

## Association Between Eccentricity Index and Stroke Volume Variation in Septic Patients: A Cross-Sectional Observational Study

Ida Julita, Bastian Lubis, Christmas G. Bangun

Departement of Anesthesiology and Intensive Therapy  
Faculty of Medicine, Universitas Sumatera Utara, Medan, Indonesia

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### Corresponding Author:

Ida Julita

Department of Anesthesiology  
and Intensive Care, Faculty of  
Medicine, University of Sumatra  
Utara, Medan, Indonesia

E-mail:

idajulita2009@gmail.com

### Abstract

**Introduction:** Fluid overload (FO) is common in septic ICU patients and increases morbidity and mortality. Assessing fluid status remains challenging. Stroke Volume Variation (SVV) is a dynamic parameter of fluid responsiveness, while the Eccentricity Index (EI) reflects right ventricular geometric changes due to volume overload. This study evaluated the relationship between EI and SVV in patients with sepsis.

**Methods:** This cross-sectional study included 29 newly diagnosed septic patients admitted to the ICU of Adam Malik Hospital. Fluid status was assessed within 24 hours after initial resuscitation (30 mL/kg crystalloids) based on the Surviving Sepsis Campaign. SVV was measured using an Ultrasonic Cardiac Output Monitor (USCOM), and EI was assessed by transthoracic echocardiography at end-systole using the Ryan protocol. FO was defined as SVV <10%.

**Results:** Participants were 55.2% male, with a mean age of 47.17±12.25 years. Respiratory tract infection was the main source of sepsis (65.5%). A strong negative correlation was found between EI and SVV ( $r=-0.802$ ;  $p<0.05$ ). Significant differences in EI and SVV were observed between patients with and without FO ( $p<0.05$ ).

**Discussion:** Higher EI values were associated with lower SVV, indicating that septal deformation corresponds with fluid overload. EI may complement SVV in evaluating fluid status.

**Conclusion:** EI shows a strong negative correlation with SVV in septic ICU patients and may serve as an adjunct parameter for fluid assessment. Further studies are required to confirm the diagnostic value.

**Keywords:** Eccentricity index; fluid overload; sepsis; stroke volume variation

### Introduction

Sepsis remains a major global health problem with high morbidity and mortality rates among critically ill patients. A systematic review published in 2016 reported that more than 30 million cases of sepsis are treated in hospitals worldwide each year, resulting in approximately 5.3 million deaths.<sup>1</sup> In Asia

alone, the estimated number of sepsis cases reaches 22.8 million annually, accounting for nearly 47% of the global sepsis burden.<sup>2</sup>

Fluid therapy plays a central role in the management of sepsis. Early fluid resuscitation is routinely performed to restore tissue perfusion and achieve hemodynamic stabilization within a short period.<sup>3</sup> Optimal fluid management requires a personalized

approach tailored to each patient's hemodynamic profile. However, excessive fluid administration may lead to fluid overload, disrupting fluid balance, worsening morbidity, prolonging mechanical ventilation, and increasing sepsis-related mortality.<sup>4</sup>

Fluid overload (FO) is defined as excessive fluid accumulation characterized by hypervolemia, tissue edema, or both, which may result in impaired tissue perfusion and organ dysfunction.<sup>5</sup> In clinical practice, daily fluid balance monitoring is commonly used to prevent FO in septic patients admitted to the ICU. Nevertheless, this method is prone to human error and may compromise the accuracy of fluid status assessment.<sup>6</sup> Ultrasonography has therefore been increasingly utilized to detect hypervolemia by assessing large vein distension, changes in venous blood flow in major organs such as the brain, kidneys, and liver, as well as increased extravascular lung water.<sup>7</sup> Additional parameters for evaluating fluid status include stroke volume variation (SVV) and the more recently introduced eccentricity index (EI).

