “alarm fatigue.”^{27–30} In general, in the emergency department, the presence of at least two markers of the systemic inflammatory response syndrome (SIRS) has good sensitivity but

variable or poor specificity for predicting life-threatening organ dysfunction due to infection.²¹ This explains why the presence of SIRS has only a weak association with mortality.^{31,32} Another clinical score used to predict sepsis is a derivative of the SOFA score, the “quick” SOFA or qSOFA.³² The ability of qSOFA to detect sepsis suffers from the “opposite” problem of the SIRS criteria. That is, qSOFA of at least two has a very good specificity (i.e., there are fewer false positives, which reduces alarm fatigue) and is a good predictor of death or ICU admission.³³ Unfortunately, qSOFA can have quite low sensitivity.^{34,35} In other words, a clinically significant proportion of patients in the ED who go on to develop life-threatening organ dysfunction do not have at least two qSOFA early in their care. Given that screening tests should minimize false negatives (i.e., have high sensitivity), qSOFA is a less-appealing trigger.^{36,37}

Efferent arm

There is great heterogeneity in SERT composition. The efferent arm (i.e., the personnel and equipment brought to the patient) may be composed of trainees (e.g., residents or fellows), critical care physicians, nurses and nurse practitioners, infectious disease specialists, phlebotomists, lab runners, radiology technologists, respiratory therapists, pharmacists, and bed coordinators. Their equipment and resources include, but are not limited to antibiotics, fluids, venous access tools, vasoactive medications, respiratory support,¹⁵ and portable ultrasound technology for hemodynamic assessment, as described below.

SERT implementation: Effects on guideline compliance and hospital mortality

As this was a literature review, approval by a research ethics board and patient consent were unnecessary. We conducted a PubMed search for SERT studies published through December 31, 2023. Additionally, we screened all the of the references of the investigations and reviews that we identified. Only full manuscripts (i.e., not abstracts) in the English language were considered further. We included investigations with a dedicated SERT (i.e., additional personnel with or without specialized equipment presenting to the patient’s bedside), and that reported the effect of SERT implementation on guideline (or bundle) compliance and/or in-hospital mortality compared to no SERT. If the study reported only single elements of contemporary SEP-1 bundle compliance (e.g., time to antibiotics, lactate draw, cultures, etc.), it was included.

SERTs are itemized below based on whether they were led by nurses or nurse practitioners, what the afferent and efferent arms were, and whether POCUS was used to individualize resuscitation. We identified 34 studies and 26 are summarized below. The reasons for excluding the eight

investigations are elaborated in the supplementary material.^{38–45} Changes in guideline or bundle compliance or mortality are listed based upon statistical significance (i.e., $p < 0.05$ or less), unless otherwise stated.

Table 2 shows heterogeneity among the studies. This is best illustrated by the variation in baseline mortality rate (i.e., mortality prior to implementation of SERT or mortality rate of non-SERT treated patients) which ranged from 4% to 68% (median 25%, IQR: 13%–37%). Differences in patient population and time may explain this dissimilarity. For example, the study with the highest baseline mortality rate studied patients between 2005 and 2007, required organ dysfunction for SERT activation and included inpatients,⁴⁶ while the study with the lowest baseline mortality rate took place between 2016 and 2018, could have included patients meeting only two SIRS criteria (i.e., without organ dysfunction), and was restricted to the ED (i.e., early in disease course).⁶⁷ The median mortality change was an 8% reduction (i.e., –8%; IQR: –5% to –18%), though not all of the studies reporting reduced mortality were statistically significant. Of the 26 studies in Table 2, 13 (50%) found a statistically significant reduction in mortality associated with SERT implementation. The remaining 13 studies (50%) either found no significant change (i.e., 9 studies) or did not report or perform a statistical evaluation (i.e., 2 studies reported mortality change without statistical analysis and two studies did not report mortality numbers). When comparing hospital mortality prior to SERT implementation to after SERT implementation for the 24 studies that reported mortality, we found a significant decrease in associated mortality by student *t*-test (Figure 1); all data had normal distribution by the Kolmogorov–Smirnov test.

Compliance with contemporary SSC guideline elements was ubiquitously improved by SERT as compared to no SERT. Because the definition of bundle compliance has changed over the last 20 years, we looked for whether SERT implementation associated with a statistically significant improvement in any or all of: antibiotic administration, blood culture or lactate collection, intravenous fluid provision or MAP goals for patients with sepsis or septic shock.¹⁵ All studies that we located showed clinically and statistically significant improvement in at least one of these elements when SERT was implemented.

