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AGREEMENT BETWEEN BIOELECTRICAL IMPEDANCE ANALYSIS, DAILY BODY WEIGHT, AND INTAKE-OUTPUT CHARTING FOR ASSESSING FLUID BALANCE IN SEPSIS AND SEPTIC SHOCK: A PROSPECTIVE OBSERVATIONAL COHORT STUDY FROM AN INDIAN INTENSIVE CARE UNIT

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ABSTRACT

Background and Aims: Assessment of cumulative fluid balance in sepsis and septic shock is clinically important but difficult in routine intensive care practice. Intake-output charting is widely used but may be affected by documentation errors and unmeasured losses. Daily body weight reflects net mass change but is logistically difficult in critically ill patients. Bioelectrical impedance analysis (BIA) may provide additional information on body-water compartments. This study evaluated the relationship and agreement between intake-output balance, daily body weight, and BIA-derived body-water measurements in adult patients with sepsis and septic shock.

Materials and Methods: This prospective observational cohort study was conducted in adult ICU patients with sepsis or septic shock between 20 April 2025 and 29 May 2026. Daily fluid input, output, body weight, and BIA-derived total body water (TBW), intracellular water (ICW), and extracellular water (ECW) were recorded. Daily net fluid balance was calculated as total input minus total output. Incremental cumulative fluid balance was derived as the running sum of daily net balance from each patient's first recorded measurement. Correlations between fluid balance and BIA/weight variables were assessed using absolute daily values and change-from-baseline values. Agreement was assessed using Bland-Altman analysis.

Results: Seventy patients contributed 230 paired daily observations. Mean age was 59.5 +/- 16.6 years, APACHE II score was 20.1 +/- 6.8, and SOFA score was 11.5 +/- 3.7. Mean daily fluid input was 2866 +/- 730 mL, output was 1420 +/- 494 mL, and daily net balance was +1447 +/- 955 mL. Mean daily body weight was 69.7 +/- 13.8 kg. BIA-derived TBW, ICW, and ECW were 36.4 +/- 6.1 L, 20.2 +/- 3.8 L, and 14.6 +/- 2.3 L, respectively. Absolute daily body weight correlated weakly with daily net balance ($r = 0.13$, $p = 0.045$), while TBW and ECW did not show meaningful absolute-value correlations with daily net balance. In repeated-measures change analysis, incremental cumulative balance showed no meaningful association with change in body weight ($r = 0.01$, $p = 0.909$), but showed weak associations with change in TBW ($r = 0.27$, $p < 0.001$) and ECW ($r = 0.24$, $p = 0.003$). Bland-Altman analysis demonstrated wide limits of agreement between methods.

Conclusion: In adult Indian ICU patients with sepsis and septic shock, intake-output balance, daily body weight, and BIA-derived body-water measurements were not interchangeable. BIA-derived TBW and ECW trends may provide useful adjunctive information on fluid accumulation and compartmental shifts but should complement rather than replace meticulous intake-output charting, serial clinical assessment, and individualized fluid stewardship.(CTRI:2025/04/085655).

KEYWORDS: Bioelectrical impedance analysis; Cumulative fluid balance; Extracellular water; Intensive care unit; Sepsis; Septic shock.

Key messages

- Fluid balance assessment in sepsis should not rely on a single bedside number.
- In this prospective Indian ICU study, daily weight did not reliably track incremental cumulative fluid balance.
- BIA-derived TBW and ECW trends showed weak but clinically plausible longitudinal relationships with fluid accumulation, while agreement with intake-output-derived balance remained wide.

- For Indian critical care units, the practical approach is to combine careful I/O charting, serial weight where feasible, BIA trends, and clinical examination rather than using any one method in isolation.

INTRODUCTION:

Fluid therapy is central to the management of sepsis and septic shock. Early resuscitation restores intravascular volume, cardiac output, and tissue perfusion. However, persistent positive fluid balance after initial resuscitation may contribute to interstitial edema, impaired oxygen diffusion, delayed liberation from mechanical ventilation, acute kidney injury, and worse outcomes. The clinical challenge is not merely how much fluid to administer, but how accurately to assess fluid accumulation over time.

In most intensive care units, cumulative fluid balance is estimated using intake-output records. Although simple and inexpensive, this method is prone to error because drug diluents, flushes, nutrition, drain losses, stool losses, and insensible losses may be incompletely recorded. Daily body weight is often considered a practical surrogate for net fluid change, based on the assumption that 1 kg of weight change approximates 1 L of fluid. In critically ill patients, however, accurate weighing is difficult because of immobility, ventilator tubing, monitoring devices, bed-scale variation, linen, dressings, drains, and frequent interruptions in care.