The Eccentricity Index is derived from the ratio reflecting left ventricular deformation caused by interventricular septal flattening secondary to increased right ventricular pressure or volume.<sup>8-9</sup> Through its ability to depict changes in ventricular geometry, EI has the potential to facilitate early identification of fluid overload. Despite its established use in evaluating right ventricular pressure overload and other cardiovascular conditions, the application of EI in sepsis remains limited.<sup>8-9</sup> Its potential role as an early indicator of fluid imbalance, enabling more precise fluid resuscitation strategies, warrants further investigation.

Therefore, this study aims to evaluate the association between the Eccentricity Index and Stroke Volume Variation for assessing fluid status in septic patients, particularly to understand the relationship between ventricular geometric changes and fluid responsiveness parameters in the intensive care unit.

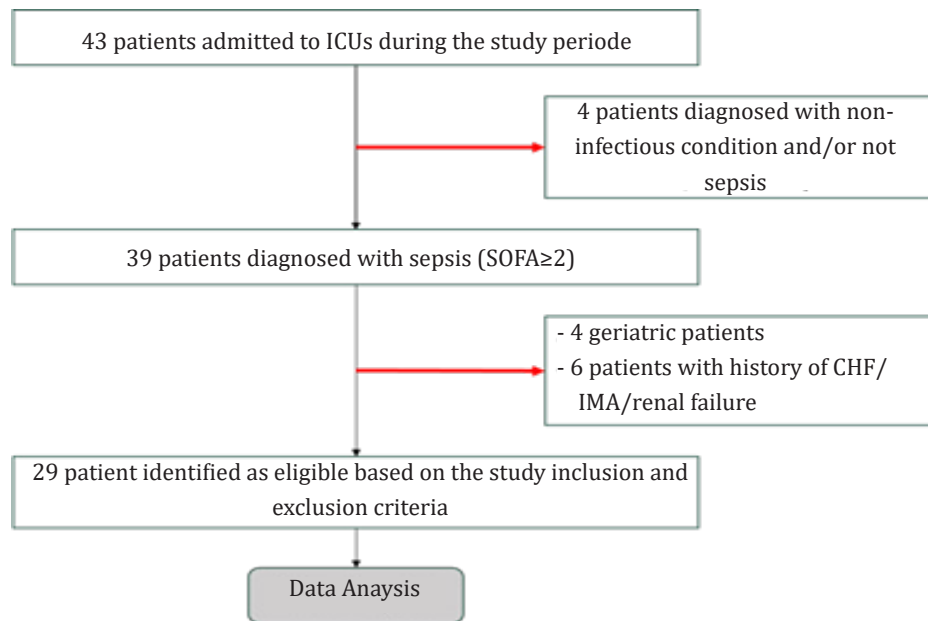
## Subjects and Methods

This study employed a cross-sectional observational design. The research was conducted in the Intensive Care Unit (ICU) of Adam Malik Hospital, Medan, from August to October 2025. Ethical approval was obtained from the Health Research Ethics Committee of Universitas Sumatera Utara (No: 578/KEPK/USU/2025), and research permission was granted by the Ethics Committee of Adam Malik Hospital (No: DP.04.03/D.XXVIII.2.2.3/1146/2025).

Participants were recruited using consecutive sampling (Figure 1). Patients were eligible if (1) they were aged 18–65 years, (2) newly diagnosed with sepsis (SOFA score >2), (3) hemodynamically stable (MAP  $\geq$ 65 mmHg), and (4) on controlled mechanical ventilation (tidal volume 8 mL/kg) under deep sedation. All patients included in the study had received initial fluid resuscitation according to the 2021 surviving sepsis campaign (SSC) guidelines, which consisted of at least 30 mL/kg of intravenous crystalloids within the first three hours for patients with sepsis-induced hypoperfusion. Following this initial resuscitation, patients underwent endotracheal intubation and were managed in the ICU for further stabilization. Baseline severity parameters, including SOFA score, presence of septic shock, serum lactate level, norepinephrine dose, MAP, and PEEP, were recorded to assess comparability between groups and potential confounding.

