

The Correspondence between Fluid Balance and Body Weight Change Measurements in Critically Ill Adult Patients

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ABSTRACT

Introduction: Positive fluid status has been associated with a worse prognosis in intensive care unit (ICU) patients. Given the potential for errors in the calculation of fluid balance totals and the problem of accounting for indiscernible fluid losses, measurement of body weight change is an alternative non-invasive method commonly used for estimating body fluid status. The objective of the study is to compare the measurements of fluid balance and body weight changes over time and to assess their association with ICU mortality. **Methods:** This prospective observational study was conducted in the 34-bed multidisciplinary ICU of a tertiary teaching hospital in southern Brazil. Adult patients were eligible if their expected length of stay was more than 48 hours, and if they were not receiving an oral diet. Clinical demographic data, daily and cumulative fluid balance with and without indiscernible water loss, and daily and total body weight changes were recorded. Agreement between daily fluid balance and body weight change, and between cumulative fluid balance and total body weight change were calculated. **Results:** Cumulative fluid balance and total body weight change differed significantly among survivors and non survivors respectively, +2.53L versus +5.6L ($p=0.012$) and -3.05kg vs -1.1kg ($p=0.008$). The average daily difference between measured fluid balance and body weight was +0.864 L/kg with a wide interval: -3.156 to +4.885 L/kg, which remained so even after adjustment for indiscernible losses (mean bias: +0.288; limits of agreement between -3.876 and +4.452 L/kg). Areas under ROC curve for cumulative fluid balance, cumulative fluid balance with indiscernible losses and total body weight change were, respectively, 0.65, 0.56 and 0.65 ($p=0.14$). **Conclusion:** The results indicated the absence of correspondence between fluid balance and body weight change, with a more significant discrepancy between cumulative fluid balance and total body weight change. Both fluid balance and body weight changes were significantly different among survivors and non-survivors, but neither measurement discriminated ICU mortality.

Keywords: fluid balance, body weight change, critical illness

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INTRODUCTION

Positive fluid status has been consistently associated with worse prognosis in critically ill adult patients [1-8]. Daily and cumulative fluid balance are routine nursing activities in an intensive care unit (ICU), and are widely used as a basis for decisions concerning other therapies such as the use of diuretics, intravenous fluid administration, and renal replacement therapy. Despite its widespread utilization, the allegedly simple method of subtracting fluid output from the patient's input requires the recording of multiple infusions of fluid such as nutrition, blood products and intravenous medications, as well as hourly urinary output and loss of other body fluids, such as fluid lost from surgical drains. As a result, the process of charting fluid balance is very

time-consuming and subject to calculation errors [9], which tend to build up when it comes to cumulative fluid balance [10]. Moreover, accounting for indiscernible water loss or diarrhoea is also inaccurate [11].

Beds with built-in weighing scales can offer an option for the estimation of fluid status changes. One kilogram change in body weight is assumed to equate to one litre gain or loss in body fluid volume [12]. Discipline is also required during the weighing process. Scales need to be zeroed before patients are weighed, and extra items placed on the bed often cannot be removed. Poor compliance in obtaining regular body weight measurements is also an issue which can raise concerns regarding the clinical practicality and cost-effectiveness of weighing beds in the management of ICU patients [13, 14].

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Previous studies [8, 10, 13-17] have established that charting fluid balance totals, both under- and overestimated body weight changes in unpredictable patterns. However, short stays in an ICU, enrolment of a specific low-risk population, use of multiple types of scales and emphasis on cumulative fluid balance, prevented generalization of data. No study attempted to assess the superiority of fluid balance or body weight measurements on the prediction of ICU mortality.

The study aimed to compare the correspondence of daily and cumulative fluid balances with simultaneous changes in body weight in critically ill patients admitted to a multidisciplinary ICU.

The null hypothesis was that there was no correspondence between fluid-balance and body weight change measurements in critically-ill adult patients.

■ MATERIAL AND METHODS

The study was conducted in the 34-bed multidisciplinary ICU of Hospital de Clínicas de Porto Alegre, a tertiary teaching hospital in southern Brazil.

The local research ethic board approved the methodology, and the committee waived the need for informed consent. The study was registered as NCT04434079 at ClinicalTrials.gov.

The inclusion criteria were adult patients over 18 years of age consecutively admitted to the ICU from June 26th to October 31st 2018, if their expected length of stay was more than 48 hours.

