The relationship of bioimpedance analysis to central venous pressure, degree of edema, and cumulative fluid balance in septic shock patients in the intensive care unit

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Abstract

***Objective*: To determine the relationship between bioimpedance analysis (BIA) parameters and central venous pressure (CVP), degree of edema, and cumulative fluid balance in patients with sepsis and septic shock in the Intensive Care Unit (ICU) of Dr. Wahidin Sudirohusodo Hospital.**

***Design*: This study was an observational, analytical study with a cross-sectional design.**

***Setting*: The study was conducted at the ICU of Dr. Wahidin Sudirohusodo Hospital, Makassar, Indonesia, from January to March 2025.**

***Patients*: The study included 50 adult patients diagnosed with sepsis or septic shock who met the inclusion criteria and underwent BIA measurements.**

***Measurements*: BIA parameters, including extracellular water (ECW), intracellular water (ICW), total body water (TBW), ECW/TBW ratio, phase angle, resistance, and reactance, were measured on day 3 after sepsis diagnosis. Clinical data included CVP, degree of edema, cumulative fluid balance, length of stay in the ICU, and in-hospital mortality.**

***Results*: There was a significant correlation between CVP and several BIA parameters, including ICW (r=-0.348, p=0.013), ECW (r=0.482, p<0.001), ECW/TBW ratio (r=0.747, p<0.001), phase angle (r=-0.499, p<0.001), resistance (r=-0.561, p<0.001), and reactance (r=-0.492, p<0.001). ECW and the ECW/TBW ratio were positively associated with the degree of edema, while phase angle and reactance showed negative associations (p<0.05). ICW, ECW/TBW ratio, phase angle, resistance, and reactance also showed significant associations with mortality (p<0.05). No significant correlation was found between any BIA parameter and cumulative fluid balance or length of stay in the ICU (p>0.05).**

***Conclusions*: BIA parameters, especially low ICW, phase angle, resistance, and reactance, as well as high ECW and ECW/TBW ratio, were significantly associated with increased CVP, degree of edema, and mortality in sepsis and septic shock patients. These findings suggest that BIA could serve as a valuable tool in assessing fluid status and predicting clinical outcomes in critically ill patients.**

Keywords: Bioimpedance analysis, sepsis, central venous pressure, cumulative fluid balance, degree of edema.

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Background

Sepsis is a significant cause of death globally, ranging from 34% to 46%. (1) In sepsis, systemic volume dysregulation occurs due to endothelial dysfunction caused by inflammation. Consequently, it increases interstitial permeability, so volume resuscitation with intravenous crystalloids becomes the mainstay of acute treatment. (2) Current guidelines recommend early administration of antibiotics and intravenous (IV) fluids. (3) According to the Surviving Sepsis Campaign, patients with hypoperfusion caused by sepsis should receive at least 30 ml/kg of IV fluids within the first three hours. (4) However, in fluid resuscitation, the prognosis can worsen when the microcirculatory system cannot respond to fluids. (2)

Volume excess increases central venous pressure (CVP) and renal vascular pressure, leading to organ edema. (5) Tissue edema causes mortality. (6) Meanwhile, hypovolemia can cause decreased tissue perfusion, which is associated with morbidity and mortality. (7) Therefore, hemodynamic measurement and monitoring in resuscitation patients are necessary to improve short and medium-term outcomes and prevent death. (2,8)

Hemodynamic monitoring can be done by monitoring CVP, mean arterial pressure (MAP), and cardiac output. However, these parameters have limitations in tracking fluid shifts accurately. (9) Bioimpedance analysis (BIA) parameters have been proposed as a safe, rapid, and non-invasive alternative hemodynamic measurement for measuring whole-body composition and fluid compartments. BIA can monitor body composition and fluid status, potentially providing more precise data on fluid shifts and hemodynamic stability. (10)