Bioelectrical impedance analysis is a non-invasive bedside method that estimates body-water compartments by measuring tissue resistance and reactance. Multifrequency segmental BIA can estimate total body water, intracellular water, extracellular water, and the ECW/TBW ratio. This is physiologically attractive in sepsis, where endothelial dysfunction, glycocalyx injury, capillary leak, and third spacing may alter fluid distribution without being fully reflected by body weight or intake-output charts.

Evidence on the role of BIA in critically ill septic patients remains limited, especially in Indian ICUs. The present study compared intake-output-derived fluid balance, daily body weight, and BIA-derived body-water compartments in patients with sepsis and septic shock, and examined whether these methods can be used interchangeably or should be interpreted as complementary tools

MATERIALS AND METHODS

Study design and setting: This was a prospective observational cohort study conducted in the adult intensive care units of S.L. Raheja Hospital, A Fortis Associate, Mumbai, India. Consecutive eligible patients were recruited and followed prospectively between 20 April 2025 and 29 May 2026. Serial paired daily measurements were recorded during ICU stay until ICU discharge, transfer, death, or cessation of study measurements.

Reporting guideline: This manuscript has been prepared and reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement for cohort/observational studies. The completed STROBE checklist is provided as Supplementary File 1.

Ethics approval: The study was approved by the Institutional Ethics Committee of S.L. Raheja Hospital. The IEC approval number was ECR/70/Inst/MH/2013/RR-24. Written informed consent was obtained from the patient or legally acceptable representative before study-related data collection.

Study population: Adult patients aged 18 years or older admitted to the ICU with sepsis or septic shock were screened for inclusion. Sepsis and septic shock were defined according to Sepsis-3 criteria. Patients were included if serial intake-output records, daily body weight, and BIA measurements were available during ICU stay.

Patients were excluded when reliable BIA measurement could not be performed because of limb amputation, major limb dressing, severe technical interference, or inability to place electrodes appropriately. Patients with clinical conditions expected to substantially distort BIA interpretation, such as dialysis-dependent chronic kidney disease or severe left ventricular dysfunction, were excluded based on protocol feasibility. A data audit check was performed prior to analysis to identify implausible transcription errors and protocol-relevant inconsistencies.

Study size: The planned study size was 70 patients. This sample size was chosen for feasibility in a single-center ICU study and to provide adequate paired serial observations for correlation and agreement analyses of bedside fluid-assessment methods. The final dataset provided 230 daily observations, corresponding to a mean of 3.3 paired measurement-days per patient. The study was not designed or powered for mortality prediction.

Data collection and definitions: Demographic variables, comorbidities, diagnosis, APACHE II score, SOFA score, routine laboratory variables, ICU length of stay, and ICU outcome were recorded. Daily fluid input included resuscitation fluids, maintenance fluids, blood products, medication diluents, enteral nutrition, and parenteral nutrition. Daily output included urine, drain output, and other measurable losses. Insensible losses were not directly measured.

Daily net fluid balance was calculated as total fluid input minus total fluid output. The source spreadsheet labeled this variable as cumulative fluid balance; for analysis and reporting, it was treated as daily net balance. Incremental cumulative fluid balance was calculated as the running sum of daily net balance after the first recorded study measurement for each patient.

Bias and data quality: To reduce measurement bias, body weight and BIA measurements were preferentially obtained within a consistent morning window before major fluid interventions. BIA measurements were performed by trained operators using standardized electrode placement. The dataset was audited for implausible values; obvious physiologically impossible values were corrected after source data review or excluded from the affected comparison. Missing data were handled by pairwise exclusion for the relevant analysis only. The number of missing observations was low: body weight was missing in 1/230 observations, TBW in 2/230 observations, ECW in 1/230 observations, and ICW in 0/230 observations. These missing observations were not imputed.

Body weight measurement: Body weight was recorded once daily, preferably between 07:00 and 09:00 hours, before major morning interventions whenever feasible. Bed scales or patient-lifting devices were used as clinically feasible. Efforts were made to maintain consistency in linen, clothing, drains, and attached equipment during serial measurements.

