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Noninvasive cardiac output monitoring in septic shock patients

A retrospective study on hemodynamic status and outcomes

Yu-Jang Su, MD[a,b,c,d,*], Sheng-Teck Tan, MD[a] and Yasser Nassef, MD, PhD[e]

Abstract

Septic shock is a frequent condition in emergency departments, requiring rapid hemodynamic assessment. Noninvasive cardiac output monitoring (NICOM) offers a convenient method for evaluating these patients. In this study, we retrospectively analyzed 50 septic shock patients (34 males, 16 females) from a cohort of 627 NICOM cases in northern Taiwan emergency department between January 2020 and December 2021. Patients were classified into normal and high stroke volume variation percentage groups, and survivors versus non-survivors. The high stroke volume variation percentage group had an older average age (72.1 vs 59.5, $P = .004$) and required more fluid resuscitation before inotropic agents (1322 mL vs 864 mL, $P = .043$). Non-survivors were older (77.6 vs 64.7 years, $P = .013$), had higher NT-proBNP levels (655 vs 307, $P = .029$), and longer ICU stays (3.7 vs 1.2 days, $P = .007$). The overall mortality rate was 22%. NICOM is a valuable tool for guiding fluid resuscitation in septic shock patients. Further studies are recommended to refine its application.

Abbreviations: BNP = B-type natriuretic peptide, CHF = Congestive heart failure, CO = cardiac output, COPD = chronic obstructive pulmonary disease, EC = electrical cardiometry, ED = emergency department, FTC = corrected flow time, HIV = human immunodeficiency, HR = heart rate, ICON = index of contractility, NICOM = noninvasive cardiac output monitoring, NT-proBNP = N-terminal prohormone of brain natriuretic peptide, PAC = pulmonary artery catheters, SBP = systolic blood pressure, STR = systolic time ratio, SV = stroke volume, SvO2 = central venous oxygen saturation, SVR/SVRI = systemic vascular resistance, SVV = stroke volume variation, TFC = thoracic fluid content, WBC = white blood cell count.

Keywords: inotropic agent, outcome, sepsis, shock

1. Introduction

Shock is a common issue in emergency department (ED) patients, requiring immediate management. EDs often use noninvasive cardiac output (CO) monitoring (NICOM; ICON™) to assess a patient's shock status. This method provides a rapid and less invasive way to determine the hemodynamic status of shock patients, aiding in resuscitation. In this study, we aim to explore the application of NICOM in treating septic shock patients and analyze the outcomes.

In clinical practice, shock leads to tissue hypoxia, often unnoticed in its early stages. If untreated, it can result in multisystem organ failure and high mortality. Traditionally, pulmonary artery catheters (PAC) were used to monitor shock, with key parameters including central venous pressure (8–12 mm Hg), central venous oxygen saturation (SvO2 > 70%), and mean arterial blood pressure (70 mm Hg). Vasopressor and inotrope management also played crucial roles.[1] In this study, we utilized ICON™ to compare normal and high stroke volume (SV) variation (SVV%) groups, as well as survivors and non-survivors.

The Aesculon and ICON devices, manufactured by Osypka Medical (Germany) and Cardiotronic (USA), respectively, help monitor shock patients. We sought to establish a relationship between ICON parameters to predict outcomes and optimize treatment strategies, making this study highly practical for clinical use in ED settings. ICON™ uses electrical cardiometry (EC) to measure the electrical impedance of the heart and major vessels, providing a beat-by-beat assessment of overall hemodynamic status. This is done through 4 surface sensors that detect changes in thoracic impedance, caused by red blood cell alignment during different cardiac cycle phases.

2. Materials and methods

2.1. Selection of patients

A unique aspect of EC is its ability to evaluate the percentage of participating tissue in the body, offering high accuracy, particularly in critically ill patients. For this study, we retrospectively