Previous studies have separately reported the relationship between CVP, edema, and cumulative fluid balance with BIA. Suh et al.'s study stated that the extracellular water (ECW)/total body water (TBW) ratio <0.378 correlated with CVP<5 mmHg in liver resection patients. (11) The study by Shin et al. showed that the ECW/TBW ratio showed significantly higher extracellular edema in patients with sepsis. (12) In the study by Kharadi et al., it was stated that the length of stay was associated with greater fluid balance and was associated with mortality. (13) Kyosebekirov et al. noted that an increase in the ECW/TBW ratio is associated with higher mortality rates. (14) However, no study has examined the relationship between BIA and CVP, degree of edema, and cumulative fluid balance in sepsis and septic shock in the intensive care unit (ICU). These results aimed to identify the optimal measurement tool for monitoring fluid status in septic patients undergoing fluid therapy, thereby improving outcomes and preventing mortality. Therefore, this study aimed to determine the relationship between BIA and CVP, the degree of edema, and cumulative fluid balance in sepsis and septic shock in the ICU.

Methods

Study design, population, and sampling method

A cross-sectional study was conducted on patients with sepsis and septic shock in the ICU of Dr. Wahidin Sudirohusodo Hospital from January to March 2025. Inclusion criteria included patients aged 18–65 years, with a body mass index (BMI)<30 kg/m², American Society of Anesthesiologists Physical Status (ASA PS) 2–3, ventilated, requiring hemodynamic monitoring, and willing to participate in the study. Exclusion criteria included patients with kidney or heart diseases, malignancy, history of thoracic surgery, radiation therapy, and conditions that could interfere with the validity of the measurement, such as severe edema or high positive end-expiratory pressure (PEEP). Patients who experienced complications or withdrew were categorized as dropouts.

Data collection

The BIA-based fluid management protocol using the InBody S10® device was carried out; BIA was measured on the 3rd day after sepsis was diagnosed, including the parameters of ECW, intracellular water content (ICW), TBW, ECW/TBW ratio, phase angle, resistance, and reactance. CVP was measured with a manometer based on clinical standards, while the fluid balance was determined by recording fluid input and output. The degree of edema was calculated based on the degree of pitting edema. (15) Data on in-hospital mortality and length of stay in the ICU were also recorded.

Data analysis

Data analysis was performed using SPSS version 27, including independent sample t-test, Mann-Whitney, chi-square, and Spearman correlation tests.

Ethical approval

The study was conducted based on the permit from the Hasanuddin University Ethics Committee, number DP.04.03/D.XIX.2.3.1/026/2025.

Results

Sample characteristics

The total sample in this study consisted of 50 patients diagnosed with sepsis and septic shock who were admitted to the ICU of Dr. Wahidin Sudirohusodo Hospital.

Table 1 presents the baseline characteristics of the 50 patients with sepsis and septic shock. The average age of participants was 46.82 years, with a normal mean BMI of 22.88 kg/m^2. The majority of patients were male (58%) and had a mean Sequential Organ Failure Assessment (SOFA) score of 10.24, indicating significant organ dysfunction. Based on CVP classification, most patients were in a hypervolaemic state (48%), followed by euvolaemic (46%), and hypovolaemic (6%). The mean edema score was 2.30, while the average cumulative fluid balance was 2110.04 ml. A total of 28 patients (56%) died during hospitalization, and the average length of ICU stay was 8.38 days.

Table 2 shows the relationship between bioimpedance parameters and fluid status indicators, including CVP, edema score, and cumulative fluid balance. There was a statistically significant relationship between CVP and ICW, ECW, ECW/TBW ratio, phase angle, resistance, and reactance ($p<0.05$), whereas TBW was not significantly associated with CVP. ICW, phase angle, resistance, and reactance showed negative correlations with CVP, while ECW and ECW/TBW ratio showed positive correlations. For the edema score, ECW, ECW/TBW ratio, phase angle, and reactance were significantly associated ($p<0.05$), but ICW, TBW, and resistance were not. No BIA parameters were significantly correlated with cumulative fluid balance ($p>0.05$), indicating limited sensitivity of fluid balance records in capturing true fluid status.

Table 3 compares bioimpedance parameters between patients who died and those who survived. There were significant differences in ICW, ECW/TBW ratio, phase angle, resistance, and reactance between the two groups ($p<0.05$), suggesting that patients with lower ICW, phase angle, resistance, and reactance and higher ECW/TBW ratio were more likely to experience mortality. However, ECW and TBW did not show a statistically significant relationship with mortality ($p>0.05$), indicating that absolute fluid volumes may not predict outcomes as reliably as distribution patterns and cellular integrity.