Limitations

Although these findings are noteworthy, causal inference cannot be drawn from the investigations reviewed in Table 2. As mentioned by Bloos,²⁰ before-and-after studies are quasi-experimental and at high risk of bias.^{20,72} Similar association between traditional RRT implementation and reduced mortality was observed, however, a randomized trial did not show significant benefit.⁷³ Furthermore, our review was not systematic, and we did not perform a funnel plot, so our search methodology as well as publication bias could partially account for these results. Thus, the effect on mortality

Table 2. Overview of included SERT studies.

Study	RN or NP led?	SERT call-point	Afferent arm	Efferent arm	POCUS used	SSC guideline or bundle compliance	Hospital mortality
Giradis et al. ⁴⁶	No	Hospital wide	≥ 2 SIRS criteria plus organ dysfunction	ICU and infectious disease attending physicians	Not mentioned	Improved	Decreased
Schramm et al. ⁴⁷	No	ICU	≥ 2 SIRS criteria plus organ dysfunction	ICU physician, nurse, respiratory therapists, pharmacist, vascular access technician, portable radiology technician, and the medical ICU secretary	Not mentioned	Improved	Decreased
Shiramizo et al. ⁴⁸	No	Hospital wide	≥ 2 SIRS criteria plus organ dysfunction	ICU MD and managing nurse	Not mentioned	Improved	Decreased
LaRosa et al. ⁴⁹	No	Hospital wide	≥ 2 SIRS criteria plus organ dysfunction	ICU MD, ICU RN, respiratory therapist, and pharmacist	Not mentioned	Improved	Decreased
Berg et al. ⁵⁰	No	Hospital wide	≥ 2 SIRS criteria plus organ dysfunction	Trauma surgeon, trauma NP or PA, SICU RN, RT, anaesthesiologist, and ICU pharmacist	Not mentioned	Improved (MAP goal and CVP measurement only)	No change
Seoane et al. ⁵¹	No	ED or floors	RRT activation on floor with ≥ 2 SIRS criteria plus 2 organ failures or serum lactic acid ≥ 4.0	Experienced ICU nurse, respiratory therapist with backup from the ICU resident	Not mentioned	Improved	Not reported
Benson et al. ⁵²	Yes	Medical and surgical floors	≥ 2 SIRS criteria (however, HR ≥ 120bpm; RR ≥ 26 bpm)	Nurse practitioner	Not mentioned	Improved	No change
Flynn et al. ⁵³	No	ED, floors, ICU	≥ 2 SIRS criteria + order set by provider	Pharmacists, nursing RRT, bed control, and materials management with a "sepsis cart"	Not mentioned	Improved	No change
Jones et al. ⁵⁴	Yes	Floors	≥ 4 on an "early sepsis screening tool"	NP	Not mentioned	Not reported	Decreased
Umscheid et al. ⁵⁵	No	Inpatient acute care services	Novel EWRS score of at least 4	Covering physician (e.g., intern), the bedside RN, and rapid response coordinators	Not mentioned	Improved	No change
Greik et al. ⁵⁶	No	ED	≥ 2 SIRS criteria plus organ dysfunction	ICU attending and fellow or resident, NP/PA, nursing supervisor, and pharmacist	Not mentioned	Improved (no <i>p</i> -value reported)	Decreased
Hayden et al. ⁵⁷	No	ED	≥ 2 SIRS criteria plus organ dysfunction (SWAT-A)	ED attending, ED technician, additional ED RN, radiology technician, pharmacist, pulmonary fellow as needed	Not mentioned	Improved	No change
Arabi et al. ⁵⁸	No	ED	≥ 2 SIRS criteria plus organ dysfunction	ICU physician and sepsis-trained RN	Not mentioned	Improved	Decreased
Guirgis et al. ⁵⁹	No	Hospital wide	≥ 2 SIRS criteria plus new altered mental status, or a systolic blood pressure ≤ 90 mm Hg, or a serum lactate level ≥ 3 mmol/L; rising MEWS-SRS of at least 5 triggered "possible sepsis"	RRT nurse, clinical pharmacist, and a respiratory technician (for general floor patients)	Not mentioned	Not reported	Decreased
Maclay and Rephann ⁶⁰	Yes	Floors	qSOFA ≥ 2	Critical care charge RN, respiratory therapist, laboratory phlebotomist	Not mentioned	Not reported	Decreased (no statistical analysis)

(Continued)

Table 2. (Continued)