Bioelectrical impedance analysis

BIA was performed using a multifrequency direct segmental BIA device, the InBody S10. Measurements were performed in the supine position after a period of rest whenever feasible. Electrode contact points were cleaned, and electrodes were placed according to manufacturer recommendations. Measurements were preferably performed in the same morning time window as body weight assessment. The recorded BIA variables were TBW, ICW, and ECW.

Statistical Analysis

Continuous variables are expressed as mean +/- standard deviation. Categorical variables are expressed as numbers and percentages. Because patients contributed repeated daily observations, the dataset was interpreted as a longitudinal repeated-measures dataset rather than as independent observations.

Two levels of analysis were performed. First, absolute daily values of fluid balance, body weight, and BIA variables were examined. Second, change-from-baseline variables were calculated using each patient's first recorded measurement as baseline. The clinically relevant longitudinal analysis assessed the relationship between incremental cumulative fluid balance and changes in body weight, TBW, ICW, and ECW.

Correlation was assessed using Pearson correlation for absolute daily values and repeated-measures correlation for longitudinal change analysis. Agreement between methods was assessed using Bland-Altman analysis. Since correlation does not imply agreement, Bland-Altman findings were used to determine whether the methods could be considered interchangeable. A p-value<0.05 was considered statistically significant.

RESULTS

Study cohort

Of 983 screened ICU admissions, 70 patients fulfilled eligibility criteria and contributed 230 paired daily observations of intake-output balance, body weight, and BIA-derived water compartments (Figure 1). The data-collection period extended from 20 April 2025 to 29 May 2026. The mean number of paired measurement-days was 3.3 per patient, with a median of 3 observations per patient. Missing observations were uncommon: body weight was missing in 1 observation, TBW in 2 observations, ECW in 1 observation, and ICW in no observations. Missing values were excluded only from analyses requiring that specific paired variable.

Daily fluid balance and BIA measurements

Across all daily observations, mean daily fluid input was 2866 +/- 730 mL and mean daily output was 1420 +/- 494 mL. The mean daily net fluid balance was positive at +1447 +/- 955 mL. Mean daily body weight was 69.7 +/- 13.8 kg. Mean BIA-derived TBW was 36.4 +/- 6.1 L, mean ICW was 20.2 +/- 3.8 L, and mean ECW was 14.6 +/- 2.3 L (Table 2).

Correlation between absolute daily values

When absolute daily values were analyzed, daily body weight showed only a very weak correlation with daily net fluid balance (r = 0.13, p = 0.045). BIA-derived TBW (r = -0.01, p = 0.886) and ECW (r = 0.05, p = 0.458) did not show meaningful correlations with daily net fluid balance. ECW correlated with TBW ($r = 0.51$, $p < 0.001$), supporting physiological consistency within the BIA compartment measurements.

Longitudinal change-from-baseline analysis

In repeated-measures correlation analysis, incremental cumulative fluid balance showed no meaningful association with change in daily body weight ($r = 0.01$, $p = 0.909$). In contrast, incremental cumulative fluid balance showed weak but statistically significant associations with change in BIA-derived TBW ($r = 0.27$, $p < 0.001$) and ECW ($r = 0.24$, $p = 0.003$). Change in ICW was not meaningfully associated with incremental cumulative balance ($r = -0.002$, $p = 0.977$). The relationship between incremental cumulative fluid balance and change in ECW is shown in Figure 2.

Agreement between methods

Bland-Altman analysis demonstrated wide limits of agreement between incremental cumulative fluid balance and changes in daily body weight, TBW, and ECW (Figure 3). The bias for change in weight minus incremental cumulative balance was -2.26, with 95% limits of agreement from -12.69 to +8.16. The bias for change in TBW minus incremental cumulative balance was -1.80 L, with 95% limits of agreement from -6.06 to +2.46 L. The bias for change in ECW minus incremental cumulative balance was -1.85 L, with 95% limits of agreement from -6.10 to +2.39 L. These wide limits indicate that the methods cannot be used interchangeably for individual patient-level quantification of fluid accumulation.

Outcome observations

ICU mortality and disposition were recorded. Outcome analysis was interpreted cautiously because patients who survived longer contributed more daily observations and therefore had a greater opportunity to accumulate recorded fluid balance. This duration-related bias limits simple comparisons of total observed fluid balance between survivors and non-survivors. The study was therefore not designed or powered to establish mortality prediction based on BIA or fluid balance variables.

