

Early Use of Norepinephrine in Septic Shock Resuscitation (CENSER) A Randomized Trial

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Abstract

Rationale: Recent retrospective evidence suggests the efficacy of early norepinephrine administration during resuscitation; however, prospective data to support this assertion are scarce.

Objectives: To conduct a phase II trial evaluating the hypothesis that early low-dose norepinephrine in adults with sepsis with hypotension increases shock control by 6 hours compared with standard care.

Methods: This single-center, randomized, double-blind, placebo-controlled clinical trial was conducted at Siriraj Hospital, Bangkok, Thailand. The study enrolled 310 adults diagnosed with sepsis with hypotension. The patients were randomly divided into two groups: early norepinephrine ($n = 155$) and standard treatment ($n = 155$). The primary outcome was shock control rate (defined as achievement of mean arterial blood pressure ≥ 65 mm Hg, with urine flow ≥ 0.5 ml/kg/h for 2 consecutive hours, or decreased serum lactate $\geq 10\%$ from baseline) by 6 hours after diagnosis.

Measurements and Main Results: The patients in both groups were well matched in background characteristics and disease severity. Median time from emergency room arrival to norepinephrine administration was significantly shorter in the early norepinephrine group (93 vs. 192 min; $P < 0.001$). Shock control rate by 6 hours was significantly higher in the early norepinephrine group (118/155 [76.1%] vs. 75/155 [48.4%]; $P < 0.001$). The 28-day mortality was not different between groups: 24/155 (15.5%) in the early norepinephrine group versus 34/155 (21.9%) in the standard treatment group ($P = 0.15$). The early norepinephrine group was associated with lower incidences of cardiogenic pulmonary edema (22/155 [14.4%] vs. 43/155 [27.7%]; $P = 0.004$) and new-onset arrhythmia (17/155 [11%] vs. 31/155 [20%]; $P = 0.03$).

Conclusions: Early norepinephrine was significantly associated with increased shock control by 6 hours. Further studies are needed before this approach is introduced in clinical resuscitation practice.

Clinical trial registered with www.clinicaltrials.gov (NCT01945983) (CENSER trial).

Keywords: septic shock; norepinephrine; resuscitation; early norepinephrine administration; sepsis with hypotension

Septic shock is characterized by systemic vasodilatation and vascular leakage arising from systemic inflammation induced by serious infection (1). Management, besides specific treatments consisting of antibiotics and source removal, includes effective

restoration of the hemodynamic derangement and effective organ support. Generally, intravenous fluid is given first, followed by infusion of vasopressors when the blood pressure goal is not achieved after reaching the optimal intravascular volume (2).

Recently, several studies advocated the benefits of administering norepinephrine at the beginning of resuscitation. A rat model of endotoxic shock (3) demonstrated that norepinephrine administration at the early stage of endotoxic shock improved mean

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At a Glance Commentary

Scientific Knowledge on the Subject:

Recent evidence from animal studies and retrospective human studies has indicated the efficacy of early norepinephrine administration during septic shock resuscitation. However, there was limited information from prospective randomization trials to support this postulation.

What This Study Adds to the Field:

In this double-blind, randomized, controlled trial that enrolled 310 adults with sepsis with hypotension, early norepinephrine administration resulted in a significantly higher shock control rate than standard treatment (76.1% vs. 48.4%, respectively). The findings of this study support the benefit of early administration of norepinephrine at the initiation of sepsis with hypotension resuscitation, together with fluid therapy.

arterial pressure, aortic blood flow, and sustained mesenteric blood flow. In humans, a retrospective study on a patient cohort with early norepinephrine administration revealed a shorter time to blood pressure goal achievement and favorable mortality outcome (4). Another study demonstrated increased cardiac preload and cardiac output in patients with life-threatening hypotension who received early norepinephrine after fluid replacement (5). Finally, a cohort analysis of patients who underwent septic shock resuscitation showed a mortality advantage from early norepinephrine use and illustrated the effect of delayed use of this agent (6). Notably, all of these studies were retrospective, which means that they were all subject to unavoidable selection biases, such as hypotension severity, and fluid volume administered before norepinephrine initiation. Therefore, we performed a randomized controlled trial to examine the hypothesis that administering low-dose norepinephrine at the beginning of sepsis-induced hypotension resuscitation accelerates shock control. Some of the results of these studies have been previously reported in the form of an abstract (7).

Methods

Trial Design

This phase II, randomized, double-blind, placebo-controlled clinical trial was conducted at the Department of Medicine, Faculty of Medicine, Siriraj Hospital, Mahidol University, Bangkok, Thailand during the October 2013 to March 2017 study period. Siriraj Hospital is Thailand's largest university-based national tertiary referral center. The trial was funded by Siriraj Critical Care Research Funding, and the funder had no role in the study design, analysis, or outcome assessment. The study protocol was developed by the investigator committee and approved by the Siriraj Institutional Review Board (approval no. Si 507/2013). The study complied with all of the principles set forth in the Declaration of Helsinki (1964) and its subsequent provisions. Informed consent to participate was obtained from each patient, or their legal guardian if the participant was unable to provide consent, before inclusion in the study. All participant screening and enrollment was performed by the coinvestigators (Figure 1). The details of the screening and enrollment processes are available in the online supplement. The outcome evaluation, data management, and analysis were conducted by the principal investigator and a statistician, both of

whom were blinded to the patient enrollment and treatment process.