Study	RN or NP led?	SERT call-point	Afferent arm	Efferent arm	POCUS used	SSC guideline or bundle compliance	Hospital mortality
Viale et al. ⁶¹	No	ED	≥ 2 SIRS criteria plus organ dysfunction and ED consultation	A single infectious disease attending	Not mentioned	Improved	Decreased (14-day mortality). No change for 30-day mortality
Rosenqvist et al. ⁶²	No	ED	SBP < 90 mmHg, oxygen saturation < 90%, RR > 30, HR > 130 or unconscious state plus documented or history of fever	ED and infectious disease attending	Not mentioned	Improved	No change
Thursky et al. ⁶³	No	Oncology hospital without an ED	≥ 2 SIRS criteria, or hypotension with SBP < 100 mmHg with an infection	Physician	Not mentioned	Improved	Decreased
MacMillan et al. ⁶⁴	No	MICU	≥ 2 SIRS criteria	Critical care pharmacist, phlebotomist, and the supervising resident physician	Not mentioned	Improved	No change
Delawder et al. ⁶⁵	Interdisciplinary	ED	≥ 3 SIRS criteria, 1 being either temperature or WBC criteria	Unit coordinator, technician, pharmacist, RT, and primary ED physician	Not mentioned	Improved	Decreased (no statistical analysis)
Ferguson et al. ⁶⁶	Yes	ED and inpatient floor	≥ 2 SIRS criteria	Physician, NP, or physician assistant	Not mentioned	Improved	Decreased
Whitfield et al. ⁶⁷	No	ED	≥ 2 of: temp > 100.4 or < 96.8°F, HR > 90 beats per minute, RR > 20 breaths per minute, SBP < 90 mmHg, confusion	ED MD, ED triage and charge nurses, clinical pharmacist, phlebotomist, and house supervisor	Not mentioned	Improved	Decreased
Sulliman et al. ⁶⁸	No	ED	≥ 2 SIRS criteria	ICU fellow or resident	Not mentioned	Improved	No change
Semanco et al. ⁶⁹	Yes	Acute care area	≥ 3 SIRS criteria or ≥ 2 SIRS criteria plus organ dysfunction	2 CCRNs	Not mentioned	Improved (no statistical analysis)	Not reported
Schinkel et al. ⁷⁰	No	ED	MEWS ≥ 3	On-call MD from: emergency medicine, internal medicine, and the admitting specialty	Not mentioned	Improved	No change
Simon et al. ⁷¹	No	ED	≥ 2 SIRS criteria	Primary MD, NP, PA, nurse, resource RN and ED pharmacist	Not mentioned	Improved	Decreased

RN: registered nurse; NP: nurse practitioner; POCUS: point of care ultrasound; SSC: surviving sepsis campaign; ICU: intensive care unit; SIRS: systemic inflammatory response syndrome; MD: medical doctor; RT: respiratory therapist; SICU: surgical intensive care unit; PA: physician assistant; MAP: mean arterial pressure; CVP: central venous pressure; ED: emergency department; HR: heart rate; RR: respiratory rate; bpm: beats or breaths per minute; EWRS: early warning and response system; SWAT: sepsis work-up and treatment; RRT: rapid response team; MEWS-SRS: modified early warning signs-sepsis recognition score; SBP: systolic blood pressure; °F: degrees Fahrenheit; CCRN: critical care registered nurse.

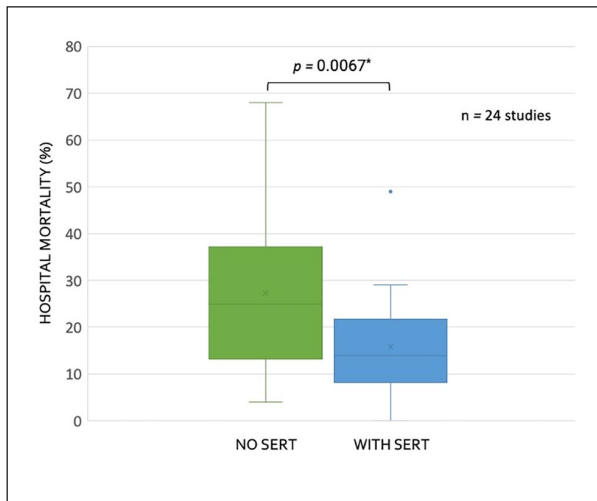


Figure 1. Box and whisker plots for reported mortality with and without sepsis emergency response team (SERT) implementation for studies ($n=24$) reporting this data in Table 2.

we report should be viewed as hypothesis-generating and warrant more rigorous study.