To prevent structural cardiac bias in the eccentricity index (EI), patients with a history of congestive heart failure (cardiothoracic ratio >50%), congenital heart disease, valvular abnormalities, or acute myocardial ischemia were excluded. Furthermore, patients with renal impairment (creatinine clearance <30 mL/min) or those requiring dialysis were excluded to minimize non-sepsis-related fluid retention.

Fluid overload (FO) was operationally defined based on fluid responsiveness; an SVV value of <10% served as the reference



**Figure 1 Flow Diagram Depicting Initial Assessment and Patient Recruitment in the Study**

standard for the presence of fluid overload, indicating that the heart was operating in the flat portion of the Frank-Starling curve.<sup>10</sup>

Stroke volume variation (SVV): measured non-invasively using the ultrasonic cardiac output monitor (USCOM) 1A (USCOM Pty Ltd, Australia). A continuous-wave doppler probe (2.0–3.3 MHz) was placed at the suprasternal notch to record the velocity-time integral (VTI) and calculate SVV over a 30-second cycle.<sup>11</sup>

Eccentricity index (EI): Assessed via two-dimensional transthoracic echocardiography (TTE) in B-mode using a 3.5 MHz cardiac probe. Following the standardized procedure established by previous researchers protocol, measurements were taken from the parasternal short-axis view at the mid-left ventricular level. The diameters perpendicular to  $D_1$  and parallel to  $D_2$  to the interventricular septum were measured at end-systole to capture septal deformation. Values of EI 1 indicated the absence of FO, while EI 1.1 indicated the presence of FO.<sup>12</sup>

The formula used was:

$$\text{Eccentricity Index (EI)} = \frac{D_2}{D_1}$$

All echocardiographic examinations were performed by a single intensivist certified in critical care echocardiography with more than three years of experience. To minimize measurement bias, EI measurements were obtained in three consecutive cardiac cycles and averaged. SVV values were recorded simultaneously under the same hemodynamic condition, ensuring a stable heart rhythm and the absence of spontaneous breathing effort. Patients with arrhythmias were excluded to maintain the validity of SVV.

Before analysis, a minimum sample size was estimated for a correlation analysis, assuming an expected moderate correlation coefficient ( $r=0.45$ ), a two-sided alpha of 0.05, and a statistical power of 80%, resulting in a required minimum sample of 29 subjects. Missing data were handled using complete-case analysis, as no variable included in the final analysis had missing values exceeding 5%. All statistical tests were two-tailed, and a p-value  $<0.05$  was considered statistically significant.

Data were analyzed using IBM SPSS Statistics version 26. Normality was tested using the Shapiro-Wilk test. Descriptive statistics were presented as the mean SD or

**Table 1 General Characteristics of Research Subjects**

Characteristic	Total (n=29)	p-value
Age (year)	47.17±12.25	0.815 <sup>†</sup>
Sex (n[%])		
Male	16 (55.2)	0.321*
Female	13 (44.8)	
BMI (kg/m <sup>2</sup> )	24.21±2.34	0.36
SBP (mmHg)	129.41±15.43	0.893
DBP (mmHg)	75.34±11.45	0.446
MAP (mmHg)	93.37±11.41	0.654
HR (beat/minute)	89.14±12.74	0.367
Diagnosis (n [%])		
Respiratory System	19 (65.5)	0.643*
Gastrointestinal System	2 (6.9)	
Genitourinary	3 (10.3)	
SSTI	3 (10.3)	
Neurological system	2 (6.9)	
Fluid balance (mL)	1542.24±441.9	<0.001
Vasopressor dose (mcg/kg/hr)	0.18±0.1	0.856

Note: Chi-square test; T-Independent Test

median (min-max). The relationship between EI and SVV was evaluated using the Spearman correlation test (given the distribution of the variables) and was further validated with Linear Regression. Linear regression analysis was performed to quantify the relationship between EI and SVV. The analysis primarily focuses on the direct association between ventricular geometry and fluid responsiveness.

## Results

A total of 29 patients were included in this cross-sectional observational study. Of these, 22 patients did not develop fluid overload, while 7 patients were classified as having fluid

overload. Age, sex, body mass index (BMI), hemodynamic parameters, and primary diagnosis were analyzed stratified according to fluid overload status.