Participant Enrollment, Randomization, and Intervention Assignment

Adults aged 18 years or older who presented at the emergency room with hypotension determined by mean arterial blood pressure (mABP) lower than 65 mm Hg and infection as the suspected cause were eligible for enrollment if they met the diagnostic criteria for sepsis according to the Surviving Sepsis Campaign: International Guidelines for Management of Severe Sepsis and Septic Shock: 2012 (8). Patients who met the septic shock diagnostic criteria for more than 1 hour before randomization and those who had acute cerebral vascular event, acute coronary syndrome, acute pulmonary edema, status asthmaticus, active cardiac arrhythmias, active gastrointestinal hemorrhage, pregnancy, seizure, drug overdose, burn injury, trauma, requirement for immediate surgery, or advanced-stage cancer were excluded. Patients who signed to refuse medical treatment, including fluid resuscitation, vasopressor, and endotracheal intubation, were also excluded.

After enrollment, patients were randomly assigned in a 1:1 ratio by their sequential number of enrollment to receive either early norepinephrine administration

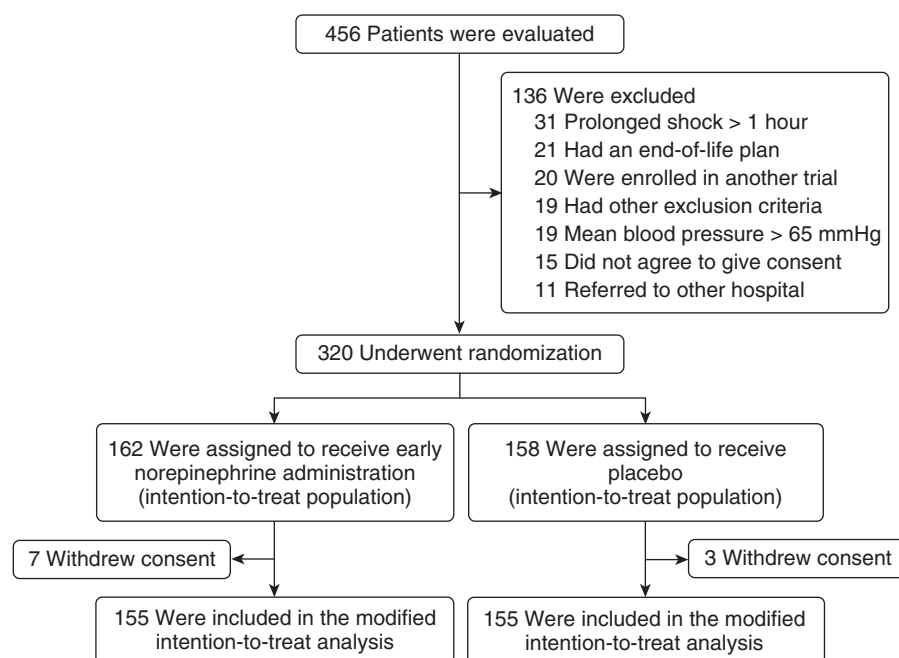


Figure 1. Flow diagram describing the screening, recruitment, and randomization of patients.

(early norepinephrine group) or placebo (standard treatment group), together with fluid resuscitation at the initiation of hypotension resuscitation. Randomization was performed using a computer-generated randomization table derived from www.randomization.com. This process was performed by an investigator (S.T.) who had no other role in patient enrollment or management. The other investigators, the patients, the patients' relatives, the attending physicians, and the nurses were all blinded to the study assignment. The study drug (norepinephrine or placebo) was prepared by a pharmacist, who had no other role in the trial. The study drugs were packaged in identically shaped containers labeled with sequential numbers according to the randomization table order. For the study drug, 4 mg of norepinephrine was mixed with 250 ml of 5% dextrose in water (5%D/W), giving a final norepinephrine concentration of 16 µg/ml. For the placebo comparator, 250 ml of 5%D/W was prepared. The study drug was infused via either peripheral line or central venous catheter (when available) at an individually adjusted rate according to the patient's body weight to achieve a dose of norepinephrine of 0.05 µg/kg/min. The study drug was infused for a period of 24 hours without titration in both groups.

All eligible patients received treatment for septic shock according to the Surviving Sepsis Campaign: International Guidelines for Management of Severe Sepsis and Septic Shock: 2012 (8). This included infusion of crystalloid solution, appropriate antibiotic therapy, source control, and organ support as directed by the attending physicians. The infusion rate and volume of intravenous fluid therapy was ordered according to the discretion of the treating clinician. If the hemodynamic goal (mABP $\geq$ 65 mm Hg) was not reached after optimal fluid (at least 30 ml/kg) and study drug infusion, open-label vasopressors were permitted when no attenuation of shock was observed.

After initial resuscitation in the emergency room, patients who required endotracheal intubation for mechanical ventilation, required initiation of renal replacement therapy, and/or required invasive hemodynamic monitoring were transferred to the medical ICU. Hemodynamically stable patients with no indications for mechanical ventilator or renal replacement therapy support were transferred to the general medical ward. The

nurse to patient ratio was 1:1 in ICU and 1:3 in general medical ward. All patients admitted to the ICU had an arterial line inserted for continuous blood pressure monitoring.

Outcome Assessment

The primary outcome of this study was shock control rate by 6 hours after diagnosis of sepsis with hypotension. Shock control rate was defined as achievement of sustained mABP of at least 65 mm Hg (9), together with evidence of adequate tissue perfusion. Patient's blood pressure was measured every 15 minutes after enrollment, either by automated noninvasive method or via an arterial line, when available. Target mABP achievement was defined as mABP of 65 mm Hg or higher, persisting for two consecutive measurements. Adequate tissue perfusion was defined as continuation of urine flow at more than 0.5 ml/kg/h for 2 consecutive hours, or decreased in serum lactate by more than 10% from the initial lactate level (10–12).