Sepsis emergency response team structure: Our experience

Our SERT is composed of 14 RNs with specific training in POCUS and sepsis resuscitation. The SERT RNs work in collaboration with the primary care team and present the data collected including POCUS exam imaging and fluid responsiveness. The SERT is managed by the sepsis coordinator who also employs three RN data registrars. The data registrars audit each sepsis activation, afford feedback to care providers, and present the current data to the sepsis committee.

There is a total of three SERT RNs on duty per 12-h shift. All SERT nurses have worked in the ICU or ED for a minimum of 2 years prior to joining the team; their certifications

include advanced cardiac and basic life support (i.e., ACLS, BLS), and pediatric advanced life support (PALS). SERTs may be initiated anywhere in the hospital as soon as the patient meets the internal activation criteria. The internal activation criteria utilized by our institution is defined as the presence of two or more SIRS with an end organ dysfunction and a known or suspected source of infection (Table 3).

Changes in vital signs or laboratory values can trigger Best Practice Alerts (BPAs) in the electronic medical record to help identify patients with severe sepsis while in the hospital. Once a BPA is triggered, the staff report findings to the primary care provider, who may then activate the SERT through the internal paging system. Once severe sepsis criteria are met, the SERT team is activated. The majority of activations begin in the ED. The first responders to the patient are the primary RN, the SERT RN, and pharmacist. If the patient is hemodynamically unstable, a physician will also be present. The SERT RN employs bedside ultrasound and a device to assess fluid responsiveness and/or fluid tolerance⁷⁴⁻⁷⁶; this is discussed in more detail below. The primary physician, pharmacist, and the SERT RN then discuss the plan of care, including suspected source of infection with appropriate antibiotic coverage and orders are placed to ensure that the first hour bundle is met. If a fluid bolus is ordered, the SERT nurse will continue to recheck the patient post-bolus until resuscitation goals are met. Throughout the SERT activation the RN works actively with the primary team to ensure all bundle elements are completed, and the patient receives the highest quality of sepsis care.

Concerns and considerations

Though there are benefits to having dedicated care teams, one challenge faced by the SERT is that during times of high census, it can be difficult to get timely follow-up ultrasound exams—as described below—after a fluid bolus is given, because the SERT also responds to code strokes, cardiac arrests, and rapid responses. Therefore, human resource constraints are an obvious, ubiquitous, problem. Another

Table 3. SIRS criteria and end-organ dysfunction.

SIRS criteria	Recognized organ dysfunctions
(1) Heart rate > 90 beats per min	(1) Lactate > 2 mmol/L
(2) Respiration rate > 20 breaths per min	(2) Acute altered level of consciousness (from patient's baseline)
(3) Temperature > 38 or < 36°C	(3) Systolic blood pressure < 90 mmHg or MAP < 65 mmHg
(4) White blood cell (WBC) > 12,000 or < 4,000	(4) Increased oxygen requirements including intubation, CPAP/BiPAP or ≥ 8 L/min of oxygen to maintain SpO ₂ ≥ 90%
	(5) Consistent end tidal CO ₂ of ≤ 34 mmHg or ≥ 46 mmHg
	(6) Urine output < 30 mL/kg/h for 2 h, and acute changes in creatinine > 2 mg/dL
	(7) Platelets < 100,000/μL
	(8) Total bilirubin > 2 mg/dL
	(9) INR > 1.5

Mmol: millimole; mmHg: millimeters of mercury; MAP: mean arterial pressure; CPAP and BiPAP: continuous positive and bilevel positive airway pressure, respectively; SpO₂: oxygen saturation; CO₂: carbon dioxide; L/min: liters per minute; mmHg: millimeters of mercury; mL/kg/h: milliliters per kilogram per hour; mg/dL: milligram per deciliter; mL: microliter; INR: international normalized ratio.

Table 4. Basic and advanced POCUS competencies for SERT nurses.

Basic POCUS training: Training in anatomical structures for probe placement to identify the inferior vena cava (IVC), cardiac structures, and lung landmarks. Competency in identifying and interpreting each of the below

IVC	Cardiac	Pulmonary
(1) Identification of the IVC and hepatic vein	(1) 4 windows: parasternal long and short axes, apical 4 chamber and subxiphoid views	(1) Lung sliding (normal)
(2) Measurement of the IVC collapsibility utilizing M-mode (motion mode)	(2) Identification of chambers (RV, LV, RA, LA) and valves (TV, MV, PV, AV), and LVOT	(2) A-line profiles (normal)
(3) Measurement proficiency from either a subxiphoid or transverse view 2 cm distal from the hepatic vein	(3) Qualify LV function: normal, hyperdynamic/kinetic, hypodynamic/kinetic	(3) B-lines (hyperechogenic vertical cones emanating from the pleural line, suggesting pulmonary edema in the correct clinical context)
	(4) Identify RV pressure or volume overload (D-sign or septal shift)	(4) Pleural spaces for effusions, loculations
	(5) Identify pericardial pathology	