Baseline clinical characteristics, including MAP, heart rate, and vasopressor requirements, were similar across the cohort (p>0.05), suggesting hemodynamic comparability among participants. All subjects required a similar range of norepinephrine doses (0.18±0.1 mcg/kg/hour) to maintain target MAP, minimizing the confounding effect of varying shock severity.

The mean age of the study population was 47.17±12.25 years. Patients in the fluid overload (FO) group had a mean age of

**Table 2 Correlation of EI and SVV in Evaluating FO Status in Sepsis**

Characteristic	EI	SVV	r	p-value
Mean±SD	0.96±0.19	12.02±2.36	-0.802	<0.001

Note: \*Spearman Test

**Table 3 Regression Analysis of EI and SVV in Evaluating FO Status in Sepsis**

Variable	$\beta$	95% CI	p-value
Constant	21.28	18.51-24.07	<0.001
EI	-9.65	(-12.49)-(-6.81)	<0.001

Note: Linear Regression Test

48.14±15.96 years, while those in the non-FO group had a mean age of 46.86±11.26 years. No significant difference in age was observed between the two groups (p>0.05).

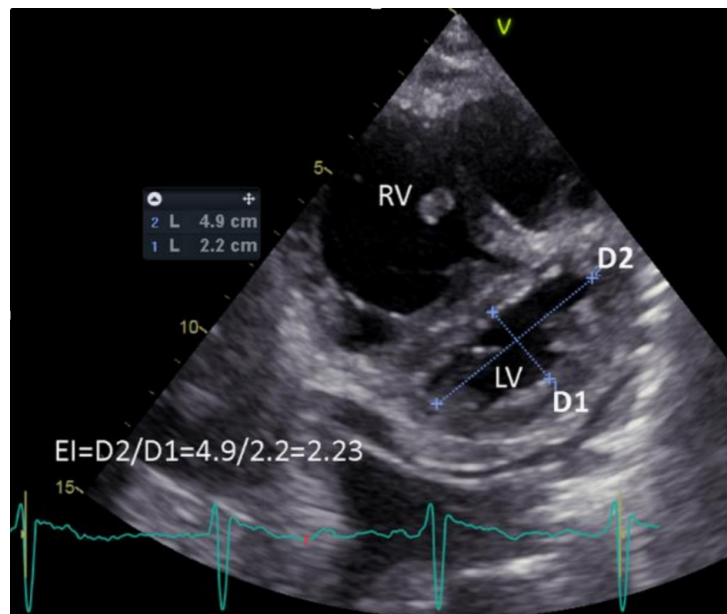
Of the 29 patients included, 16 (55.2%) were male, and 13 (44.8%) were female. In the FO group, 5 patients (71.4%) were male, and 2 (28.6%) were female. In contrast, the non-FO group showed an equal distribution between male and female patients (11 patients each, 50%). There was no statistically significant difference in sex distribution between groups (p>0.05).

The overall mean body mass index (BMI) was 24.21±2.34 kg/m<sup>2</sup>. The mean BMI in the FO group was 24.92±1.66 kg/m<sup>2</sup>, compared with 23.98±2.51 kg/m<sup>2</sup> in the non-FO group. This difference was not statistically significant (p>0.05).

Hemodynamic parameters evaluated

included systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), and heart rate (HR). The mean SBP for the entire cohort was 129.41±15.43 mmHg, with values of 128.71±17.58 mmHg in the FO group and 129.64±15.12 mmHg in the non-FO group. The mean DBP was 75.34±11.45 mmHg overall, with 78.28±4.49 mmHg in the FO group and 74.41±12.86 mmHg in the non-FO group. The mean MAP was 93.37±11.41 mmHg, measuring 95.05±8.29 mmHg in the FO group and 92.82±12.35 mmHg in the non-FO group. The mean HR was 89.14±12.74 beats per minute, with values of 93.00±16.76 beats per minute in the FO group and 87.91±11.38 beats per minute in the non-FO group. No significant differences were found in any hemodynamic parameters between the two groups (all p>0.05).