Table 4 presents the correlation between bioimpedance parameters and length of stay in the ICU. None of the BIA-derived variables, including ICW, ECW, TBW, ECW/TBW ratio, phase angle, resistance, and reactance, demonstrated a significant association with ICU length of stay ($p>0.05$). This finding suggests that while bioimpedance parameters may reflect acute fluid status and predict mortality, they may not serve as predictors for ICU duration.

Discussion

The results showed that the lower the ICW, phase angle, resistance, and reactance values were, the higher the CVP and ECW; the higher the ECW/TBW ratio values, the higher the CVP. These results aligned with the study of Suh et al., on 192 patients undergoing liver resection, with the results showing a significant relationship between ECW/TBW ratio and CVP. Low ECW/TBW ratio was associated with low CVP values, showing that ECW/TBW ratio values <0.378 correlated with CVP <5 mmHg. (11) These results were supported by research by Sakaguchi et al., which stated that there was a positive, but weak, correlation between CVP and ECW in acute phase acute decompensated heart failure. (16) A low phase angle indicated lower body cell mass and an imbalance in cellular water, resulting in increased ECW. (17) High ECW increases venous return, thereby increasing cardiac output and vascular resistance. (18) Increased venous return and rise in vascular resistance could increase CVP. (19)

In this study, the greater the ECW and ECW/TBW ratio values and the lower the phase angle and reactance, the greater the edema. In the study by Nakanishi et al., it was reported that the ECW/TBW ratio was often used to assess edema in sepsis with a cutoff value of 0.40. (20) Similar results were reported by Kusaka et al., who found that the ECW/TBW ratio usually ranges from 0.36 to 0.4, with ECW/TBW ratio values >0.4, indicating edema status. (21) Increased ECW/TBW ratio indicates an increased systemic inflammatory response with oxidative stress and production of reactive oxygen species associated with damage to the immune system's cell membranes and loss of cell wall integrity, resulting in capillary leakage and interstitial edema. (12) Low reactance and phase angle reflect a response to lower damaged cell membrane capacitance, reflecting high inflammation. (17)

In this study, ICW, ECW, TBW, ECW/TBW ratio, phase angle, resistance, and reactance were unrelated to cumulative fluid balance. Different results from this study were reported by Balik et al., who stated that changes in ECW and TBW correlated well with 24-hour fluid balance between two bioimpedance measurements in all patients. (22) Meanwhile, in the study by Jeong et al., it was reported that changes in ECW/TBW ratio were positively correlated with hourly fluid balance. (23) This difference in results was because previous studies measured changes in cumulative fluid balance over time, whereas this study measured cumulative fluid balance values at a specific time.

This study found that patients who died had lower

ICW, phase angle, resistance, and reactance than patients who lived. This result aligned with the study by Iguacel et al., which found that low ICW was correlated with muscle wasting and inflammation and was an independent risk factor for mortality. (24) Similar results were reported by Cleymaet et al. that patients who died in the ICU had significantly lower ICW levels. (10) This was because decreased ICW was associated with low energy intake and high inflammation, thus associated with high mortality. (24) In addition, decreased reactance and resistance could reduce the phase angle, which was related to a decrease in the number of cells and changes in membrane integrity and hydration status, thus causing mortality. (25)

ICW, ECW, TBW, ECW/TBW ratio, phase angle, resistance, and reactance were not associated with the length of stay in the ICU. This result aligned with the research of Lee et al., which found that studies on critically ill patients treated in the ICU yielded results indicating that ECW, ICW, TBW, and ECW/TBW ratio were not significantly associated with length of stay in the ICU. (26) Different results were reported in the study by Xiong et al., indicating that the length of stay in the ICU had a very weak correlation with the ECW/TBW ratio in pediatric patients. (27) This difference in results may be due to differences in population, and this study was conducted across all ages.

This study's limitations were that it only measured BIA and cumulative fluid balance at one point and did not measure the cut-off value for using BIA parameters to assess the fluid status and outcomes of sepsis and septic shock patients.