Table 1: Baseline characteristics of the study population

Variable	Value
Number of patients	70
Number of paired daily observations	230
Age, years	59.5 +/- 16.6
Female sex	45 (64.3%)
Male sex	25 (35.7%)
BMI, kg/m2	25.3 +/- 7.2
APACHE II score	20.1 +/- 6.8
SOFA score	11.5 +/- 3.7
Lactate, mmol/L	3.14 +/- 1.54
Creatinine, mg/dL	1.39 +/- 0.64
ICU length of stay, days	3.3 +/- 1.3
Data-collection period	20 April 2025 to 29 May 2026
Paired measurement-days per patient, mean	3.3

Values are expressed as mean +/- standard deviation or number (%).

Table 2: Daily fluid balance, body weight, and BIA-derived body-water measurements

Variable	Value
Daily fluid input, mL	2866 +/- 730
Daily fluid output, mL	1420 +/- 494
Daily net fluid balance, mL	+1447 +/- 955
Daily body weight, kg	69.7 +/- 13.8
BIA-derived TBW, L	36.4 +/- 6.1
BIA-derived ICW, L	20.2 +/- 3.8
BIA-derived ECW, L	14.6 +/- 2.3

BIA: bioelectrical impedance analysis; TBW: total body water; ICW: intracellular water; ECW: extracellular water. Missing observations: body weight 1/230, TBW 2/230, ECW 1/230, ICW 0/230. Missing values were excluded only from analyses requiring the affected paired variable.

Table 3: Relationship and agreement between fluid-balance methods

Comparison	Statistic	Interpretation

Daily net balance vs daily body weight	Pearson r = 0.13; p = 0.045	Very weak absolute-value association
Daily net balance vs BIA-TBW	Pearson r = -0.01; p = 0.886	No meaningful absolute-value association
Daily net balance vs BIA-ECW	Pearson r = 0.05; p = 0.458	No meaningful absolute-value association
Incremental cumulative balance vs delta weight	Repeated-measures r = 0.01; p = 0.909	Daily weight change did not track cumulative balance
Incremental cumulative balance vs delta TBW	Repeated-measures r = 0.27; p < 0.001	Weak longitudinal association
Incremental cumulative balance vs delta ECW	Repeated-measures r = 0.24; p = 0.003	Weak but clinically plausible longitudinal association
Bland-Altman agreement	Wide limits of agreement	Methods are complementary but not interchangeable

Figure 1: Study flow diagram showing screened ICU admissions, exclusions, enrolled patients, and paired daily observations analyzed

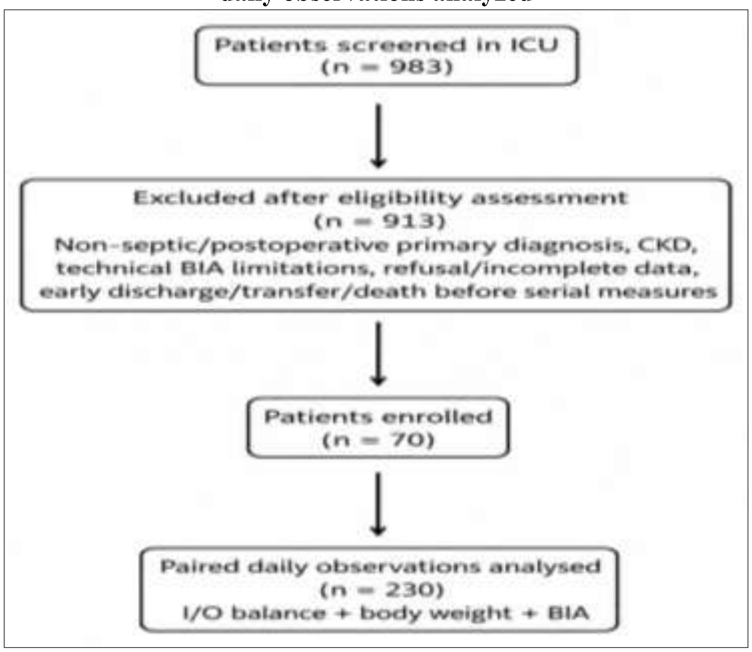


Figure 2: Relationship between incremental cumulative fluid balance and change in BIA-derived extracellular water. The scatter plot supports a weak but clinically plausible longitudinal association between progressive fluid accumulation and ECW change.

