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Research paper

A comparison of compliance in the estimation of body fluid status using daily fluid balance charting and body weight changes during continuous renal replacement therapy

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At the conclusion of this article a Continuing Professional Development activity is attached

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1. Introduction

The survival and recovery of critically ill patients is adversely affected by the presence of fluid overload.[1,2] The transition between fluid resuscitation and restoration of homoeostasis is a critical period for the seriously ill patient and of particular importance for survival in patients with acute kidney injury who are at increased risk of developing fluid overload.[3] This has led to a renewed interest in methods used to evaluate body fluid status. The charting of daily fluid balances is one method commonly used in the intensive care unit (ICU) when assessing patients' body fluids. Errors in daily fluid balance totals have been shown to occur and can accumulate.[4–6] Over time, this increases the inaccuracy of cumulative fluid balance totals.[7] In view of the potential for errors in the calculation of fluid balance, measurement of body weight changes is another approach commonly used in assessing fluid status. Similar to the reported association of worse patient outcomes with charting a positive fluid balance,[8] more weight gain was shown in one study to correlate with increases in ICU mortality, duration of mechanical ventilation, and length of stay (LOS).[9] It is suggested that measurement of daily body weight change can provide a more accurate method of monitoring body fluid status.[7,9] Monitoring changes in body weight is different to the charting of inputs and outputs as body weight provides a "physical" rather than a "calculated" picture of the patient's body fluid status.

Monitoring of fluid-related changes in body weight using conventional scales can be difficult. A sling and hoist is required to lift patients, so they "hang" freely off the bed. This not only places the patient at risk of harm but also is an occupational health and safety hazard for staff who are required to manually handle patients.[10,11]

After the introduction of "smart" beds with built-in electronic scales, the practicalities of weighing patients can be addressed. Patients now remain in bed, and provided extra equipment not included in the original tarring procedure is removed, the patient's body weight can be accurately measured. It is reported that electronic bed weighing in clinical practice has not been entirely successful in improving compliance of weighing patients,[12] nor measurement of bodyweight changes found to be sufficiently

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reliable to replace fluid balance charting after cardiac surgery.[13] Given that compliance continues to be a problem in obtaining consecutive daily measurements and concerns regarding the ability of obtaining a reliable bodyweight measurement, it is uncertain how successful reliance on changes in body weight as opposed to a calculated fluid balance would be in the management of patients with critical fluid assessment needs, such as those requiring continuous renal replacement therapy (CRRT).

The aims of this study were to (i) investigate the frequency of compliance in weighing patients daily using electronic bed scales and (ii) evaluate the relationship between calculated fluid balance and bodyweight changes in patients receiving CRRT.

2. Method

Following the institutional ethics committee approval (EC2012/121), a prospective cohort interventional observation study was conducted in a tertiary Level III,[14] medical/surgical ICU between June 2015 and February 2016. Patients who required CRRT were screened for eligibility. Those who met the inclusion criteria of (i) > 18 years and (ii) ICU admission > 24 h were enrolled. Patient characteristics, reason for ICU admission, disease severity score, laboratory values on admission, ICU and hospital LOS, and survival were obtained by reviewing patient medical records.

The Prismaflex CRRT machine (Baxter Healthcare Corporation, Deerfield, IL, United States) was used to deliver continuous venovenous haemodiafiltration (CVVHDf) using a Hospal 100ST haemofilter (Gambro AB, Stockholm, Sweden). Determination of dialysis dose prescription (ml/kg/h) was by severity of illness and admission of body weight. A record was made of the number of days each patient required CRRT along with the duration of circuit life matched by the type of vascular access and choice of anticoagulation.

Patients were weighed using a Medical Surgical Hill-Rom 1000 bed (Batesville, IN, USA) first introduced at the study site in 2010. All nursing staff are given training before using the bed to weigh patients. It requires the bed to be tared before patients are placed on the bed. A standardised list of items are placed on or attached to the bed during the taring procedure. Thereafter, extra items not originally tared with the bed are removed each time the patient is weighed, or if the extra items are unable to be removed, the weight of each piece of equipment was deducted. Standard practice at the study site required patients to be weighed within 24 h of ICU admission and repeated every second day for patients receiving CRRT. For the purpose of the study, a change from standard practice increased the frequency and timing of when patients were weighed from every second day to daily measurements. Measurements were recorded at midnight on the day CRRT commenced and a final daily measurement taken on the day treatment ceased. Each measurement was double-checked for accuracy by a “buddy” nurse and agreement reached before daily changes were calculated by subtracting the recorded body weight from the previous day's measurement. The electronic scales operated within a range of 0–204 kg with an accuracy of ±1% and a repeatability of 0.1%.[15]