Conclusion

Bioimpedance parameters such as low ICW, phase angle, resistance, and reactance values, and high ECW and ECW/TBW ratio had significant associations with increased CVP, degree of edema, and mortality, but not with cumulative fluid balance or length of stay in the ICU. Therefore, bioimpedance analysis had the potential to be used as a method for assessing fluid status and predicting clinical outcomes in patients with sepsis and septic shock. Further studies with longitudinal designs that focus on changes in parameter values and diagnostic tests to determine clinical threshold values are recommended to strengthen the evidence for using bioimpedance as a decision-making tool in the ICU

Conflict of interest

All authors have no conflict of interest regarding this article. This research did not receive research funding from any party.

Table 1. Characteristics of research subjects

Characteristics		n (%) or mean±SD
Age (years)		46.82±15.94
Gender	Male	29 (58.0)
	Female	21 (42.0)
SOFA score		10.24±2.23
Body mass index (kg/m^2)		22.88±3.66
CVP	Hypovolemic	3 (6.0)
	Euvolemic	23 (46.0)
	Hypervolemic	24 (48.0)
Edema score		2.30±0.73
Cumulative fluid balance (ml)		2110.04±1856.71
Mortality	Died	28 (56.0)
	Survived	22 (44.0)
Length of stay in ICU (days)		8.38±6.89

Legend: SD=standard deviation; SOFA=Sequential Organ Failure Assessment; CVP=central venous pressure; ICU=intensive care unit.
Gender data was processed using the chi-square test; other variables were processed using the Mann-Whitney U test.

Table 2. Relationship of bioimpedance analysis to CVP, degree of edema, and cumulative fluid balance

BIA	CVP		Degree of edema		Cumulative fluid balance	
	r-value	p-value	r-value	p-value	r-value	p-value
ICW	-0.348	0.013*	-0.175	0.225	-0.48	0.304
ECW	0.482	<0.001*	0.396	0.004*	-0.079	0.568
TBW	0.035	0.810	0.121	0.402	-0.135	0.349
ECW/TBW ratio	0.747	<0.001*	0.513	<0.001*	0.015	0.915
Phase angle	-0.499	<0.001*	-0.319	0.024*	-0.257	0.072
Resistance	-0.561	<0.001*	-0.276	0.053	-0.097	0.504
Reactance	-0.492	<0.001*	-0.332	0.018*	0.024	0.856

Legend: CVP=central venous pressure; BIA=bioimpedance analysis; ICW=intracellular water content; ECW=extracellular water content; TBW=total body water.
Data were tested using Spearman's correlation test. *significant (p<0.05); r 0–0.19=very weak, r 0.2–0.39=weak, r 0.4–0.59=moderate, r 0.6–0.79=strong, r 0.8–1.00=very strong. (28)

Table 3. Relationship between bioimpedance analysis and mortality

BIA	Mortality, mean±SD		p-value
	Yes	No	
ICW	18.78±3.96	22.98±5.09	0.001[b*]
ECW	17.93±4.66	16.34±4.31	0.222[a]
TBW	36.70±7.65	39.32±7.83	0.077[b]
ECW/TBW ratio	65.43±93.50	41.65±6.42	0.001[b*]
Phase angle	2.84±0.66	3.85±0.82	<0.001[b*]
Resistance	314.73±53.76	403.97±71.24	<0.001[b*]
Reactance	23.38±6.91	37.89±22.48	<0.001[b*]

Legend: BIA=bioimpedance analysis; SD=standard deviation; ICW=intracellular water content; ECW=extracellular water content; TBW=total body water.
[a]Independent sample t test; [b]Mann-Whitney U test; [*]significant ($p<0.05$).

Table 4. Relationship between bioimpedance analysis and length of stay in the ICU

BIA	r-value	p-value
ICW	-0.130	0.370
ECW	0.049	0.734
TBW	-0.103	0.477
ECW/TBW ratio	0.134	0.355
Phase angle	0.021	0.887
Resistance	-0.013	0.927
Reactance	0.041	0.778

Legend: BIA=bioimpedance analysis; ICW=intracellular water content; ECW=extracellular water content; TBW=total body water.
Data were tested using Spearman's correlation test. r 0–0.19=very weak, r 0.2–0.39=weak, r 0.4–0.59=moderate, r 0.6–0.79=strong, r 0.8–1.00=very strong. (28)

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