The authors have no conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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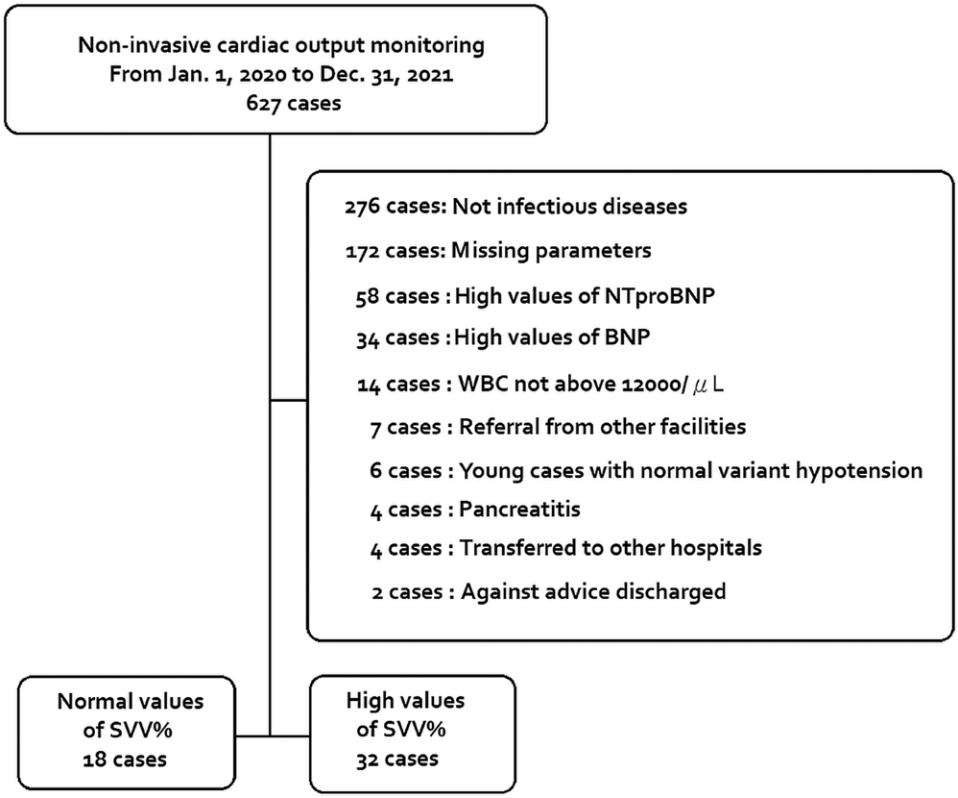

Figure 1. A total of 627 shock patients underwent ICON evaluation in the emergency department of a medical center in northern Taiwan from January 1, 2020, to December 31, 2021. After excluding noninfectious cases, missing data, and loss to follow-up, 50 septic shock patients were enrolled in this study. ICON = index of contractility.

Table 1

The distributions in diseases of these 50 septic shock patients receiving NICOM.

	n	Survivor (male: female)	Non-survivor (male: female)
Pneumonia	20	16 (13: 3)	4 (3: 1)
UTI	9	6 (4: 2)	3 (1: 2)
Cholangitis	4	4 (4: 0)	0
Liver abscess	3	3 (3: 0)	0
Pyelonephritis	3	3 (0: 3)	0
Infectious diarrhea	2	2 (1: 1)	0
Intra-abdominal infection	2	1 (1: 0)	1 (0: 1)
Ischemic bowel disease	1	1 (0: 1)	0
Cellulitis	1	1 (1: 0)	0
Hollow organ perforation	3	1 (0: 1)	2 (1: 1)
Necrotizing fasciitis	2	1 (1: 0)	1 (1: 0)
Total	50	39 (28: 11)	11 (6: 5)

sampled shock patients who visited the ED at a medical center in northern Taiwan between January 1, 2020, and December 31, 2021. Emergency Department at MacKay Memorial Hospital treats 132,000 patients annually. The department has 48 attending physicians and is divided into 4 specialties: emergency internal medicine, emergency surgery, emergency toxicology, and emergency disaster medicine.

The inclusion criteria were as follows: Age ≥ 20 years old.

Diagnosis of shock (R57.9) or sepsis (A41.9), with a white blood cell count (WBC) >12,000 or band >6%, and systolic blood pressure <90 mm Hg, based on ICD-10 codes. Patients who received NICOM treatment during their clinical course

The exclusion criteria included: History of cardiogenic shock (R57.0), hypovolemic shock, trauma, emergent surgery, ascites (R18), or congestive heart failure (CHF) B-type natriuretic peptide (BNP) > 100 pg/mL, possible undiagnosed CHF, following the ESC heart failure guidelines.[2] N-terminal prohormone of brain natriuretic peptide (NT-proBNP) > 450 pg/mL (below 50 years of age), > 900 pg/mL (50–75 years), and > 1800 pg/mL (above 75 years) were based on age-adjusted reference values recommended by the American Heart Association and previous studies.[3] History of chronic obstructive pulmonary disease, spinal cord injury, pancreatitis, burns, or human immunodeficiency (HIV) infection. We collected data on NICOM parameters and calculated the volume of crystalloids, albumin supplements, and the timing required for inotropic agent administration. These data provide practical insights for treating shock patients in the ED.

2.2. ICON™ and parameters

The ICON™ EC provides a more accessible and direct assessment of hemodynamic status compared to traditional methods like clinical observation and standard bedside monitors.[4] Four surface sensors were applied to the patient – 2 on the left side of the neck and 2 on the lower left thorax. After calibration, the device recorded hemodynamic parameters continuously, with data points extracted every 5 minutes over a 30-minute interval post-inotropic stabilization. Measurements were only accepted if the signal quality index exceeded 80%, as recommended by the manufacturer.