The exclusion criteria were body weight above the bed safe working load of 226kgs (or 500lb) [18], any food taken orally, and incomplete recording of fluid balance or body weight measurements.

All patients were placed on Hill-Rom™ Total Care bed systems (Batesville, Ind). As stated by the manufacturer [18], the accuracy of the scale is 1% of the patient's weight, and the repeatability goes from $\pm 0.1\%$ to $\pm 0.3\%$. Daily fluid balance of all enteral and parenteral provisions and excretions was performed manually at midnight for each patient and routinely recorded on report sheets by the responsible nurse. Fluid losses were calculated according to the predetermined formula: $800 + 20\% \times 800 \times (\text{maximum body temperature} - 37; \text{divided by } 2 \text{ if the patient was intubated})$, in millilitres. [11]. Weight changes of the soaked linen estimated the output from watery diarrhoea. The cumulative fluid balance was the sum of the daily fluid balance between the day of ICU admission and the day of discharge. To identify arithmetic errors, all ICU fluid balance chart

input and output measurements were recalculated. The weighing procedure was obtained at midnight to coincide with the 24-hour fluid balance calculation [18].

Demographic data including age, gender, body mass index, the reason for ICU admission, the severity of illness at the time of ICU admission, comorbidities, caloric and protein intake, the need of diuretics or renal replacement therapy, duration of invasive mechanical ventilation, length of ICU stay, and ICU mortality were recorded.

Descriptive statistics are presented as mean (SD) or median and interquartile range. The Student *t*-test or the Mann-Whitney *U* test were used to compare continuous variables, and the Chi-square test or the Fisher exact test to compare proportions. The significance level was set at $\alpha = 0.05$.

Correlation tests were performed for a relationship between fluid balance and body weight changes. A Bland-Altman assessment for agreement between daily fluid balance and body weight changes and between cumulative fluid balance and total body weight change was calculated. The range of agreement was defined as the mean bias ± 2 SDs. A receiver operating characteristic (ROC) curve was plotted for each technique according to ICU survival.

Data were analysed using STATA version 16.1 (Stata-Corp LP, College Station, TX, USA).

■ RESULTS

During the study period, there were 469 admissions to the ICU. Of those, ninety-four (20%) patients were enrolled in the study (Figure 1). Two patients were re-admitted, and thirty (31.9%) died in ICU during the study period. Their baseline characteristics are described in Table 1.

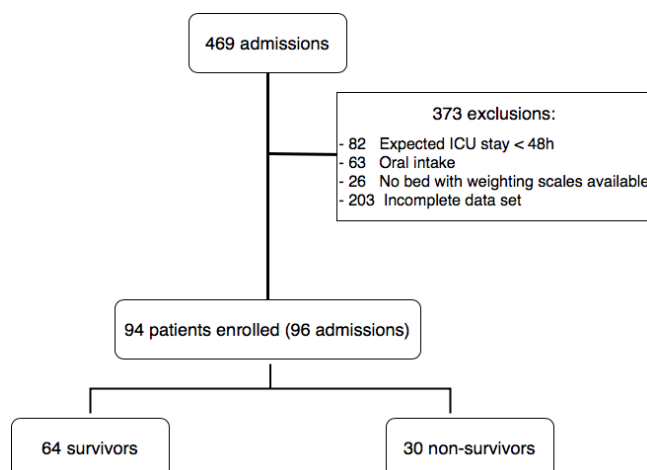


Fig. 1. Study flow.

The main cause of ICU admission was respiratory sepsis (30.8%), and ninety (95.7%) individuals required invasive mechanical ventilation at some point during their ICU stay.

Non-survivors were more likely to receive RRT (53.3% vs 25%, Chi-square test $p=0.01$) and to suffer from nosocomial infections (43.3% vs 18.7%, Chi-square test $p=0.023$), and spent more days on mechanical ventilation (8 days vs 6 days, Mann-Whitney U test $p=0.012$).