Respiratory tract infections were the most



**Figure 2 Measurement of the Short Axis of LV using Ultrasonography and EI Calculation <sup>12</sup>**

common source of sepsis, accounting for 19 patients (65.5%), including 5 (71.4%) in the FO group and 14 (63.6%) in the non-FO group. Genitourinary infections and skin and soft tissue infections (SSTIs) were each identified in 3 patients (10.3%). Gastrointestinal and neurological infections were each observed in 2 patients (6.9%). There was no significant association between the source of infection and the occurrence of fluid overload ( $p > 0.05$ ).

The mean cumulative fluid balance for the entire study population was  $1542.24 \pm 441.90$  mL. Patients in the FO group had a significantly higher mean fluid balance compared with those in the non-FO group ( $2193.57 \pm 314.20$  mL vs.  $1335.00 \pm 213.91$  mL;  $p < 0.05$ ). The mean vasopressor dose administered was  $0.18 \pm 0.10$  mcg/kg/hour, with no significant difference between the FO and non-FO groups ( $0.17 \pm 0.76$  vs.  $0.18 \pm 0.11$  mcg/kg/hour;  $p > 0.05$ ).

The distribution of Eccentricity Index (EI) and Stroke Volume Variation (SVV) values according to fluid overload status is presented in Table 2.

Based on Table 2, the mean EI and SVV values were  $0.96 \pm 0.19$  and  $12.02 \pm 2.36\%$ , respectively. A statistically significant, strong negative correlation was observed between EI and SVV in assessing fluid overload in septic patients in the ICU ( $r = -0.802$ ;  $p < 0.05$ ).

Regression analysis of EI and SVV further supported these findings. The EI showed a significant negative regression coefficient ( $\beta = -9.65$ ; 95% CI:  $-12.49$  to  $-6.81$ ;  $p < 0.001$ ), indicating that for each one-unit increase in EI, the SVV value decreased by an average of 9.65 units.

## Discussion

This study is the first to evaluate the use of the Eccentricity Index (EI) for assessing fluid volume status in septic patients admitted to the ICU and to examine its correlation with stroke volume variation (SVV). The findings demonstrate a statistically significant and strong negative correlation between EI and SVV ( $r = -0.802$ ;  $p < 0.05$ ), indicating that higher

EI values are associated with lower SVV values. This relationship reflects alterations in right ventricular (RV) geometry caused by increased intrathoracic volume. It is consistent with the pathophysiology of sepsis, in which changes in preload and afterload influence ventricular interdependence and cardiovascular responsiveness to intravascular volume variations.

In septic patients with increased RV workload, RV dilatation may lead to compression of the left ventricular (LV) chamber, manifested as flattening of the interventricular septum and quantified by an increase in EI.<sup>13</sup> Physiologically, RV enlargement shifts the interventricular septum toward the LV, reducing LV filling space and subsequently altering stroke volume responsiveness to preload changes.<sup>14</sup> This septal displacement not only serves as an indicator of RV pressure or volume overload but is also associated with clinically relevant hemodynamic consequences in sepsis, including reduced effective cardiac output and impaired organ perfusion.<sup>15</sup>

However, it is crucial to consider that EI reflects interactions between right ventricular afterload and pressure rather than volume status alone. In septic patients, increased EI may be significantly influenced by ventilator-lung-RV interactions. Factors such as high positive end-expiratory pressure (PEEP), acute respiratory distress syndrome (ARDS), hypoxia-induced pulmonary vasoconstriction, or pulmonary embolism can elevate RV afterload. These conditions lead to RV pressure overload, causing interventricular septal flattening even in the absence of primary volume overload. Therefore, the observed association between EI and SVV in this study should be interpreted as a reflection of complex hemodynamic interactions in critically ill patients on mechanical ventilation.