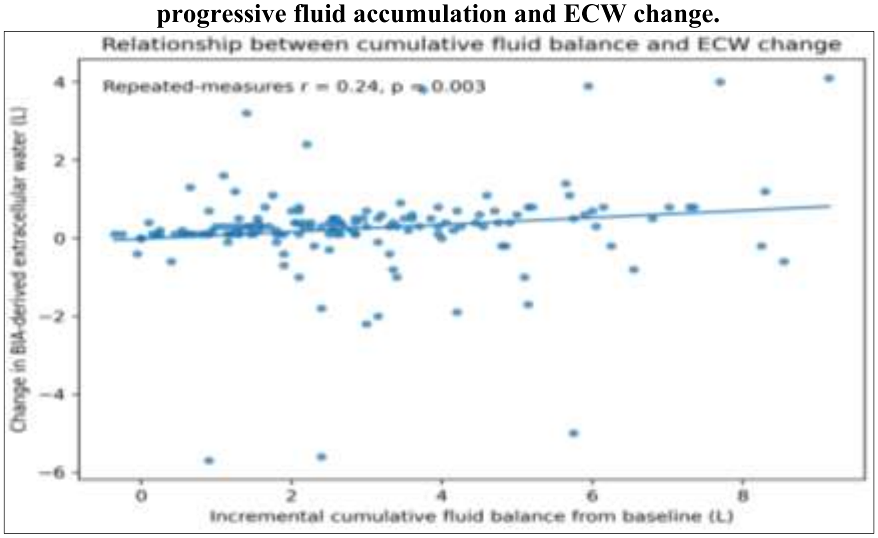
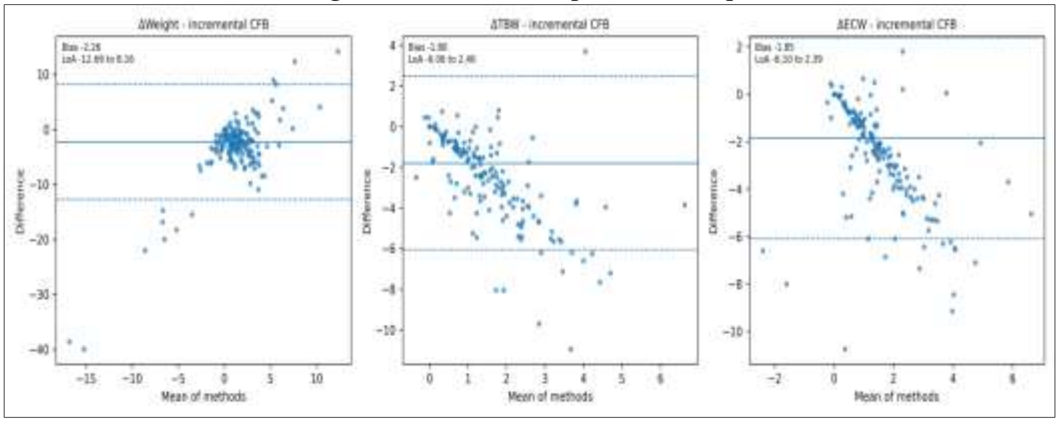


Figure 3: Bland-Altman plots comparing incremental cumulative fluid balance with change in daily body weight, BIA-derived TBW, and BIA-derived ECW. Wide limits of agreement indicate that these methods are not interchangeable for individual patient-level quantification.



DISCUSSION

In this prospective observational study of adult ICU patients with sepsis and septic shock, daily intake-output balance, body weight, and BIA-derived water compartments were compared as bedside methods of fluid assessment. The main finding was that these methods were not interchangeable. Daily body weight, although simple and familiar, showed poor longitudinal association with incremental cumulative fluid balance. BIA-derived TBW and ECW showed statistically significant but weak longitudinal associations with progressive fluid accumulation, while Bland-Altman limits of agreement remained wide.

These findings are clinically important for Indian ICUs. In many units, fluid balance decisions are still based predominantly on intake-output charts and bedside clinical examination. Daily weight is often recommended but inconsistently feasible because of patient immobility, lack of calibrated beds, attached devices, oxygen interfaces, drains, catheters, and variable nursing workload. BIA is attractive because it is non-invasive, portable, and provides compartmental data. However, the present findings suggest that BIA should be interpreted as a trend-based adjunct rather than as a stand-alone numerical replacement for charted balance.

The weak relationship between daily weight change and cumulative fluid accumulation is clinically plausible. ICU body weight measurements are affected by measurement conditions, linen, attached devices, bed-scale calibration, edema distribution, nutritional changes, and catabolism. In a short ICU stay, true fluid shifts may be masked by these measurement artifacts. Therefore, while daily weight may still be useful when measured consistently, it should not be treated as a precise estimate of cumulative fluid balance in septic patients.