Table 1. Characteristics of the study cohort

	All patients (n = 94)	Survivors (n= 64)	Non-survivors (n= 30)	p Value
Age; years (SD) I	57.36 (17.20)	57.83(17.92)	56.37 (15.78)	0.70
Female gender (%)	48 (51.06)	32 (50)	16 (53.3)	0.83
SAPS3; points (SD)	69.03 (18.46)	67.78 (16.17)	71.67 (22.60)	0.34
BMI; kg/m2 (SD)	27.81 (7.25)	28.54 (7.49)	26.26 (6.54)	0.16
Origin (%)				
Emergency room	47 (50)	34 (53.12)	13 (43.33)	0.35
Hospital ward	34 (36.17)	20 (31.25)	14 (46.67)	
Other hospital	13 (13.83)	10 (15.62)	3 (10)	
Energy delivered on 3rd day of ICU stay; kcal/day (SD)	21.05 (6.47)	22.12 (6.42)	18.50 (5.98)	0.014
Protein delivered on 3rd day of ICU stay; g/kg (SD)	1.42 (0.52)	1.49 (0.44)	1.25 (0.65)	0.045
Comorbidities (%)				
COPD	13 (13.83)	9 (14.06)	4 (13.33)	1.0
EF < 35%	11 (11.70)	8 (12.50)	3 (10)	1.0
Cirrhosis	9 (9.57)	6 (9.38)	3 (10)	1.0
Cancer	23 (24.47)	16 (25)	7 (23.33)	1.0
End-stage renal disease	7 (7.45)	4 (6.25)	3 (10)	0.68
Immunosuppression	15 (15.96)	8 (12.50)	7 (23.33)	0.23
Reason for ICU admission (%)				
Respiratory sepsis	29 (30.85)	18 (28.12)	11 (36.67)	0.13
Non respiratory sepsis	7 (7.45)	3 (4.69)	4 (13.33)	
Cardiovascular disease	5 (5.32)	5 (7.81)	0 (0)	
Coma	18 (19.15)	11 (17.19)	7 (23.33)	
Postoperative ARF	7 (7.45)	4 (6.25)	3 (10)	
COPD/Asthma	3 (3.19)	2 (3.12)	1 (3.33)	
Pulmonary Embolism	2 (2.13)	1 (1.56)	1 (3.33)	
ARDS	23 (24.47)	20 (31.25)	3 (10)	
Organ dysfunction at ICU admission*				
Hemodynamic	74 (78.72)	50 (78.12)	24 (80)	1.0
Lung	86 (91.49)	59 (92.19)	27 (90)	0.71
Renal	35 (37.23)	24 (37.5)	11 (36.67)	1.00
Hematologic	25 (26.60)	13 (20.31)	12 (40)	0.078
Liver	8 (8.33)	3 (4.55)	5 (16.67)	0.10
Neurological	39 (41.49)	23 (35.94)	16 (53.33)	0.12
Diuretic provision during ICU stay (%)**	30 (31.91)	20 (31.25)	10 (33.33)	1.0
Need of RRT during ICU stay (%)**	32 (34.04)	16 (25)	16 (53.33)	0.010
ICU-acquired infection (%)**	25 (26.60)	12 (18.75)	13 (43.33)	0.023
MV duration (days)**	7 (3 – 10)	6 (2 – 9)	8 (6 – 13)	0.012
Length of ICU stay (days)**	9 (6 – 15)	9.5 (6 – 15.5)	8 (6 – 14)	0.87
Length of hospital stay (days)**	16 (9 – 27)	16 (9.5 – 28)	15.5 (8 – 27)	0.95
Time between hospitalization and ICU admission (days)	3 (1 – 10)	3 (1 – 9)	3 (1 – 10)	0.98

Data are presented as mean \pm standard deviation, median (interquartile range) or n(%). * Identified as a Sequential Organ Failure Assessment (SOFA) score 1 in each system. ** Including data from 96 ICU admissions. SAPS: Simplified Acute Physiology Score. BMI: body mass index. ICU: intensive care unit. COPD: chronic obstructive pulmonary disease. EF: Ejection fraction. LV: left ventricular. RRT: renal replacement therapy. ARF: acute respiratory failure. ARDS: acute respiratory distress syndrome. MV: mechanical ventilation.

Table 2 displays values of fluid balance with and without indiscernible water loss and body weight changes according to ICU survival. The median net body weight change was negative in both survivors and non-survivors, although there was a significantly different between them (respectively -3.05kg vs -1.1kg, Mann-Whitney U test p= 0.008). Only crude cumulative fluid balance, without indiscernible water loss, dif-

fered significantly between groups. (Mann-Whitney U test p <0.05).