The secondary outcomes were 28-day mortality and hospital mortality. Rate of respiratory failure requiring mechanical ventilator support, rate of renal failure requiring renal replacement therapy, and number of organ support-free days to Day 28 were also recorded. The calculation of organ support-free days to Day 28 was based on the formula proposed by Russell and colleagues (13) (*see the online supplement*).

For safety outcome assessment, we recorded new onset of cardiac arrhythmia, organ ischemia, and cardiogenic or noncardiogenic pulmonary edema from diagnosis of sepsis with hypotension to hospital discharge or death. Causes of death were classified into refractory septic shock, sequelae of multiple organ failure, recurrent infection, sudden cardiac death unrelated to septic shock, and other causes. The definitions of all safety outcomes and causes of death are presented in the online supplement. The adjudication of safety outcomes and causes of death was performed by the attending physician according to the prespecified definitions. These assessments were performed prospectively on a day-by-day basis.

Statistical Analysis

According to our previous study (12), the sample size calculation was based on a predicted rate of shock control by 6 hours after sepsis with hypotension resuscitation

of 60% in the standard treatment group versus 80% in the early norepinephrine group. Enrollment of 150 participants per group would provide at least 80% power to assess the difference in the primary outcome between the two groups at a two-sided alpha error of 0.05. All primary and secondary outcomes analyses were based on the intention-to-treat principle. Patients who died before primary outcome assessment were considered treatment failure.

We used the Wilcoxon rank sum test for continuous variables and the chi-square test or Fisher exact test, where appropriate, for categorical variables. The primary outcome and safety outcomes were evaluated by the chi-square test. For the 28-day mortality analysis, time to death was calculated from date of septic diagnosis to date of death. Survival distributions in the two groups were estimated by plotting Kaplan-Meier curves. The hazard ratio of 28-day mortality was calculated by the Cox proportional hazards model. Values of *P* less than 0.05 were considered to indicate statistical significance. All data analyses were performed using SPSS Statistics version 18 (SPSS Inc.).

Results

Patients

A total of 456 patients with an mABP lower than 65 mm Hg were screened. Of those, 320 patients satisfied the inclusion criteria and were randomized into either the early norepinephrine group or the standard treatment group. Seven patients in the study group and three patients in the control group later withdrew their consent to participate. Of the remaining 310 patients, 155 patients were randomly allocated to each of the two groups (Figure 1). Patients' baseline characteristics, including age, underlying conditions, and disease severity, were well matched between groups. The following median baseline values indicate the severity of the study participants: Acute Physiology and Chronic Health Evaluation II score of 20 (interquartile range [IQR], 16–26), mABP of 56 mm Hg (IQR, 51–60), and serum lactate level of 2.8 mmol/L (IQR, 1.8–5.3) (Table 1). No patients in either group required mechanical ventilator or renal replacement therapy before randomization.

There was no significant difference in median time from diagnosis to study drug

Table 1. Patients' Baseline Characteristics*

Characteristics	Early Norepinephrine (n = 155)	Standard Treatment (n = 155)
Age, median (IQR), yr	65 (54–76)	68 (55–77)
Male sex, n (%)	71 (45.8)	77 (49.7)
Body mass index, median (IQR), kg/m ²	21.6 (19.6–23.8)	22.1 (19.4–24.3)
APACHE II score, median (IQR) [†]	21 (15–26)	20 (16–26)
Time from emergency room arrival to diagnosis, median (IQR), min	23 (5–168)	25 (10–185)
Comorbidities, n (%)		
Hypertension	77 (49.7)	85 (54.8)
Diabetes mellitus	51 (32.9)	53 (34.2)
Malignancy	41 (26.5)	41 (26.5)
Immunosuppression	38 (24.5)	34 (21.9)
Chronic kidney disease	27 (17.4)	37 (23.9)
Coronary artery disease	25 (16.1)	28 (16.8)
Stroke	19 (12.3)	15 (9.7)
Cirrhosis	14 (9)	13 (8.4)
Source of infection, n (%)		
Urinary tract infection	47 (30.3)	45 (29)
Pneumonia	40 (25.8)	37 (23.9)
Intraabdominal infection	31 (20)	33 (21.3)
Skin and soft tissue infection	15 (9.7)	12 (7.7)
Others	12 (7.7)	14 (9)
Unable to identify source of infection	10 (6.5)	14 (9)
Hemoculture positive for organism	25 (16.1)	27 (17.4)
Identified pathogens, n (%) [‡]		
Gram-positive cocci	20 (12.7)	21 (13.5)
Gram-negative bacilli	87 (56.1)	73 (47.1)
Fungus	2 (1.3)	4 (2.6)
Virus	3 (1.9)	6 (3.9)
Unable to identify pathogen	39 (26.2)	51 (33.1)
Physiologic variables, median (IQR)		
Temperature, °C	38.0 (36.8–38.9)	38.1 (36.8–39.0)
Initial mean arterial pressure, mm Hg	56 (50–59)	57 (52–62)
Initial heart rate, beats/min	110 (90–128)	108 (86–122)
Initial respiratory rate, breaths/min	24 (22–30)	24 (24–32)
White cell count, cells/mm ³	11,990 (7,070–19,890)	13,690 (6,480–19,630)
Platelet count, platelets/mm ³	169,000 (85,000–266,000)	157,000 (79,000–251,000)
Lactate, mmol/L	3.0 (1.8–5.7)	2.7 (1.8–4.8)
Lactate >2 mmol/L, n/total n (%)	106/155 (68.3)	102/155 (65.8)

Definition of abbreviations: APACHE = Acute Physiology and Chronic Health Evaluation; IQR = interquartile range.