EC measures various hemodynamic parameters such as:

Heart rate (HR) and SV (mL/min)

CO (L/min), representing the volume of blood ejected from the heart per minute

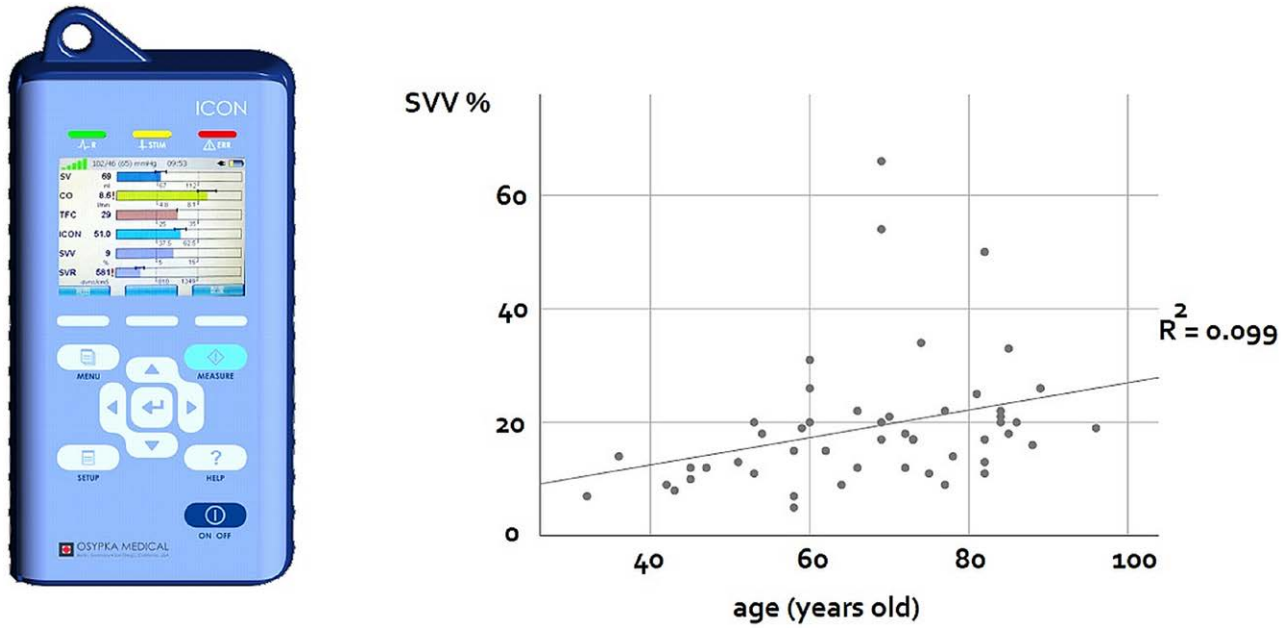

Figure 2. Older age and higher SVV% were observed among the septic shock patients. Although the correlation between age and SVV% was statistically significant, the *R* value was low (*R* = 0.099), indicating a weak linear association. Clinically, this suggests that while age contributes to SVV%, other hemodynamic factors also play a significant role.

Systemic vascular resistance (SVR/SVRI), reflecting vascular tone and afterload

Index of contractility (ICON), indicating the strength of left ventricular contraction, useful for titrating inotropic agents

Systolic time ratio, estimating ejection fraction

Additional fluid status indicators include SV variation (SVV), thoracic fluid content, and corrected flow time (FTC). A high SVV indicates fluid responsiveness, and FTC provides insight into venous return, while thoracic fluid content helps detect lung congestion.[5]

2.3. Comparisons and endpoints

We conducted 2 main comparisons:

Septic shock patients with normal SVV% versus high SVV%

Survivors versus non-survivors

Data collection occurred once the inotropic agents were stabilized, and vital signs remained stable for 24 hours (HR 60–100 bpm, systolic blood pressure > 90 mm Hg).

2.4. Ethics approval

This study was approved by the institutional review board of MacKay Memorial Hospital, Taipei, Taiwan (22MMHIS124e).

2.5. Statistical analyses

We compared survivor and non-survivor groups, as well as normal and high SVV% groups, using Chi-square tests. Student's t tests were used to compare mean values, and regression analysis determined the correlation between SVV% and age. All data were analyzed using SPSS software (version 26.0), with statistical significance set at $P < .05$.

3. Results

A total of 627 shock patients who underwent ICON evaluation visited the ED of a medical center in northern Taiwan between January 1, 2020, and December 31, 2021. After excluding non-infectious cases, patients with missing data, and those without follow-up, we enrolled 50 septic shock patients (Fig. 1). The cohort consisted of 34 males and 16 females, with 18 cases in the normal SVV% group and 32 in the high SVV% group. The average patient age was 67.6 years, and 11 patients (22%) eventually died from septic shock. The distribution of diagnoses is provided in Table 1.

We found that the high SVV% group was significantly older than the normal SVV% group (72.1 vs 59.5 years, $P = .004$). Regression analysis also showed a correlation between older age and higher SVV% in septic shock patients (Fig. 2). Although statistically significant, the correlation between age and SVV% was weak ($R = 0.099$), indicating that while age contributes to SVV%, other hemodynamic factors are also significant.

Although the mortality rates did not differ significantly between the normal and high SVV% groups (16.7% vs 25%, $P = .495$), the high SVV% group required a significantly larger volume of normal saline before inotropic agent administration compared to the normal SVV% group (1322 mL vs 864 mL, $P = .043$; Table 2, Fig. 3).