Advanced POCUS training: Dedicated training in arterial and venous Doppler with advanced hemodynamic calculations. For example, quantification and qualification of right and left ventricular outflow tract velocity time integrals, estimating pulmonary artery systolic pressure (i.e., using the modified Bernoulli equation in the presence of tricuspid regurgitation), tricuspid annular plane systolic excursion, and VExUS

LVOT: left ventricular outflow tract; VExUS: venous excess ultrasound score; SERT: sepsis emergency response team; POCUS: point of care ultrasound; IVC: inferior vena cava. RV and LV are right and left ventricles; RA and LA are right and left atria. TV, MV, PV, and AV are tricuspid, mitral, pulmonic, and aortic valves, respectively.

challenge involved in SERT success is promoting effective team performance when caring for the acutely ill. Regular feedback from the “quality assurance” arm of the SERT in addition to peer-to-peer feedback after challenging cases improves team-based care over time; others note success with simulation training for improving teamwork.⁷⁷ Finally, the methods and technologies described below do require significant capital and human investment as we have previously described.⁷⁸ While long-term, patient-centered, outcome studies using our approach and technologies are lacking, we note that a similar argument can be made for many monitoring paradigms and tools in the ED and ICU (e.g., arterial lines, end-tidal carbon dioxide, pulse oximetry) where data are used to make physiologically guided decisions without obvious mortality benefit in a wide diversity of patients. Indeed, using point of care ultrasound to guide fluid resuscitation is a nascent area of research with a small and conflicted body of evidence to date.^{79–81}

Integrating point of care ultrasound into our SERT

In order to reduce mortality associated with sepsis, early recognition, source control, and antimicrobial therapy are essential.^{12,14} Nevertheless, there is controversy regarding SSC bundle compliance and patient outcome,^{6,11,16,17,19,21} especially with regards to IV fluid provision.¹⁰ Criticism of mandated IV fluid administration to septic patients ultimately reduces to the tension between “guideline-based” and “personalized” medicine. That is to say, following “check boxes” disconnects the clinician from deliberating each patient’s unique presentation, pathology, physiological reserve, and therapy.¹⁷ On the other hand, proponents of guidelines argue

that bundles ensure basic standard-of-care for each patient, reduces practice variability and cognitive load, which can be important in fast-paced clinical scenarios.⁸² To reconcile discord between guideline-informed and bespoke therapy, our nursing-led SERT employs POCUS for each patient to gauge the risk–benefit profile of IV fluid administration.²³

POCUS training

Initially, SERT trainees receive basic POCUS instruction, which includes operating specific ultrasound machines, differentiating phased, linear, and convex array probes, and determining their optimal use. The details of heart and lung ultrasound training are outlined in Table 4.

During all sepsis activations on their shift, the trainee performs a POCUS examination with an experienced rapid response RN preceptor. All images are saved and reviewed with a physician. Each trainee reviews 10 POCUS exams and clinical assessments with the lead physician in charge of ultrasound instruction. The trainee must demonstrate aptitude in order to pass training and certify competency. Afterward, SERT RNs maintain competency by exhibiting the aforementioned POCUS skills with the lead physician instructor yearly. To illustrate the effectiveness of our training program, we conducted a prospective observational study revealing that ED physicians agreed with SERT RN POCUS assessments in 99% of cases.^{78,83}

Gauging the benefit–risk profile for IV fluids

When our SERT responds to a patient, we perform a clinical examination supplemented by POCUS to gauge the benefit–risk profile for IV fluid. We consider IV fluid like a drug with