*There were no significant differences between the two groups in baseline characteristics, excepted for initial mean arterial pressure, which was lower in the early norepinephrine administration group ($P = 0.02$).

[†]The APACHE II score, a severity-determining score, ranges from 0 to 71. Higher scores indicate more severe disease.

[‡]Data of identified pathogens were missing for four patients in the early norepinephrine group.

initiation, or time from diagnosis to open-label norepinephrine initiation between early norepinephrine and standard treatment groups. Median time from emergency room arrival to norepinephrine administration was significantly shorter in the early norepinephrine group than in the standard treatment group (93 min [IQR, 72–114] vs. 192 min [IQR, 150–298]; $P < 0.001$) (Table 2). The proportion of patients that was admitted to the ICU was not different between groups (54.8% in the early norepinephrine group vs. 51.6% in the standard treatment group; $P = 0.57$). Among patients who were admitted to the ICU, the median time from diagnosis to

ICU admission was similar between the study group and the control group (6 h and 36 min [IQR, 4:35–9:52] vs. 6 h and 35 min [IQR, 5:15–10:34]; $P = 0.34$). Among those who were transferred to the general medical ward, median time from diagnosis to admission was also not significantly different between the early norepinephrine group and the standard treatment group (6 h and 23 min [IQR, 4:25–10:34] vs. 6 h and 45 min [IQR, 4:24–10:54]; $P = 0.66$) (Table 2).

Outcomes

The shock control rate by 6 hours after the initiation of resuscitation was higher in the

early norepinephrine group than in the standard treatment group (76.1% vs. 48.4%; odds ratio, 3.4; 95% confidence interval [CI], 2.09–5.53; $P < 0.001$) (Table 3). For the individual endpoints by 6 hours, the achievement of target mABP (>65 mm Hg), urine output (>0.5 ml/kg), and lactate clearance (>10%) were all significantly higher in the early norepinephrine group (all $P < 0.05$). However, the rate of lactate normalization was not different between groups. There were more patients in the early norepinephrine group who achieved all targets by 6 hours than patients in the standard treatment group (31.0% vs. 17.4%; $P = 0.005$). Similarly, there were more

Table 2. Treatments Administered

Data on Hemodynamic Management and Organ Support	Early Norepinephrine (<i>n</i> = 155)	Standard Treatment (<i>n</i> = 155)	<i>P</i> Value
Time from diagnosis to study drug initiation, median (IQR), h:min	1:10 (0:50–1:30)	1:10 (0:45–1:40)	0.66
Time from diagnosis to open-label norepinephrine initiation, median (IQR), h:min	3:00 (2:12–4:30)	2:47 (2:05–4:33)	0.38
Time from diagnosis to any norepinephrine initiation, median (IQR), h:min	1:10 (0:50–1:30)	2:47 (2:05–4:33)	<0.001
Time from emergency room arrival to administration of any norepinephrine, median (IQR), h:min	1:33 (1:12–1:54)	3:12 (2:30–4:58)	<0.001
Vasopressors (open label)			
Norepinephrine, <i>n</i> (%)	105 (67.7)	124 (80)	0.014
Maximum dose, median (IQR), $\mu\text{g/kg/min}^*$	0.1 (0.05–0.18)	0.1 (0.05–0.15)	0.59
Epinephrine, <i>n</i> (%)	27 (17.4)	31 (20)	0.56
Maximum dose, median (IQR), $\mu\text{g/kg/min}^*$	0.41 (0.28–1.2)	0.4 (0.26–0.60)	0.41
Dopamine, <i>n</i> (%)	6 (3.9)	3 (1.3)	0.31
Maximum dose, median (IQR), $\mu\text{g/kg/min}^*$	10.3 (4.7–14.7)	6.7 (4.9–7.2)	0.31
Dobutamine, <i>n</i> (%)	5 (3.2)	5 (3.2)	1.0
Maximum dose, median (IQR), $\mu\text{g/kg/min}^*$	4.7 (2.4–6.7)	3.8 (3.3–4.3)	0.69
Fluid administered			
Fluid administered before study drug initiation, median (IQR), ml	800 (600–1,000)	800 (500–1,000)	0.34
Fluid administered before open-label norepinephrine initiation, median (IQR), ml	2,080 (1,400–2,600)	1,900 (1,345–2,278)	0.32
Fluid administered before open-label norepinephrine initiation, median (IQR), ml/kg	32.3 (24.5–45.9)	29.8 (21.8–40.9)	0.3
Fluid administered in first 1 h, median (IQR), ml	800 (600–1,000)	800 (600–1,000)	0.64
Fluid administered in 0–6 h, median (IQR), ml	2,450 (1,914–3,200)	2,600 (2,154–3,240)	0.33
Fluid administered in Day 1, median (IQR), ml	5,032 (3,950–6,060)	5,025 (3,855–5,853)	0.66
Fluid administered in Day 2, median (IQR), ml	1,825 (964–2,575)	1,680 (987–2,275)	0.28
Fluid administered in Day 3, median (IQR), ml	845 (185–1,733)	1,000 (120–1,755)	0.87
Central venous catheter insertion, <i>n</i> (%)	67 (43.8)	71 (46.1)	0.68
Time from diagnosis to central venous catheter insertion, median (IQR), h:min, (<i>n</i> = 138)	4:10 (2:45–8:30)	4:00 (2:30–6:40)	0.64
Initial central venous pressure, median (IQR), mm Hg, (<i>n</i> = 138)	8 (5–14)	9 (7–12)	0.41
ICU admission, <i>n</i> (%)	85 (54.8)	80 (51.6)	0.57
Time from diagnosis to ICU admission, median (IQR), h:min, (<i>n</i> = 165)	6:36 (4:35–9:52)	6:35 (5:15–10:30)	0.34
Time from diagnosis to general medical ward admission, median (IQR), h:min, (<i>n</i> = 145)	6:23 (4:25–10:34)	6:45 (4:24–10:54)	0.66
ICU length of stay, median (IQR), d, (<i>n</i> = 165)	2 (0–6)	1 (0–5)	0.57
Hospital length of stay, median (IQR), d, (<i>n</i> = 310)	10 (6–21)	10 (7–17)	0.37