Regarding septic shock outcomes, non-survivors were significantly older than survivors by an average of 12.9 years (77.6 vs 64.7, $P = .013$), had lower body temperatures (36.4°C vs 37.7°C, $P = .006$), and were non-tachycardic compared to survivors (95.4 vs 115.6 bpm, $P = .028$). Additionally, non-survivors had higher NT-proBNP levels (655 vs 307, $P = .029$) and longer ICU stays (3.7 vs 1.2 days, $P = .007$) (Table 3, Fig. 4).

Lastly, statistical analysis revealed no significant correlation between time to shock, time to NICOM, or the interval between shock and NICOM with mortality ($P = .328$, 0.607, and 0.986, respectively).

4. Discussion

4.1. The practicality of NICOM in overcrowded emergency departments

In Taiwan, emergency departments are often overcrowded, and physicians typically lack the time necessary to perform invasive procedures efficiently. In this context, procedures such as inserting a pulmonary artery catheter (PAC) or central venous catheters are time-consuming, costly, and come with a risk of

Table 2

Comparisons are made via SVV% normal and high value.

	SVV normal	SVV high	Two-tailed *p*-value
Age (years old)	59.5 ± 15.0	72.1 ± 13.5	.004*
Gender (male: female)	11:7	23:9	.434
Body temperature (celsius)	37.5 ± 1.5	37.3 ± 1.4	.671
Heart rate (per min)	110.4 ± 14.6	112.6 ± 26.9	.755
SBP (mm Hg)	90.9 ± 24.6	108.3 ± 38.3	.090
DBP (mm hg)	54.2 ± 15.7	66.0 ± 31.3	.140
Time to shock (min)	62.1 ± 112.8	117.7 ± 200.0	.283
Time to NICOM (min)	263.5 ± 373.7	257.3 ± 289.1	.948
Shock to NICOM (min)	201.4 ± 388.6	140.0 ± 287.4	.524
WBC	16983 ± 8598	16203 ± 5389	.695
Band%	7.9 ± 11.2	6.9 ± 10.1	.745
Segment%	75.9 ± 16.6	79.1 ± 11.5	.430
Creatinine (mg/dL)	2.1 ± 2.2	2.0 ± 1.3	.818
CK (U/L)	56.7 ± 57.8	107.5 ± 189.4	.275
Troponin I (ng/mL)	0.275 ± 0.723	0.008 ± 0.103	.362
NT-proBNP (pg/mL)	255.7 ± 301.2	455.1 ± 534.6	.153
BNP (pg/mL)	20.1 ± 28.8	20.9 ± 34.5	.937
CRP (mg/L)	15.1 ± 11.4	11.3 ± 10.8	.253
Lactate (mg/dL)	23.5 ± 21.6	28.8 ± 27.5	.148
Normal saline (mL)	863.9 ± 651.7	1321.9 ± 797.8	.043*
Lactate ringer (mL)	372.2 ± 531.2	506.3 ± 634.1	.452
Albumin (bottle)	1.2 ± 1.4	2.0 ± 1.3	.065
Time to stable (min)	428.5 ± 280.4	560.1 ± 506.2	.315
ICU stay (d)	1.9 ± 5.0	1.6 ± 4.0	.859
LOS (d)	15.7 ± 12.7	14.5 ± 11.2	.719
CO (L/min)	5.0 ± 1.1	5.6 ± 2.1	.222
TFC (1/Zo)	20.7 ± 4.3	23.1 ± 7.0	.203
Icon	39.6 ± 15.0	41.0 ± 19.6	.798
SVV%	10.6 ± 2.9	24.0 ± 12.0	.001
SVRI (BSA)	1465.9 ± 612.9	1701.4 ± 1852.2	.604
CHF	1/18	2/32	.921
Liver cirrhosis	2/18	3/32	.844
Uremia	7/18	9/32	.434
DM	7/18	11/32	.729
Mortality	3/18	8/32	.495

BNP = B-type natriuretic peptide, BSA = body surface area, CHF = congestive heart failure, CK = creatinine kinase, CO = cardiac output, CRP = C-reactive protein, DBP = diastolic blood pressure, DM = diabetes mellitus, ICON = index of contractility, ICU = intensive care unit, LOS = length of stay, MIN = minute, NICOM = noninvasive cardiac output monitoring, NT-proBNP = N-terminal pro-brain natriuretic peptide, SBP = systolic blood pressure, SVRI = index of systemic vascular resistance, SVV = variation of stroke volume, TFC = thoracic fluid content, WBC = white blood cell.
*reaches statistical significance.

complications. As a result, NICOM (noninvasive continuous CO monitoring) offers a practical alternative for rapidly assessing the hemodynamic status of septic shock patients, allowing emergency physicians to make quick decisions.