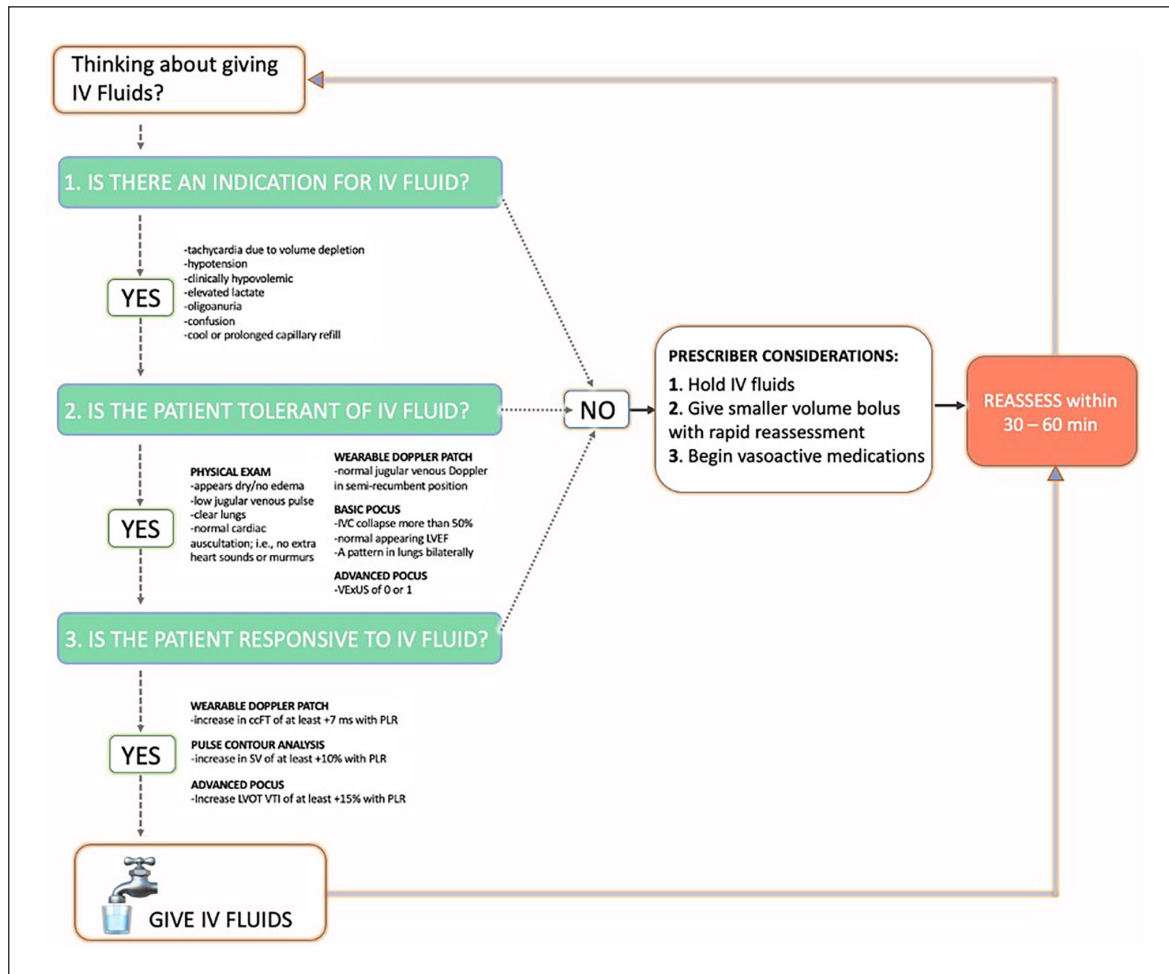


Figure 2. Overview of suggested fluid therapy pathway for our SERT.

organ-specific side-effects.^{84,85} We are particularly diligent about IV fluids because we see a high volume of septic patients with dialysis dependence, methamphetamine use, pulmonary hypertension, and congestive heart failure. As well, sepsis itself commonly associates with right ventricular dysfunction, which predicts mortality.⁸⁶ Given this, our approach to IV fluid is shown in Figure 2 and reduces to 3 basic questions:

- (1) Does the patient have a clinical indication for IV fluid?
- (2) Is the patient clinically tolerant to IV fluid?
- (3) Is the patient fluid responsive?

If the answer to all three questions is “yes,” then the patient has a high benefit–risk ratio and IV fluids are encouraged. If the answer to any of these questions is “no,” then the provider is advised to reconsider fluids or give a smaller bolus volume with rapid re-evaluation (Figure 2). Accordingly, the more of these questions that are answered “no,” the lower the benefit–risk ratio for the individual patient. Brief elaboration of these concepts is considered in turn.

Question 1: Does the patient have a clinical indication for IV fluid?