Definition of abbreviation: IQR = interquartile range.

*The median and IQR of vasopressor doses are derived from the patients who received a dose more than zero.

patients in the study group than in the control group who achieved both target mABP and target urine output (35.5% vs. 24.5%; $P = 0.04$). In contrast, achievement of both target mABP and target lactate clearance greater than 10% within 6 hours was not different between the study and control groups (9.7% vs. 6.5%; $P = 0.3$) (Table 3).

Median time from diagnosis to achieving target mABP greater than or equal to 65 mm Hg was shorter in the early norepinephrine group (3:30 h vs. 4:45 h; $P < 0.001$). The median time from diagnosis to achieving shock control was 4 hours 45 minutes in the study group, which was significantly shorter than the 6 hours 2 minutes in the control

group ($P < 0.001$). Median of mABP was significantly higher in the early norepinephrine group during the fourth to sixth hour after diagnosis ($P < 0.05$) (see Figure E3A in the online supplement).

Regarding the amount of intravenous fluid, there was no significant difference between groups for the total volume of fluid administered at any time. Open-label norepinephrine was used in 67.7% of study group patients, compared with 80% of control group patients ($P = 0.01$). Although patients in the early norepinephrine group received a higher median norepinephrine dosage during the second to fifth hours after diagnosis, the norepinephrine dosage

was the same between groups after the sixth hour (see Figure E3B). Other vasoactive agents, including epinephrine, dopamine, and dobutamine, were used in similar proportions when compared between groups. No patient in either group had cessation of study medication because of high blood pressure.

Mortality at 28 days was 15.5% in the early norepinephrine group and 21.9% in the standard treatment group (relative risk, 0.79; 95% CI, 0.53–1.11; $P = 0.15$) (Table 3). The Kaplan-Meier curves of 28-day mortality are shown in Figure 2. There was no difference between groups for the rates of mechanical ventilator support or renal replacement

Table 3. Clinical Outcomes

Outcome	Early Norepinephrine (n = 155)	Standard Treatment (n = 155)	Odds Ratio or Relative Risk (95% CI)*	P Value
Primary outcome, n (%)				
Achieved target mABP + tissue perfusion goal by 6 h	118 (76.1)	75 (48.4)	3.4 (2.09–5.53)	<0.001
Achieved target mABP + urine output + lactate clearance >10% by 6 h	48 (31.0)	27 (17.4)	2.13 (1.24–3.64)	0.005
Achieved target mABP + urine output by 6 h	55 (35.5)	38 (24.5)	1.69 (1.04–2.77)	0.04
Achieved target mABP + lactate clearance >10% by 6 h	15 (9.7)	10 (6.5)	1.55 (0.68–3.57)	0.3
Secondary outcomes				
Mortality at 28 d, n (%)	24 (15.5)	34 (21.9)	0.79 (0.53–1.11)	0.15
Hospital mortality, n (%)	35 (22.6)	38 (24.5)	0.95 (0.72–1.24)	0.69
Time from initial treatment to achieving target mABP + tissue perfusion goal, median (IQR), h:min	4:45 (3:30–5:56)	6:02 (4:20–9:18)		<0.001
Achieved target mABP by 6 h, n (%)	134 (86.5)	104 (67.1)	3.13 (1.77–5.53)	<0.001
Mean arterial pressure at 6 h, median (IQR), mm Hg	74 (69–79)	72 (66–78)		0.22
Time from initial treatment to achieving target mABP ≥65 mm Hg, median (IQR), h:min	3:30 (2:09–5:00)	4:45 (3:15–7:00)		<0.001
Achieved target urine output within 6 h, n (%)	107 (69)	75 (48.4)	2.47 (1.55–3.95)	<0.001
Achieved target urine output by 0–2 h, n (%)	13 (8.4)	12 (7.7)	1.09 (0.48–2.47)	0.84
Time from initial treatment to achieving target urine output, median (IQR), h:min	4:30 (3:00–5:52)	5:10 (4:00–9:37)		0.003
Achieved target lactate clearance >10% by 6 h, n (%)	64 (41.3)	43 (27.7)	1.87 (1.16–3.02)	0.009
Lactate level <2 mmol/L by 6 h	73 (47.1)	62 (40.3)	1.32 (0.84–2.07)	0.23
Time from initial treatment to achieving target lactate <2 mmol/L, median (IQR), h:min	6:00 (3:57–15:12)	8:45 (5:10–13:45)		0.003
Days alive and free of vasopressors to Day 28, median (IQR), d [†]	26 (23–27)	25 (7–27)		0.35
Mechanical ventilator support, n (%)	58 (37.4)	59 (38.1)	0.99 (0.79–1.24)	0.91
Days alive and free of mechanical ventilator to Day 28, median (IQR), d [†]	28 (14–28)	28 (7–28)		0.42
Renal replacement therapy, n (%)	19 (12.3)	23 (14.8)	0.89 (0.67–1.22)	0.51
Days alive and free of renal replacement therapy to Day 28, median (IQR), d [†]	28 (20–28)	28 (20–28)		0.7
Days alive and free of organs support to Day 28, median (IQR), d [†]	25 (0–27)	25 (0–26)		0.23

Definition of abbreviations: CI = confidence interval; IQR = interquartile range; mABP = mean arterial blood pressure.