Permpikul and Leelayuthachai (2014) conducted a study in a 14-bed ICU in Thailand, which demonstrated that noninvasive continuous CO monitoring correlated well with CO measurements obtained through PAC, particularly in patients who had recovered from shock.[6] Similarly, a study from the Netherlands (Koopmans et al, 2021) found that fluid responsiveness in sepsis patients could be identified by a >15% increase in cardiac index following fluid challenges.[7] However, a meta-analysis from the Netherlands concluded that EC cannot replace thermodilution or transthoracic echocardiography when measuring absolute CO values.[8]

Despite these findings, our research has uncovered valuable applications of NICOM, along with other practical references, particularly within the fast-paced environment of an emergency room setting.

4.2. Hemodynamic monitoring in septic shock: the role of SVV% and age-related variations

Septic shock is a rapidly evolving illness that requires frequent or continuous monitoring of various hemodynamic parameters, including CO, systemic vascular resistance, and SV variation (SVV%). These parameters are crucial for guiding fluid therapy and the administration of inotropic and vasoactive drugs, allowing for personalized treatment and reducing both morbidity and mortality.[9,10]

Several monitoring techniques, such as serial NICOM, are employed to optimize fluid resuscitation and overall management. In the current study, 64% of septic shock patients exhibited high SVV%. The mean SVV value was 24 and this elevated SVV is likely due to dehydration resulting from fever or inflammation, as an increase in SVV typically indicates intravascular volume depletion.[11] Our regression analysis revealed that the high SVV% group tended to be older, a finding that has not been widely reported in previous studies. Future research should explore whether adjustments to standard SVV% values based on patient age are warranted. The elevated SVV% observed in older patients may be attributed to age-related vascular changes, including increased arterial stiffness and decreased baroreceptor sensitivity. These factors reduce the vascular system's ability to compensate for volume fluctuations, thereby elevating SVV%. Additionally, reduced left ventricular compliance and diastolic dysfunction, common in elderly patients, may impair SV consistency during the respiratory cycle.[12] Although in our study, older patients exhibited higher SVV%, age alone did not predict mortality in our cohort. This may be due to confounding protective factors, such as earlier ED presentation, more aggressive fluid resuscitation, or fewer comorbidities compared to younger non-survivors.

4.3. The role of NICOM in fluid resuscitation and septic shock management

NICOM technology is not always suitable for evaluating all types of shock patients, as demonstrated by Rali et al (2020) in the United States. The study found NICOM to be an unreliable method for measuring CO in patients with decompensated heart failure and cardiogenic shock (n = 263).[13] However, NICOM remains a commonly used and generally reliable method for trauma patients.[14]

Septic shock is characterized by sepsis-induced cardiovascular dysfunction, leading to hypotension despite adequate fluid resuscitation, where volume depletion is excluded as a cause.[15] NICOM has been successfully used to assess fluid resuscitation in septic shock patients. A U.S. study by Kuttab et al (2019) introduced the "30by3 rule," recommending the administration of 30 mL of fluid per kilogram of body weight within 3 hours of severe sepsis or septic shock.[16] Failure to meet this fluid target was associated with higher in-hospital mortality, regardless of patient comorbidities. NICOM can help identify predictors of inadequate resuscitation, potentially enabling life-saving interventions.[16]

Current guidelines, based on a large randomized controlled trial in septic shock patients, advocate for the use of crystalloids for initial fluid resuscitation, with human albumin recommended if crystalloids fail to achieve stabilization.[15] In our study, we found that the high SVV% group required significantly more fluid resuscitation prior to the use of inotropic agents compared to the normal SVV% group (1322 mL vs 864 mL, $P = .043$). The total volume of fluids administered in the high SVV% group included 1322 mL of normal saline, 506 mL of lactated Ringer solution, and 2 bottles of albumin, totaling 1928 mL. For a septic shock patient weighing 64.3 kg, this aligns closely with the 30by3 rule.

4.4. Afebrile status and mortality risk in septic shock patients

In this study, non-survivors of septic shock were normothermic (mean body temperature: 36.4°C) and non-tachycardic (mean