Previous studies demonstrated that increasing severity of RV dysfunction is associated with worsening LV dysfunction, while severe RV dilatation is linked to a reduction in LV size rather than LV dilatation.<sup>16</sup> Similarly, another study reported that elevated EI values correlate with right-

to-left ventricular functional parameters assessed through invasive hemodynamic measurements. Furthermore, higher EI values have been associated with an increased risk of hospitalization and the need for escalation of therapy.<sup>17</sup> Collectively, these findings reinforce the potential utility of EI in evaluating RV pressure overload and identifying underlying causes of increased RV pressure, particularly in critically ill and septic populations.

The observed inverse relationship between EI and SVV further supports the concept that excessive fluid administration, intended to augment RV preload, may paradoxically worsen ventricular interdependence by shifting the interventricular septum leftward, thereby increasing EI while reducing SVV values.

This phenomenon highlights an important limitation of SVV as a preload indicator in patients with complex cardiopulmonary conditions. As noted by a study that SVV may be less reliable in the presence of RV dysfunction, a common feature in sepsis.<sup>18</sup> In this context, EI offers a complementary echocardiographic parameter capable of capturing the structural impact of fluid overload on the RV, independent of some of the limitations inherent to SVV, such as dependence on mechanical ventilation, cardiac function, and thoracic compliance.

From a clinical perspective, these findings underscore the clinical relevance of EI as a sensitive physiological marker and the importance of a multimodal approach to fluid management in septic patients. Integrating echocardiographic parameters such as EI with conventional hemodynamic monitoring may provide a more comprehensive evaluation of preload conditions and fluid overload risk. This approach may assist clinicians in optimizing fluid resuscitation strategies and avoiding excessive fluid administration, which has been associated with increased morbidity and mortality in sepsis.<sup>19</sup>

It is important to acknowledge that the eccentricity index does not exclusively reflect volume overload. EI may also increase in the setting of right ventricular pressure overload or increased afterload, such as in patients with

elevated positive end-expiratory pressure (PEEP), acute respiratory distress syndrome (ARDS), hypoxic pulmonary vasoconstriction, or pulmonary embolism. Under these conditions, interventricular septal flattening may occur due to increased right ventricular pressure rather than intravascular volume expansion alone. Therefore, the observed association between EI and SVV in this study may partly reflect complex ventilator–lung–right ventricular interactions rather than isolated fluid-related changes.<sup>20</sup>

Several limitations of this study should be acknowledged. The study population exhibited considerable heterogeneity in demographic and clinical characteristics, which may influence EI and SVV measurements.

Additionally, stratification based on objectively assessed cardiopulmonary, renal, or hepatic function was not performed, potentially affecting the interpretation of the relationship between EI and SVV. Potential confounders such as detailed ventilatory parameters, ARDS severity, and vasopressor dosages were not specifically adjusted for, which may influence RV afterload and the EI–SVV relationship.

Therefore, the findings should be interpreted as preliminary and hypothesis-generating rather than confirmatory. Future studies with larger sample sizes and diagnostic accuracy or agreement analysis are warranted to refine its clinical applicability.

Furthermore, this study focused on correlation and linear regression to demonstrate the association between EI and SVV. It did not involve diagnostic performance metrics such as receiver operating characteristic (ROC) curves, Area under the curve (AUC), or Bland-Altman agreement analysis. Therefore, the findings should be interpreted as proof of association rather than a formal validation of EI as a substitute for SVV. Future studies with larger cohorts are necessary to establish precise EI cut-off values and evaluate its sensitivity and specificity in detecting fluid overload. Despite these limitations, the present findings offer an important initial insight into the interaction

between EI and SVV in septic patients.

## Conclusion

This study demonstrates a significant strong negative correlation between the eccentricity index (EI) and stroke volume variation (SVV) in septic ICU patients. While these findings suggest that EI may provide complementary insights into fluid status, the present study was not designed to determine diagnostic accuracy or causal inference.

However, given the cross-sectional design and potential confounding factors including ventilator settings, right ventricular afterload, and vasoactive drug use, the observed association should be interpreted with caution. Further prospective studies incorporating diagnostic accuracy, agreement analysis, and standardized hemodynamic assessment are required before clinical equivalence or substitution can be considered.

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