*Primary outcomes are given as odds ratios, and secondary outcomes are given as relative risk.

[†]Days alive and free of vasopressors, mechanical ventilator, renal replacement therapy, and organs support to Day 28 were calculated based on method previously described in Reference 13.

therapy (Table 3). The median number of organ support-free days to Day 28 also did not differ between the two groups.

Patients in the early norepinephrine group had a lower rate of cardiogenic pulmonary edema (14.4% vs. 27.7%; $P = 0.004$) and new-onset arrhythmia (11% vs. 20%; $P = 0.03$). However, other complications, including limb ischemia and intestinal ischemia, were similar between groups (Table 4). The leading cause of death was sequelae of multiple organ system failure, followed by refractory septic shock.

Discussion

This double-blind randomized controlled trial revealed norepinephrine administration at the beginning of sepsis with hypotension resuscitation to be associated with a higher shock control rate by 6 hours compared with the standard treatment. Occurrence of organ failure, such as respiratory failure requiring ventilator support and renal failure requiring renal replacement therapy, did not differ

between groups. However, two adverse events, cardiogenic pulmonary edema and new-onset arrhythmia, occurred in lower proportions in the early norepinephrine group.

This is the first study to assess the benefit of early norepinephrine administration for sepsis-related hypotension resuscitation on surrogate short-term, shock control endpoints. Early norepinephrine administration improved mABP, urine output, and lactate clearance by 6 hours. Our selected hemodynamic endpoints represent both macrocirculation

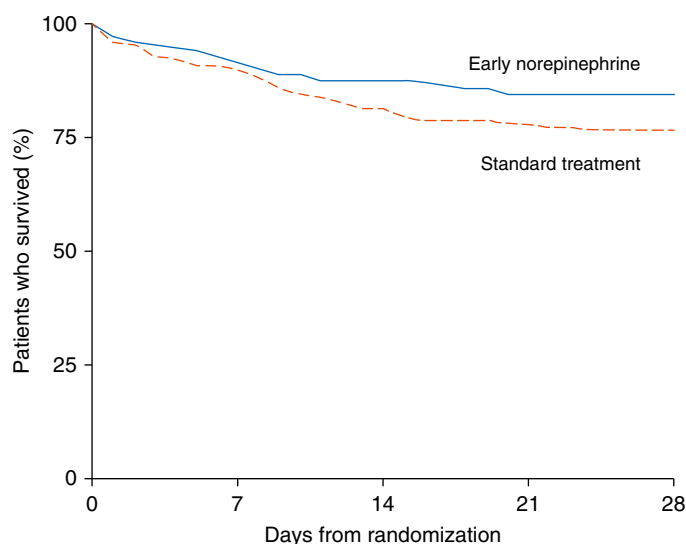


Figure 2. Kaplan-Meier analysis of 28-day survival. The hazard ratio for death in the early norepinephrine group compared with the standard treatment group was 0.69 (95% confidence interval, 0.41–1.16; $P = 0.16$).

and microcirculation restoration. A target mABP of greater than or equal to 65 mm Hg was selected to represent macrocirculation restoration, because a previous study reported that the targeted mABP higher than 65 mm Hg did not improve mortality (9). Data from a recent multicenter retrospective analysis showed that patients with sepsis who had an mABP during ICU admission lower than 65 mm Hg, had a significantly higher risk of mortality, acute kidney injury, and myocardial injury (14).

For tissue perfusion evaluation, we used urine flow greater than 0.5 ml/kg/h for 2 consecutive hours as evidence of adequate kidney blood flow and splanchnic circulation restoration. In those who had no urine or urine flow less than 0.5 ml/kg/h, lactate clearance greater than 10% was used as the evaluative parameter. That evaluation protocol was based on evidence from a previous randomized controlled trial that found that shock resuscitation guided by serum lactate reduction associated with

lower hospital mortality than those who did not monitor lactate clearance (15). From our previous report, the achievement of macrocirculation and microcirculation targets was associated with lower hospital mortality than the rate observed in patients who met only mABP target or no target at all (12).

As noted from the disease pathophysiology, vasodilatation and leakage are prominent features. Thus, effective restoration of the perfusion deficit should begin with both fluid repletion and vasopressors. Several retrospective studies in patients with septic shock support this hypothesis (4, 6). Specifically, shorter hypotension duration and lower mortality were noted in patients with early norepinephrine administration. The results of our study, which is the first randomized controlled trial to investigate the effect of early norepinephrine, revealed a shorter shock interval in the early norepinephrine group than in the standard treatment group.