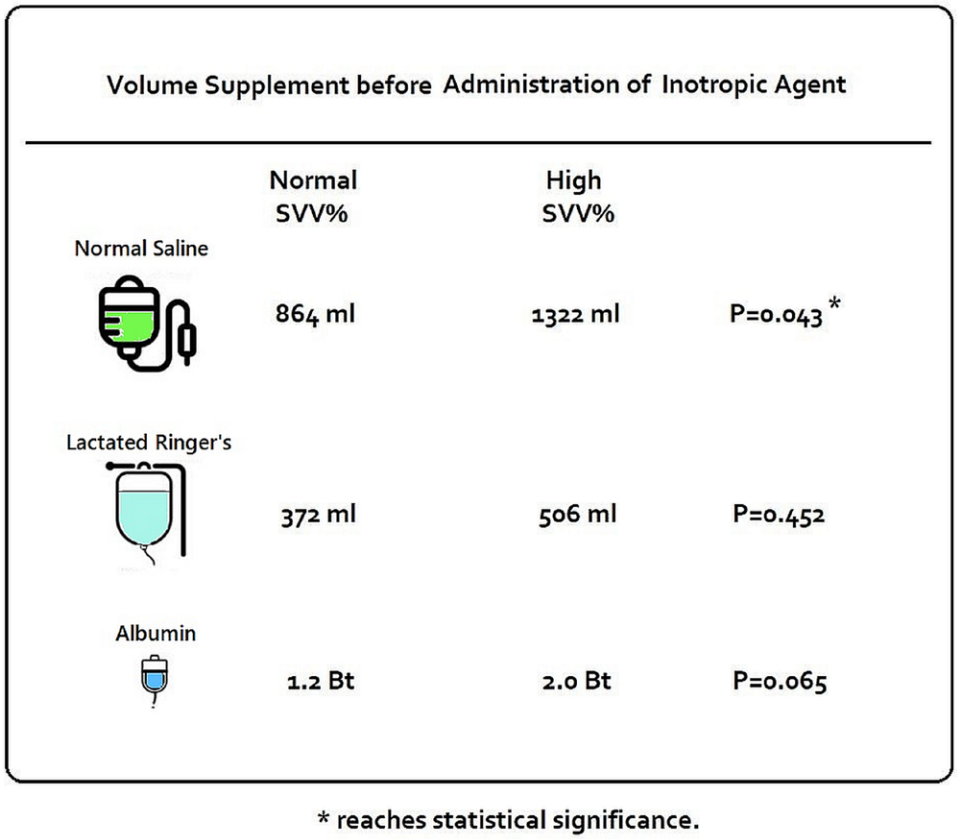

Figure 3. Before inotropic agent administration, the high SVV% group required a larger amount of normal saline supplementation compared to the normal SVV% group (1322 mL vs 864 mL, $P = .043$).

HR: 95.8 beats per minute), with statistically significant differences ($P = .006$ and $P = .028$). These findings are consistent with prior research from Italy (Sozio et al, 2021), which identified afebrile status as a significant predictor of in-hospital mortality in septic shock patients. The study also noted that afebrile patients were generally older and exhibited higher rates of organ dysfunction.[17]

Fever is a key infection symptom, representing the host's acute-phase response to pathogens. It is thought to inhibit bacterial growth, enhance cytokine production, and stimulate antibody synthesis, thereby activating the immune response. In essence, fever acts as an early warning signal that prompts immediate management of septic shock and the eradication of pathogens.[17]

4.5. Elevated NT-proBNP as a prognostic marker in septic shock patients

Our study enrolled patients with severe sepsis, excluding those with cardiogenic, hypovolemic, or spinal shock. We observed significantly higher NT-proBNP levels in the high SVV% group compared to the normal SVV% group (655 vs 307, $P = .029$). We hypothesize that the secondary elevation of NT-proBNP occurs as a result of the infectious process and septic shock, even in patients with no history of CHF. Experimental studies (Roch, 2007) have shown that endotoxins and certain cytokines can upregulate the transcription of the gene encoding BNP, suggesting that the severity of the inflammatory response may partially explain the elevated NT-proBNP levels observed during septic shock.

Additionally, research has confirmed the prognostic value of early NT-proBNP measurement,[18] with elevated levels being common in the early phase of septic shock. A study from Finland (Varpula et al, 2007) further demonstrated that NT-proBNP levels are frequently elevated in patients with severe sepsis and septic shock, and are significantly higher in non-survivors compared to survivors. Notably, NT-proBNP levels measured on day 3 in the ICU serve as an independent prognostic marker of mortality in severe sepsis patients.[19]

Serum lactate, troponin, and NT pro-B-type natriuretic peptide (NT-proBNP) have been identified as valuable prognostic markers in patients with sepsis and septic shock. A US study (n = 1242, sepsis and septic shock patients) found that elevated levels of lactate (>4 mmol/L), troponin (>0.45 ng/mL), and NT-proBNP (>8000 pg/mL) were independent predictors of 30-day mortality, with adjusted odds ratios of mortality being 3.19, 2.13, and 2.5 times higher, respectively.[20] However, understanding the mechanisms behind natriuretic peptide secretion during septic shock is essential before NT-proBNP can be fully utilized as a tool to guide treatment.[18] In our study, NT-proBNP levels in the non-survivor group were 2.1 times higher than in the survivor group. In our NT-proBNP analysis, renal function was an important consideration. A US report in 2023 showed a graded increase in NT-proBNP levels with decreasing estimated glomerular filtration rate (eGFR): NT-proBNP was 4.3-fold higher when eGFR was below 30 mL/min/1.73 m^2, 1.7-fold higher for eGFR between 30 and 60 mL/min/1.73 m^2, 1.4-fold higher for eGFR between 61 and 90 mL/min/1.73 m^2, and 1.1-fold higher for eGFR between 91 and 120 mL/min/1.73 m^2.[21] Despite these findings, we did not observe a statistically significant difference in renal function between survivors and non-survivors ($P = .271$). This suggests that in this cohort, renal function was not a major confounder in the interpretation of NT-proBNP. We acknowledge that direct measurement of the GFR would provide greater precision, and we plan to include it in future analyses.