Altogether, 781 pairs of data were available for analysis between daily fluid balance and body weight changes. As showed by the Bland Altman plot (Figure 2), the average daily difference was +0.864 (CI +0.722 to +1.007), but the interval was broad: -3.156 to +4.885 L/kg (A).

Table 2. Comparison of fluid balance and weight change of survivors and non-survivors of ICU hospitalization

	All patients* (n = 94)	Survivors (n= 64)	Non-survivors (n= 30)	p Value
First 24h-fluid balance (L)	+0.95 ([+0.09] – [+1.78])	+0.84 ([+0.08] – [+1.6])	+1.26 ([+0.41] – [+0.27])	0.10
First 24h-fluid balance + indiscernible water loss (L)	+0.05 ([-0.79] – [+0.80])	-0.004 ([-0.88] – [+0.74])	+0.64 ([-0.48] – [+1.77])	0.075
First 24h-weight change (kg)	0.0 ([-0.9] – [+1.1])	+0.25 ([-1.45] – [+0.6])	+0.9 ([-0.1] – [+2.2])	<0.001
Cumulative fluid balance (L)	+3.61 ([-0.11] – [+7.43])	+2.53 ([-0.4] – [+6.0])	+5.6 ([+1.85] – [+9.21])	0.012
Cumulative fluid balance + indiscernible water loss (L)	-3.89 ([-7.27] – [-0.1])	-3.91 ([-7.78] – [-1.1])	-3.33 ([-6.87] – [+0.97])	0.37
Total weight change (kg)	-2.55 ([-4.8] – [+0.1])	-3.05 ([-6.5] – [-0.7])	-1.1 ([-3.1] – [+0.9])	0.008

Data are presented as median (interquartile range). *Excluding data from two ICU readmissions