The lower occurrences of congestive heart failure and new-onset arrhythmia in the early norepinephrine group were not observed in other studies. A study in coronary blood flow during sepsis revealed increased perfusion together with increased oxygen demand (16). Norepinephrine restored global perfusion, but did not further increase coronary blood flow. In an observational study, patients with septic shock and severe hypotension were given norepinephrine after median fluid resuscitation of 1,000 ml. Using a noninvasive measurement (PiCCOpus),

Table 4. Adverse Events and Causes of In-Hospital Death

Events	Early Norepinephrine (<i>n</i> = 155)	Standard Treatment (<i>n</i> = 155)	Relative Risk (95% CI)	<i>P</i> Value
Adverse events, <i>n</i> (%)				
Cardiogenic pulmonary edema	22 (14.4)	43 (27.7)	0.70 (0.56–0.87)	0.004
Acute respiratory distress syndrome	17 (11)	14 (9)	1.12 (0.75–1.68)	0.56
New-onset cardiac arrhythmia	17 (11)	31 (20)	0.74 (0.56–0.94)	0.03
Hospital-acquired infection	22 (14.5)	21 (13.7)	1.03 (0.74–1.43)	0.85
Upper gastrointestinal hemorrhage	6 (3.9)	5 (3.2)	1.12 (0.58–2.15)	0.73
Acute limb and/or intestinal ischemia	5 (3.2)	3 (1.9)	1.35 (0.55–3.32)	0.47
Skin necrosis	1 (0.6)	1 (0.6)	1.0 (0.25–4.02)	1.0
Causes of in-hospital death, <i>n</i> (%)				
Sequelae of multiple organ system failure	18 (11.6)	22 (14.2)	0.9 (0.66–1.22)	0.5
Refractory septic shock	4 (2.6)	6 (3.9)	0.83 (0.49–1.39)	0.52
Recurrent infection	6 (3.9)	4 (2.6)	1.26 (0.58–2.71)	0.75
Sudden cardiac death unrelated to septic shock	5 (3.2)	3 (1.9)	1.34 (0.55–3.31)	0.72
Other causes	2 (1.3)	3 (1.9)	0.83 (0.40–1.72)	0.66

Definition of abbreviation: CI = confidence interval.

improved cardiac output was noted by the mechanism of increasing cardiac preload and cardiac contractility (17). Thus, the lower cardiac events in our patients may be explained by decreasing oxygen demand resulting from shorter shock duration and improved cardiac contractility arising from early use of norepinephrine. However, the safety of early norepinephrine administration relative to lower incidence of congestive heart failure and new-onset arrhythmia still needs to be confirmed.

Splanchnic hypoperfusion is an important concern when norepinephrine is given early. Vasoconstriction induced by norepinephrine may aggravate internal organ ischemia and lead to patient deterioration (18, 19). Recent studies examined this concern and revealed that norepinephrine did not alter perfusion to the gut and kidney (20, 21). Although no objective measurements were made in the present study, there was no difference in prevalence of organ failure between groups. Our study revealed similar rates of acute limb ischemia, intestinal ischemia, and gastrointestinal bleeding between groups, which may indicate prolonged inadequate tissue perfusion during septic shock resuscitation.

Fluid overload is a common complication during sepsis resuscitation. Systemic inflammation causes intravascular fluid leakage into the interstitial area, and subsequent large amounts of crystalloid resuscitation can fill up both intravascular and interstitial spaces, resulting in total body fluid excess. Early use of norepinephrine decreases the use of fluid replacement, possibly by constricting the dilated vascular bed, and shortens resuscitation duration. This was described in the previously mentioned and another recently reported animal studies (3, 22) but not in our study. Possible

explanations are that the study was performed during 2013–2017 when the Surviving Sepsis Campaign Guidelines were used, meaning that fluid was given toward a target intravascular volume or central venous pressure; and norepinephrine was used at a low dose (0.05 µg/kg/min) to avoid excessive vasoconstriction, a serious complication of norepinephrine, especially during inadequate preload, and this may result in suboptimal increased cardiac preload and vasoconstriction that was sufficient to reduce hypoperfusion duration, but not resuscitation volume.

Concerning the timing of intervention, our study showed a remarkably shorter duration from emergency room presentation to study drug initiation than previous septic shock management studies. The reported median time from emergency room presentation to randomization in the ProCESS, ARISE, and PROMISE trials was 162 minutes among the early goal-directed therapy groups and 159 minutes among the standard treatment group (23). In contrast, our median time from emergency room arrival to administration of the study drug was 93 minutes. Hence, patients in early norepinephrine group received norepinephrine at least 1 hour earlier than the patients in the previously mentioned trials.

This study has some limitations. First, we could not mask the effect of norepinephrine in the early norepinephrine group. The rapid increase in patient blood pressure may have provided clues to attending physicians. However, up to 20% of patients in the standard treatment group responded similarly to the placebo infusion. Second, because of the limited number of ICU beds available at our center, we had to transfer about 47% of patients that did not require mechanical ventilator or dialysis to the general medical ward. Moreover, some

patients required adjustment of their norepinephrine infusion dosage and the use of vasopressors on the ward would be unlikely to occur at many institutions worldwide.

Third, this study did not aim to evaluate mortality, so the effect of early norepinephrine administration on mortality cannot be inferred from the results of this study. Furthermore, we did not control the resuscitation fluid rate, which resulted in variation among patients. This may have affected the treatment outcome. Lastly, this is a single-center trial, which could limit the generalizability of these findings to other care settings. Physician who decide to apply the results of this study to their routine clinical practice should carefully evaluate the context of this study and compare it with their own situation and setting. A multicenter trial with a larger population size, control of the rate of fluid resuscitation, and the timing of norepinephrine initiation is certainly required to assess the survival benefit of early norepinephrine as an intervention.