Table 3

Comparisons are made by survival and non-survivals in these septic shock patients.

	All	Survivor (39, 78%)	Non-survivor (11, 22%)	2 tailed *p*-value
Age (years old)	67.6 ± 15.2	64.7 ± 14.7	77.6 ± 13.3	.013*
Gender (male:female)	34:16	28:11	6:5	.288
Body temperature (celsius)	37.4 ± 1.4	37.7 ± 1.4	36.4 ± 1.2	.006*
Heart rate (per min)	111.8 ± 23.1	115.6 ± 22.5	94.5 ± 20.7	.028*
SBP (mm Hg)	102.1 ± 34.8	107.1 ± 36.1	84.4 ± 23.4	.056
DBP (mm Hg)	61.8 ± 27.2	65.7 ± 29.3	47.6 ± 9.5	.051
Time to shock (min)	97.6 ± 174.2	110.6 ± 181.5	51.8 ± 143.3	.328
Time to NICOM (min)	259.5 ± 318.3	272.0 ± 327.4	215.3 ± 293.9	.607
Shock to NICOM (min)	161.9 ± 324.9	161.4 ± 320.9	163.5 ± 354.8	.986
WBC	16484 ± 6660	15856 ± 5989	18709 ± 8552	.549
Band%	7.2 ± 10.4	7.1 ± 10.0	7.7 ± 12.5	.240
Segment%	77.9 ± 13.5	78.7 ± 10.2	75.1 ± 22.1	.343
Creatinine (mg/dL)	2.0 ± 1.7	1.9 ± 1.7	2.4 ± 1.7	.363
CK (U/L)	89.2 ± 156.4	81.8 ± 153.1	115.4 ± 172.7	.359
Troponin I (ng/mL)	0.163 ± 0.5	0.174 ± 0.5	0.129 ± 0.1	.137
NT-proBNP (pg/mL)	383.3 ± 470.8	306.6 ± 385.8	655.2 ± 645.2	.029*
BNP (pg/mL)	20.6 ± 32.3	19.7 ± 31.9	23.7 ± 35.1	.716
CRP (mg/L)	12.7 ± 11.1	13.3 ± 12.1	10.4 ± 5.8	.468
Lactate (mg/dL)	26.9 ± 25.4	23.8 ± 24.1	32.3 ± 30.3	.362
Normal saline (mL)	1157.0 ± 774.1	1187.2 ± 813.2	1050.0 ± 638.4	.831
Lactate ringer (mL)	458.0 ± 597.0	439.7 ± 570.1	522.7 ± 711.7	.189
Albumin (bottle)	1.7 ± 1.4	1.6 ± 1.4	1.9 ± 1.4	.290
Time to stable (min)	512.7 ± 439.9	559.4 ± 460.9	347.1 ± 319.5	.387
ICU stay (d)	1.7 ± 4.4	1.2 ± 3.4	3.7 ± 6.7	.007*
LOS (d)	14.7 ± 11.6	16.2 ± 11.8	10.6 ± 10.5	.172
CO (L/min)	5.4 ± 1.8	5.8 ± 1.8	5.4 ± 2.0	.589
TFC (1/Zo)	22.2 ± 6.2	21.8 ± 6.3	23.7 ± 5.8	.737
Icon	40.5 ± 17.9	39.1 ± 18.6	45.4 ± 15.0	.433
SVV%	19.2 ± 11.7	18.3 ± 11.8	22.1 ± 11.2	.227
SVRI (BSA)	1616.6 ± 1521.1	1676.7 ± 1688.4	1403.5 ± 663.9	.433
SVV (normal: high)	18: 32	15: 24	3: 8	.495
CHF history	3/50	1/39	2/11	.054
Liver cirrhosis	5/50	3/39	2/11	.306
Uremia	16/50	11/39	5/11	.279
DM	18/50	16/39	2/11	.298

BNP = B-type natriuretic peptide, BSA = body surface area, CHF = congestive heart failure, CK = creatinine kinase, CO = cardiac output, CRP = C-reactive protein, DBP = diastolic blood pressure, DM = diabetes mellitus, Icon = Index of contractility, ICU = intensive care unit, LOS = length of stay, MIN = minute, NICOM = noninvasive cardiac output monitoring, NT-proBNP = N-terminal pro-B-type natriuretic peptide, SBP = systolic blood pressure, SVRI = index of systemic vascular resistance, SVV = variation of stroke volume, TFC = thoracic fluid content, WBC = white blood cell.
*reaches statistical significance.