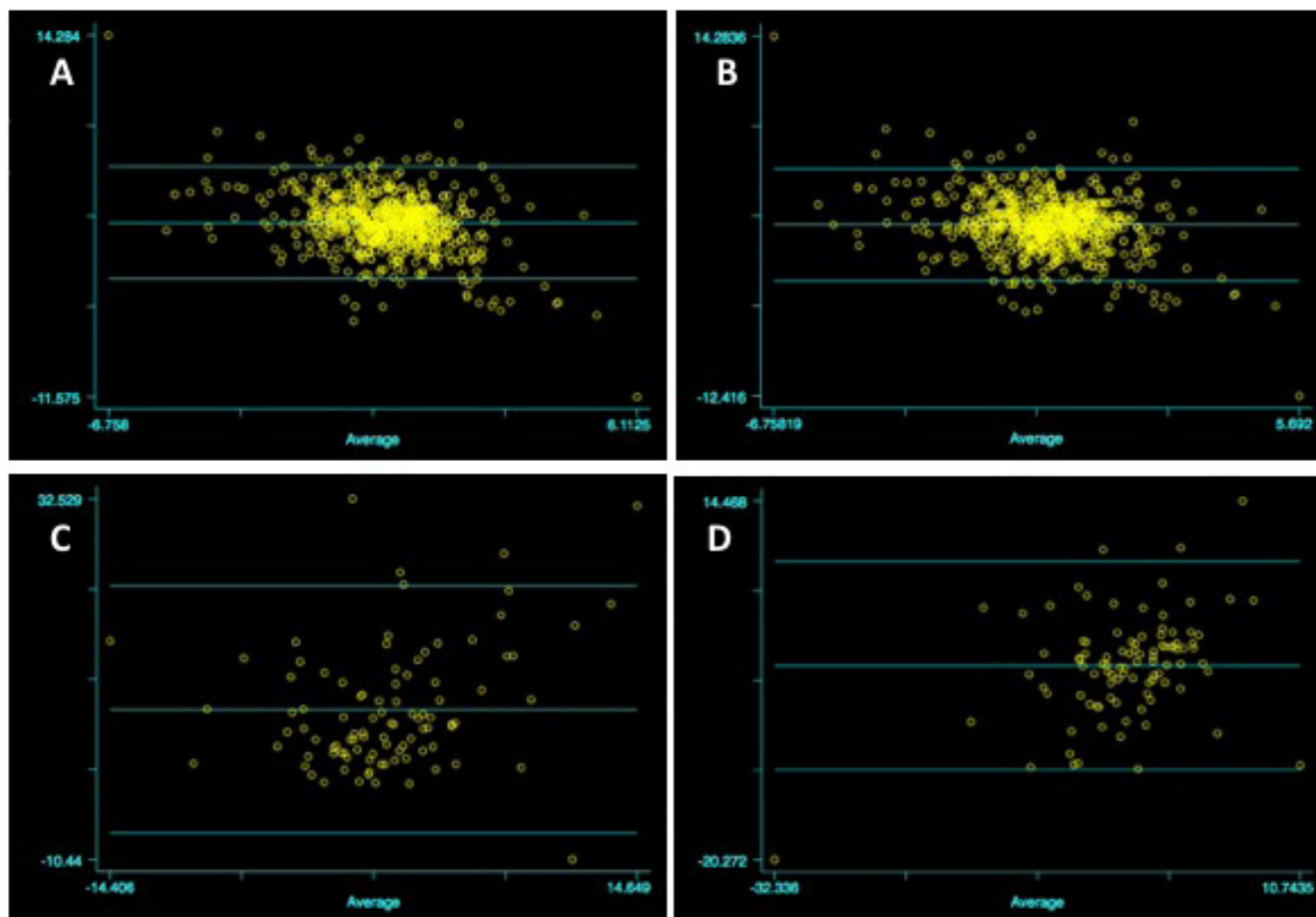


Fig. 2. Bland Altman plot for changes in fluid balance and simultaneous body weight (A) Daily fluid balance and body weight changes. B) Daily fluid balance with indiscernible water loss and body weight changes. C) Cumulative FB and total body weight change. D) Cumulative fluid balance with indiscernible water loss and total body weight change. X-axis, mean values for fluid balance and body weight. Y- axis, difference between fluid balance and body weight.

After adjustment for indiscernible water loss, the mean bias resulted in $+0.288$ (CI $+0.140$ to $+0.436$) L/kg, limits of agreement (-3.876 to $+4.452$ L/kg) remained wide (B).

The assessment of agreement between cumulative fluid balance and total body weight change occurred in 96 pairs of data, yielding a mean bias of $+7.410$ (CI $+5.917$ to $+8.902$) L/kg and an interval of -7.321 to $+22.141$ L/kg (C). After accounting for indiscernible water loss, the mean difference was -1.463 (CI -2.485 to -0.441) L/kg, and the interval was -11.552 to $+8.626$ L/kg (D). The null hypothesis was upheld.

As illustrated in Figure 3, the correlation between daily fluid balance and body weight change was poor (A), even after correction for indiscernible water loss (B). The correlation between cumulative fluid balance and total body weight change went from

poor (C) to moderate when indiscernible water loss was included (D).

The areas under the ROC curve showed a failed to poor accuracy for discrimination between ICU survivors and non-survivors. Nor did they significantly differ among cumulative fluid balance, cumulative fluid balance with indiscernible water loss and total weight change (Chi-square test $p=0.14$) (Figure 4).

DISCUSSION

The results of the study indicate an absence of correspondence between fluid balance and body weight changes, even when daily and systematic measurements are made. There was a large and diffuse dispersion of values, with a more significant discrepancy between cumulative fluid balance and total body weight change.