The relationship between the change in BIA-derived TBW/ECW and incremental cumulative balance is physiologically relevant. Sepsis and septic shock are characterized by endothelial injury, glycocalyx disruption, increased capillary permeability, and interstitial fluid accumulation. These processes expand total and extracellular water compartments. BIA may therefore capture a clinically meaningful signal that is not adequately represented by total body weight or intake-output arithmetic alone.

However, the Bland-Altman findings are critical. Correlation describes whether two measurements move in the same direction, but agreement determines whether they can be used interchangeably. The wide limits of agreement observed in this study indicate that a given patient's BIA-derived change, weight change, and charted fluid balance may differ by clinically relevant margins. Therefore, replacing intake-output charting with BIA, or replacing BIA with daily weight, would be inappropriate.

The practical implication is a multimodal bedside approach. Intake-output charting remains essential because it documents prescribed and measured fluid intake and output. Daily weight, when measured consistently, provides a crude net mass trend. BIA adds information on compartmental distribution. These should be interpreted alongside clinical examination, vasopressor requirement, lactate trend, urine output, oxygenation, renal function, lung ultrasound (where available), and the overall phase of sepsis resuscitation.

This study also highlights an important methodological point for critical care research. Repeated daily ICU measurements should not be treated as independent observations. Analyses that ignore within-patient clustering may overstate statistical significance and generate misleading conclusions. For publication-quality research, serial measurements should be analyzed using repeated-measures correlation, mixed-effects models, or other longitudinal approaches.

STRENGHTS

The study was prospective, conducted in a real-world Indian ICU, and used simultaneous daily measurement of intake-output balance, body weight, and multifrequency segmental BIA. The study addresses a practical bedside problem faced by intensivists and ICU nurses during sepsis care. It also provides clinically relevant data on the non-interchangeability of commonly used fluid assessment tools.

LIMITATIONS OF THE STUDY

This study has limitations. It was single-center and observational. The sample size was modest, and patients contributed varying numbers of daily observations, with a mean of 3.3 paired measurement-days per patient. Insensible losses were not directly measured. Daily weight measurement in ICU patients may have been affected by technical and logistical factors. BIA measurements may be influenced by electrode placement, edema, body position, electrical interference, and acute changes in tissue conductivity. Missing data were infrequent and handled by pairwise exclusion, but residual measurement error remains possible. The study was not powered to determine whether BIA-guided management improves mortality, ventilator-free days, renal outcomes, or ICU length of stay. Outcome analysis was limited by the short observation period and duration-related bias.

CLINICAL SIGNIFICANCE FOR INDIAN CRITICAL CARE

For Indian critical care practice, this study supports a pragmatic message: fluid balance should be assessed using multiple complementary signals rather than a single number. BIA-derived TBW and ECW trends may be useful when available, especially for identifying changes in body-water compartments during ongoing resuscitation or early de-resuscitation. However, BIA should not reduce the emphasis on accurate nursing intake-output documentation, careful clinical examination, and individualized fluid stewardship.

CONCLUSION

In adult ICU patients with sepsis and septic shock, intake-output-derived fluid balance, daily body weight, and BIA-derived water compartments were not interchangeable. Serial changes in BIA-derived TBW and ECW showed weak but clinically plausible relationships with progressive fluid accumulation, whereas daily body weight performed poorly as a surrogate for cumulative fluid balance. BIA may therefore be used as an adjunctive bedside tool for understanding compartmental fluid shifts, but it should complement, rather than replace, intake-output charting and clinical assessment. In resource-variable Indian ICUs, a multimodal approach to fluid monitoring is likely to be more clinically useful than reliance on any single method.

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DECLARATIONS

Competing interests: The authors declare that they have no competing interests.

Consent for publication: Not applicable.

Funding: No external funding was received for this study.

Reporting guideline compliance

The study has been reported according to the STROBE statement for observational cohort studies. The completed STROBE checklist is submitted as Supplementary File 1.

Availability of data and materials: The anonymized dataset may be made available from the corresponding author on reasonable request, subject to institutional policy and ethics approval conditions.

Authors' contributions: KS collected data and prepared the initial thesis draft. SS conceptualized the study, supervised the project, interpreted the data, and critically revised the manuscript. DL and AD assisted in data acquisition, ICU workflow coordination, and BIA measurements. All authors reviewed and approved the final manuscript.

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