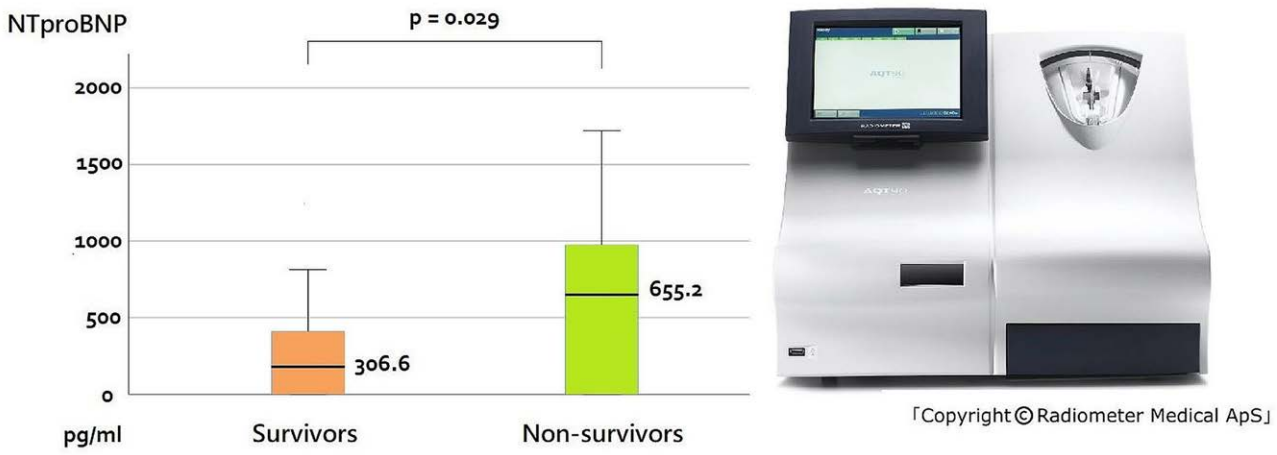

Figure 4. Non-survivors of septic shock had significantly higher NT-proBNP levels (655 vs 307, *P* = .029) and longer ICU stays (3.7 vs 1.2 days, *P* = .007). NT-proBNP = N-terminal pro-B-type natriuretic peptide.

An Asian study (n = 115, in a 30-bed ICU) demonstrated that combining the Acute Physiology and Chronic Health Evaluation II (APACHE II) score with early lactate area and NT-proBNP levels provided effective risk stratification in geriatric septic shock patients.[22] Similarly, a study in China (Chen, 2013) identified both NT-proBNP levels and the APACHE II score as independent predictors of 28-day mortality.[23] Another study (Guo et al, 2018) highlighted that a composite index of arterial

lactate, NT-proBNP, and CRP could serve as a valuable predictor of 28-day mortality in sepsis patients.[24] These findings suggest that NT-proBNP can be a reliable outcome predictor in septic shock patients.

4.6. ICU length of stay and mortality

A study from Brazil (Silva et al, 2023) identified risk factors for hospital mortality in the ICU, reporting significantly longer ICU stays for non-survivors compared to survivors (9 vs 2 days, $P < .001$). Similarly, our study found that non-survivors of septic shock had longer ICU stays than survivors (3.7 vs 1.2 days, $P = .007$).[25] The overall mortality rate in our cohort was 22%, which is consistent with findings from a previous review conducted in the U.S. (Hotchkiss et al, 2016).[15]

The ICON™ is one of the tools used for caring for these debilitated patients, there still are several tools that need to be put together to have better care policies just as communication and cooperation in different departments and divisions.[26]

5. Limitations

The Complex Role of NICOM in Septic Shock Management

Several NICOM parameters can be measured to guide the treatment of septic shock patients, with SVV% playing a significant role in assessing fluid status. However, this represents only a small part of the broader picture, as previous studies have largely focused on SVV% alone.

First, the timing of inotropic agent administration and the duration required to stabilize hemodynamic status vary significantly between patients, depending on individual conditions. This makes it challenging to compare the efficacy of inotropic agents at a standardized concentration.

Second, cardiac dysfunction in sepsis can be complex, affecting both the left and right sides of the heart, as well as systolic and diastolic function. As a result, it becomes difficult to determine the specific contribution of these dysfunctions to elevated NT-proBNP levels.

Third, although NICOM has been widely used in neonatal and pediatric care, particularly for surgical and postoperative monitoring, there is limited data available regarding its application in adult septic shock patients. This gap in the literature may limit the generalizability of certain findings, though our study's results have significant potential applications in this field.

Fourth, this study is a retrospective, and not a multi-center research, a relatively small number limited the scope of validity. We expect that more large number or even national registry research can be launched in the future.

6. Conclusions

In the overcrowded and overburdened emergency department (ED), NICOM offers a convenient and rapid method for assessing the hemodynamic status of septic shock patients. This study found that these patients tend to be older and often present with high SVV%. Fluid resuscitation is typically recommended before the administration of inotropic agents, and in cases of high SVV%, the fluid challenge often approaches the 30by3 Rule. Moreover, afebrile and non-tachycardic septic shock patients are at a higher risk of mortality. Elevated NT-proBNP levels were also observed in patients with no prior history of heart failure, suggesting that NT-proBNP may serve as a valuable outcome predictor in these cases. Finally, non-survivors of septic shock stayed an average of 2.5 days longer in the ICU compared to survivors.

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