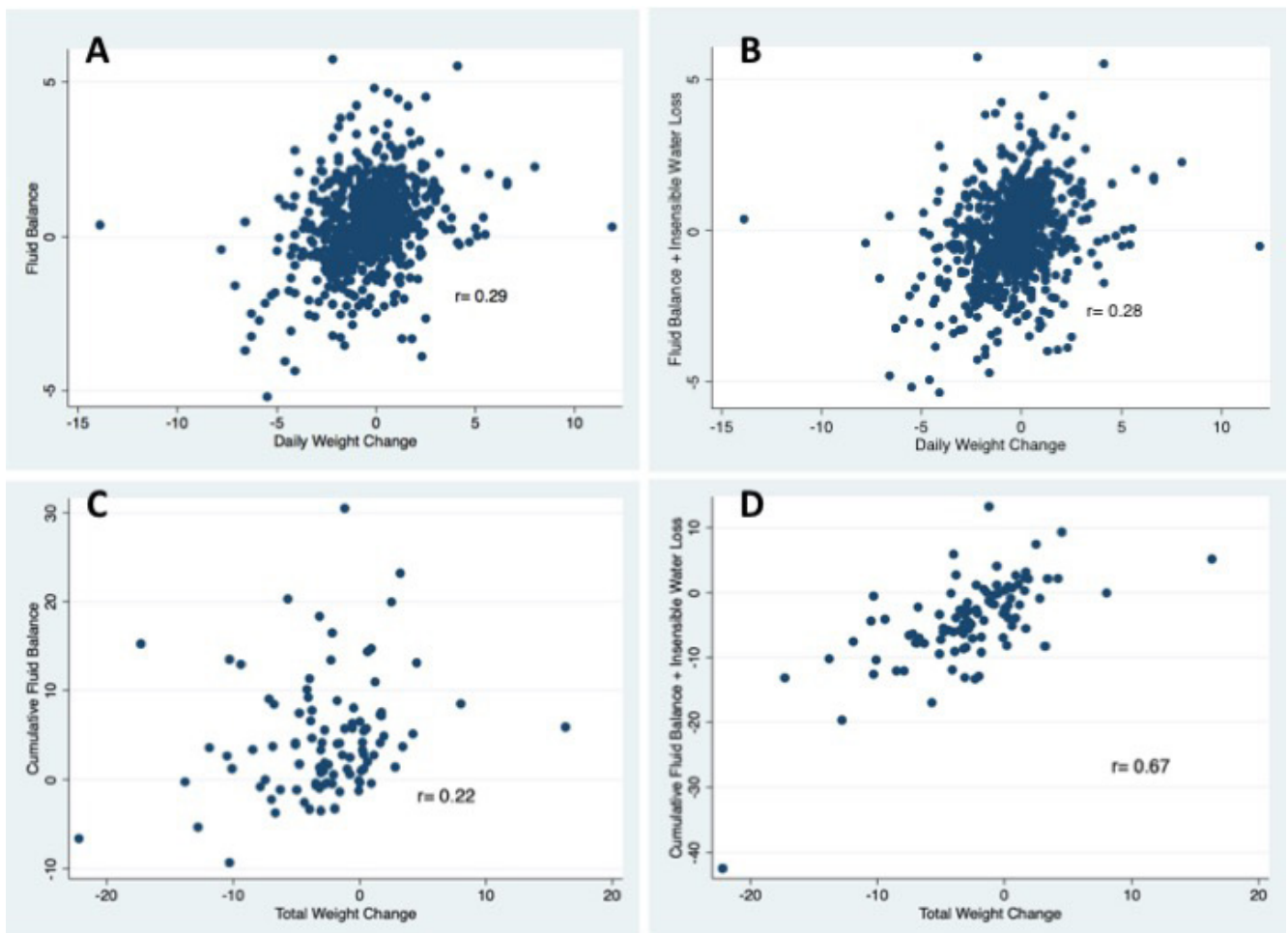


Fig. 3. Correlation between A) daily fluid balance and body weight changes (Spearman rank correlation; $p < 0.001$), B) daily fluid balance with indiscernible water loss and body weight changes (Spearman rank correlation; $p < 0.001$), C) cumulative fluid balance and total body weight change (Spearman rank correlation; $p = 0.03$), and D) cumulative fluid balance with indiscernible water loss and total body weight change (Spearman rank correlation; $p < 0.001$).