While this question is obvious, it is sometimes forgotten. Like any drug, there should be a clinical need prior to provision.⁸⁴ If there is no need, then the therapy should be reconsidered. How do we assess need for IV fluid? Because the heart pumps blood volume to the organs and tissues, we look for signs and symptoms that this particular function (i.e., stroke volume or cardiac output) is impaired. A good list is the “10 signs of vitality” enumerated by Funk et al.²² Of the 10, we pay particular attention to: unexplained tachycardia (i.e., not from pain, anxiety, fever, medication effect/withdrawal, etc.), hypotension (i.e., systolic blood pressure less than 90 mmHg or MAP less than 60–65 mmHg), tachypnea, diminished consciousness, oligoanuria (i.e., 30 mL/h for 5 h or <100 mL/4h—excluding renal failure), capillary refill longer than 3 s,⁸⁷ and elevated serum lactate. Though not specific, each of these markers could indicate reduced cardiac output and, therefore, oxygen delivery to organs and tissues. If any are present, then an indication for IV fluid (i.e., to augment stroke volume and cardiac output) is present; we

then turn to assessing the patient's safety profile for IV fluid, considered below in questions 2 and 3.

Question 2: Can the patient clinically tolerate IV fluids?

Within the sphere of critical care medicine, the entity of "fluid tolerance" has recently emerged.^{74,76,88} Nevertheless, this concept is a time-honored question grounded in the physical exam. Very simply, a patient can "tolerate" IV fluid volume if there are no signs of venous hypertension (i.e., venous congestion) or overt fluid overload. On examination, this is displayed by sunken eyes, reduced skin turgor, lack of underarm sweat, the absence of pre-tibial edema, jugular venous pulsations below the clavicle and normal cardiac and pulmonary auscultation (e.g., absence of murmurs, rubs, gallops, and bilateral crackles).⁸⁹ We supplement the clinical exam with both basic and advanced POCUS including data from a new wireless, wearable ultrasound Doppler.^{90–95} Specifically, we evaluate for ultrasound signs of venous hypertension/congestion by looking for an inferior vena cava with less than 50% collapse on inspiration (i.e., a sign that the CVP is more than 10 mmHg),⁹⁶ reduced left ventricular (LV) ejection fraction (i.e., a LV high end-diastolic volume), bilateral B-lines on lung ultrasound (i.e., an ultrasonographic sign of pulmonary edema),^{97,98} or internal jugular venous Doppler signals consistent with high CVP in the semirecumbent position ascertained by the wearable Doppler device.⁹⁰ Furthermore, some of the SERT team is comfortable with advanced POCUS measures of venous hypertension, including the venous excess ultrasound score (VExUS).⁹⁹ We consider a VExUS score of 2 or more abnormal.^{88,100} We note that the LV assessment is a qualitative one and that integrating more advanced, objective measures such as mitral annular plane systolic excursion (MAPSE), e-point septal separation (EPSS), and fractional area changes are advanced measures that could reduce operator bias. If there are no physical or ultrasound exam findings concerning for venous hypertension or fluid overload, then the patient is considered "fluid tolerant," and we proceed to question 3.

Question 3: Is the patient fluid responsive?

Fluid (or preload) responsiveness is a broad topic that has slowly gained traction over the last 20 years in the intensive care unit, operating room, and emergency department.^{101–103} The definition of fluid responsiveness is a 10%–15% increase in stroke volume or cardiac output (i.e., SV or CO) following an IV fluid bolus.¹⁰³ Measuring the change in flow from the heart (i.e., SV or CO) is critical because other measures (including blood pressure) do not adequately predict whether or not IV fluid administered to a patient actually increases the SV or CO. In other words, if you need to know if the heart will increase flow, then flow needs to be measured! To make this more concrete, consider two patients who receive

an IV fluid bolus; neither increase their mean arterial pressure (MAP). Patient A has a significant increase in SV or CO; this is quite common in sepsis (e.g., 50%–60% of patients who increase cardiac output do not increase their MAP).^{104,105} Patient A might benefit from more fluids and this clinical state would have been missed if using only MAP to guide therapy (e.g., the provider may have decided to use vasopressors prematurely). On the other hand, patient B has no change in SV or CO with IV fluids. Many patients early in sepsis care stop having a significant increase in SV or CO with IV fluids (e.g., 20%–30%).^{87,106} When these patients stop receiving IV fluid (i.e., cease trying "another bolus"), they have superior clinical outcomes and save the hospital money.^{107–109}