In conclusion, the results of this phase II clinical trial demonstrated significant association between early norepinephrine and increased shock control by 6 hours. Further studies are needed to confirm these findings before this approach can be introduced in clinical resuscitation practice. Future study should investigate the effect of early norepinephrine on organ dysfunction and mortality. ■

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References

1. Angus DC, van der Poll T. Severe sepsis and septic shock. *N Engl J Med* 2013;369:840–851.
2. Rhodes A, Evans LE, Alhazzani W, Levy MM, Antonelli M, Ferrer R, *et al*. Surviving Sepsis Campaign: International guidelines for management of sepsis and septic shock: 2016. *Crit Care Med* 2017;45:486–552.
3. Sennoun N, Montemont C, Gibot S, Lacolley P, Levy B. Comparative effects of early versus delayed use of norepinephrine in resuscitated endotoxic shock. *Crit Care Med* 2007;35:1736–1740.
4. Morimatsu H, Singh K, Uchino S, Bellomo R, Hart G. Early and exclusive use of norepinephrine in septic shock. *Resuscitation* 2004;62:249–254.
5. Hamzaoui O, Georger JF, Monnet X, Ksouri H, Maizel J, Richard C, *et al*. Early administration of norepinephrine increases cardiac preload and cardiac output in septic patients with life-threatening hypotension. *Crit Care* 2010;14:R142.
6. Bai X, Yu W, Ji W, Lin Z, Tan S, Duan K, *et al*. Early versus delayed administration of norepinephrine in patients with septic shock. *Crit Care* 2014;18:532.
7. Permpikul C, Tongyoo S, Viarasilpa T, Trainarongsakul T, Noppakaorattanananee K. Early norepinephrine administration vs. standard treatment during severe sepsis/septic shock resuscitation: a randomized control trial. *Intensive Care Med Exp* 2017;5(Suppl. 2): 0426.

8. Dellinger RP, Levy MM, Rhodes A, Annane D, Gerlach H, Opal SM, *et al.*; Surviving Sepsis Campaign Guidelines Committee including The Pediatric Subgroup. Surviving Sepsis Campaign: international guidelines for management of severe sepsis and septic shock, 2012. *Intensive Care Med* 2013;39:165–228.
9. Asfar P, Meziani F, Hamel JF, Grelon F, Megarbane B, Anguel N, *et al.*; SEPSISPAM Investigators. High versus low blood-pressure target in patients with septic shock. *N Engl J Med* 2014;370:1583–1593.
10. Rivers E, Nguyen B, Havstad S, Ressler J, Muzzin A, Knoblich B, *et al.*; 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.
11. Jones AE, Shapiro NI, Trzeciak S, Arnold RC, Claremont HA, Kline JA; Emergency Medicine Shock Research Network (EMShockNet) Investigators. Lactate clearance vs central venous oxygen saturation as goals of early sepsis therapy: a randomized clinical trial. *JAMA* 2010;303:739–746.
12. Permpikul C, Sringam P, Tongyoo S. Therapeutic goal achievements during severe sepsis and septic shock resuscitation and their association with patients' outcomes. *J Med Assoc Thai* 2014;97: S176–S183.
13. Russell JA, Lee T, Singer J, De Backer D, Annane D. Days alive and free as an alternative to a mortality outcome in pivotal vasopressor and septic shock trials. *J Crit Care* 2018;47:333–337.
14. Maheshwari K, Nathanson BH, Munson SH, Khangulov V, Stevens M, Badani H, *et al.* The relationship between ICU hypotension and in-hospital mortality and morbidity in septic patients. *Intensive Care Med* 2018;44:857–867.
15. Jansen TC, van Bommel J, Schoonderbeek FJ, Sleeswijk Visser SJ, van der Klooster JM, Lima AP, *et al.*; LACTATE Study Group. Early lactate-guided therapy in intensive care unit patients: a multicenter, open-label, randomized controlled trial. *Am J Respir Crit Care Med* 2010;182:752–761.
16. Ruokonen E, Takala J, Kari A, Saxén H, Mertsola J, Hansen EJ. Regional blood flow and oxygen transport in septic shock. *Crit Care Med* 1993;21:1296–1303.
17. Di Giandomasso D, May CN, Bellomo R. Norepinephrine and vital organ blood flow during experimental hyperdynamic sepsis. *Intensive Care Med* 2003;29:1774–1781.
18. Hollenberg SM. Vasoactive drugs in circulatory shock. *Am J Respir Crit Care Med* 2011;183:847–855.
19. Hollenberg SM, Ahrens TS, Annane D, Astiz ME, Chalfin DB, Dasta JF, *et al.* Practice parameters for hemodynamic support of sepsis in adult patients: 2004 update. *Crit Care Med* 2004;32:1928–1948.
20. Desjars P, Pinaud M, Bugnon D, Tasseau F. Norepinephrine therapy has no deleterious renal effects in human septic shock. *Crit Care Med* 1989;17:426–429.
21. Redfors B, Bragadottir G, Sellgren J, Swärd K, Ricksten SE. Effects of norepinephrine on renal perfusion, filtration and oxygenation in vasodilatory shock and acute kidney injury. *Intensive Care Med* 2011;37:60–67.
22. Byrne L, Obonyo NG, Diab SD, Dunster KR, Passmore MR, Boon AC, *et al.* Unintended consequences: fluid resuscitation worsens shock in an ovine model of endotoxemia. *Am J Respir Crit Care Med* 2018; 198:1043–1054.
23. Rowan KM, Angus DC, Bailey M, Barnato AE, Bellomo R, Canter RR, *et al.*; PRISM Investigators. Early, goal-directed therapy for septic shock: a patient-level meta-analysis. *N Engl J Med* 2017;376: 2223–2234.