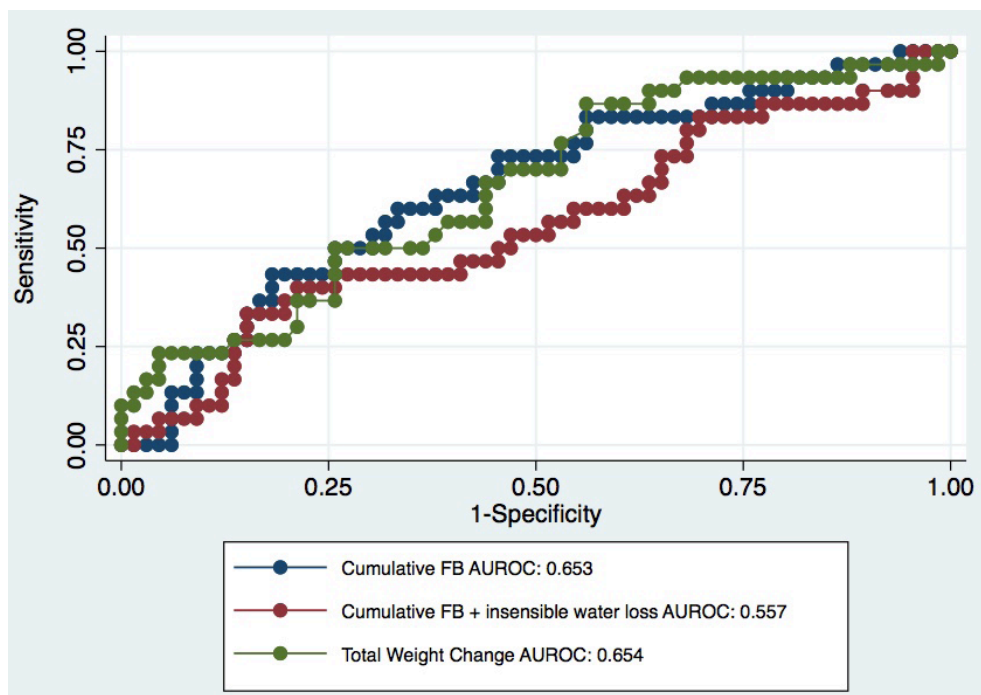


Fig. 4. Areas under ROC curve showing discrimination power of cumulative fluid balance, cumulative fluid balance corrected for indiscernible water loss and total body weight change in predicting ICU mortality.

They correlated with each other, but this had no clinical significance. Neither total change in body weight nor crude cumulative fluid balance provided even moderate discriminatory performance in predicting ICU mortality, although both significantly differed between survivors and non-survivors. To our knowledge, this is the first report encompassing a comprehensive analysis in a general tertiary ICU with a highly heterogeneous cohort and in which the weighting process was entirely performed on integrated bed scales.

Previous studies have also demonstrated poor reliability of fluid balance measures. Moreover, the correlation with body weight changes did not improve when a correction for indiscernible water loss was made [8, 10, 13-17]. Some investigations only focused on net changes [10, 15-17] which are subjected to error accumulation, the higher the duration of ICU hospitalization [16]. As there is no consensus in the literature regarding indiscernible water losses, data were presented with and without correction.

Research on daily acquired data confirmed a lack of agreement in specific populations [14, 19] and during short lengths of stay [8, 13]. One report [19] used only a correlation coefficient and a regression technique which can be misleading as they evaluate only the lin-

ear association of two sets of observations. The Bland Altman method provides an adequate analysis of the agreement of data [20]. Moreover, most prior studies implied that body weight change was the gold-standard to be pursued. However, the weighing process needs to be performed in a very standardized fashion in order to be exempt from errors [14].

The body weight obtained by weight-enabled beds cannot be used as a substitute for fluid balance recording or vice versa, as suggested by the weak correlation between them daily. The low accuracy of all net measurements in predicting ICU mortality precludes a conclusion regarding “the best one” to be employed clinically. Indeed, the magnitude of errors associated with both fluid balance and body weight assessments appears clinically important.

The current investigation was conducted in the ICU of a major tertiary referral hospital, which relies on an excellent level of experience of nursing staff and the availability of beds with built-in weighing scales. Nursing staff were trained on how to operate bed systems. Inaccuracies in both fluid balance and body weight estimations can be assumed to have occurred due to pragmatic nursing constraints amplified by highly imprecise indiscernible fluid losses formulas [9, 11, 12, 14].

There are speculations about an attenuated influence of fluid accumulation over body weight in critically ill patients who are hospitalized for longer than five days, since muscle and fat loss as well as bone demineralization must play a major role after such a period [13-15]. Nevertheless, our results are still consistent with other cohorts of very short ICU hospitalizations [8, 13]. The lack of a significant difference in the first 24-hour fluid balance between survivors and non-survivors, and even the modest absolute difference on corresponding body-weight change between them, might also reflect novel practices of careful fluid resuscitation [21, 22].

■ CONCLUSION

Obtaining daily fluid balance and body weight in ICU patients is complex and time-consuming. The assumption that a positive or negative fluid balance represents a similar gain or loss in body weight cannot be relied upon for estimating body-fluid status. There is little reason to believe that intense clinical teaching, procedure implementation, or any other intervention would enable daily fluid balance and body weight changes to be used reciprocally. Therefore, patient care and clinical decision-making should be based on other, more objective techniques.

We question the clinical importance of changes in fluid balance or body weight, as the volume load of specific compartments, such as intravascular volume, cardiac preload, extravascular lung water, is probably more relevant. Further research may assist in refining the value of routine fluid balance charting and of equipping ICUs with weighting beds.

■ CONFLICT OF INTEREST

None to declare.

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