To test for fluid responsiveness, the SERT nurses perform a passive leg raise (PLR) maneuver^{110,111} with either SV monitoring via noninvasive or minimally invasive, uncalibrated pulse contour analysis,¹¹² or measured change in the corrected flow time of the carotid artery (ccFT)¹¹³ measured by the wireless, wearable Doppler ultrasound system.^{114–116} The change in the ccFT is measured automatically by the wearable, continuous wave, Doppler ultrasound that has a fixed, 60° insonation angle.^{94,95,117} The wireless, wearable ultrasound does not generate an image; its wide (>2 cm) ultrasound beam insonates the entire carotid artery, displays a continuous Doppler spectrogram, and automatically determines the largest change in ccFT during a 2-min PLR.^{75,93} Furthermore, some SERT RNs can measure the change in left ventricular outflow tract velocity time integral (LVOT VTI)¹¹⁸; however, this is often too cumbersome to perform with the PLR, so is rarely done. Both the ccFT and LVOT VTI are Doppler ultrasound surrogates for SV. The PLR is a maneuver where a patient is moved from the semirecumbent position to supine with the legs elevated. This mobilizes 250–300 mL of blood from the abdomen and legs to the heart, acting like an internal blood bolus.¹¹⁰ How the heart responds to this maneuver predicts how the heart will respond to IV fluids.¹¹⁹

Concerns and considerations

It is not uncommon for patients to have signs, symptoms, or ultrasound findings concerning for fluid intolerance and/or fluid unresponsiveness early in their care.^{87,106,120} More specifically, and as shown in Figure 2, if a patient has findings that suggest that fluid intolerance (e.g., distended IVC, pulsatile jugular vein Doppler or B-lines, on lung ultrasound), and/or if the patient does not have a significant increase in SV or surrogate (e.g., ccFT, LVOT VTI) with PLR, the primary provider still makes the final decision regarding IV fluid. We do not treat this algorithm dogmatically or dichotomously, there is lots of physiological "gray zone," and the response need not be "stop fluids entirely" or "keep giving fluids ceaselessly." Patients can change rapidly in the ED. Therapies such as antibiotics,

antipyretics, adrenergic agents, anxiolytics, analgesics, supplemental oxygenation, or assisted ventilation can all, theoretically, mediate how the heart responds to IV fluids within minutes-to-hours. This is because the inflammatory and sympathetic milieu change early in sepsis and following treatment. Thus, we stress re-assessment when IV fluid therapy is in doubt. Additionally, while ccFT and LVOT VTI change are clinically acceptable ways to detect fluid responsiveness with PLR,^{113,121,122} measurement error and expertise level can affect accuracy.^{123–125} Lastly, in some cases of sepsis and septic shock, patients can be so “volume down” (e.g., if there is concomitant volume loss of approximately 1.5 L or more)^{126,127} that a PLR does not adequately bolus the heart and the patient will appear fluid unresponsive. In this scenario, after giving some crystalloid (i.e., roughly 20 mL/kg), the patient can become fluid responsive after the stressed venous volume is replenished.

Conclusions

We think it is likely that hospitals and health systems will form RRTs specifically for sepsis, that is, sepsis emergency response teams (SERTs). We believe this because there is good, and growing, evidence that urgently dedicating personnel and equipment to patients with sepsis increases compliance with time-sensitive treatment bundles laid out by the SSC. Because bundle compliance will soon be tied to hospital reimbursement, financial pressure will favor common-sense solutions. We believe strongly that rapid recognition and treatment of sepsis is expedited by SERTs and this likely improves patient outcome. Indeed, our review of SERT literature shows that SERT implementation associated with decreased sepsis mortality, though study methodology and variability preclude definitive conclusions. Perhaps the most controversial aspect of the SSC bundle is IV fluid provision. To address this, our SERT has trained RNs to implement a novel, ultrasound-supplemented treatment algorithm with the goal of expediting personalized sepsis resuscitation. This treatment pathway is not rigidly prescriptive; when there is uncertainty about IV fluid, the algorithm leans on the provider’s clinical judgement and suggests more frequent reassessment, just like any therapy in medicine. The algorithm is founded on using the physical exam and ultrasound to weigh the benefit–risk ratio for each patient. Incorporating “fluid responsiveness” testing in this algorithm will be considered “best practice” by the European Society of Intensive care medicine (ESICM) and has been shown to improve clinically meaningful outcomes in patients with sepsis and is cost-saving. In summary, a nursing-led SERT with competency in basic and advanced POCUS is feasible, novel and expedites individualized sepsis resuscitation.

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Author contributions

Conceptualization, TL, JB, RAF, and KH; methodology, JN, SMK, KU, and J-ESK; formal analysis, JN, SMK, KU, and J-ESK; resources, TL, JB, RAF, and KH; data curation, JN, SMK, KU, and J-ESK; writing—original draft preparation, JN, SMK, KU, and J-ESK; writing—review and editing, TL, JB, RAF, and KH; supervision and project administration, TL, JB, RAF, and KH. All authors have read and agreed to the published version of the manuscript.

Data availability statement

Data is available upon reasonable request.

Declaration of conflicting interests

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Supplemental material

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