Standard practice for the charting of fluid balance involved recording inputs and outputs on a purpose-designed paper ICU flow chart every hour or more frequently. Each chart covered a 24-h cycle from midnight to midnight. Hourly fluid records were totalled every 6 h, and a daily fluid balance was calculated at midnight. The bedside nurse had access to a pocket calculator to assist with addition and subtraction. A cumulative fluid balance was calculated daily and continued until the day of ICU discharge. For this study, fluid calculations were checked for accuracy by the research nurse (author H.D.). As standard practice at the study site and those of others,[4,16] charting of daily fluid balances did not correct for insensible water loss (IWL). To account for IWL, each fluid balance chart daily total was retrospectively corrected by including an additional output using the formula of 10 ml/kg/day.[17] No adjustment was made for perspiration due to increases in body temperature or whether the patient required mechanical ventilation.

Data were analysed using SPSS software, version 23 (IBM, Inc, Chicago Ill). Descriptive data were presented as frequencies, percentages, means, medians, and range. Comparisons between ICU survivors and nonsurvivors were tested using student's t-test for parametric data and Mann–Whitney U test for nonparametric data. Statistical significance was set at 0.05 and 95% confidence interval. Daily change in body weight was obtained from two consecutive measurements, and comparisons were made with the corresponding day's fluid balance. One litre (L) was assumed to represent 1 kg (kg). Agreement between calculated fluid balance and measured bodyweight change was checked by Pearson's correlation test. A Bland–Altman analysis was also performed to check the degree of agreement between the two variables.

3. Results

A total of 61 patients, 48 survivors, and 13 nonsurvivors were recruited. The mean age was 56.5 years, and the majority of patients (70.5%) were men. The ICU mortality was 21.3% (13/61). Table 1 compares the baseline characteristics of ICU survivors and nonsurvivors.

The median number of days patients received CRRT was 4 (range 1–32 days). This represented a total of 292 circuits. Of these, 132 (45%) were anticoagulated with prefilter heparin. The median lifespan of clotted circuits was 17 h (range, 0–111 h).

As shown in Table 2, more bodyweight gain and cumulative positive fluid balance occurred in nonsurvivors (median cumulative change of body weight 2.5 kg, range −30.5 to 11.5 kg; and median cumulative fluid balance 1,587 ml, range −26,738 to 10,234 ml) than in those who survived ICU (median cumulative change of body weight −1.5 kg, range −23.5 to 30.5 kg; and median cumulative fluid balance −602 ml, range −18,614 to 24,182 ml). No statistical significance was found between cumulative changes in fluid balance and body weight, suggesting that there was broad agreement. Table 2 shows cumulative bodyweight changes uncorrected for IWL over estimated cumulative fluid balances at the end of CRRT and on ICU discharge or death for both survivors and nonsurvivors. The reverse finding occurred when bodyweight changes at the end of CRRT and on ICU discharge or death underestimated cumulative fluid balances after daily fluid balances were corrected for IWL.

A total of 603 paper observation charts were checked for accuracy in the calculation of daily and cumulative fluid balances. Discrepancies occurred in 27% (164/603) of charts reviewed. Median daily calculation error at midnight was 58 ml (range, 1–1,464 ml). Median cumulative calculation error on ICU discharge or death was 131 ml (range, 1–2,402 ml).

A baseline body weight was measured in 98% (60/61) of patients within 24 h of ICU admission who required CRRT. One measurement was identified as outside the bed scale's operating range (217 kg). From a total of 603 ICU days, 403 days saw the delivery of CRRT. Compliance with measuring body weight at midnight while patients were receiving CRRT was 71% (286/403). One measurement recorded a daily weight change of 19.5 kg. This was determined as either an error of measurement or in documentation and removed from analysis. Of the remaining measurements (285), median daily change in body weight was −0.5 kg (range −12.7 to 12 kg).

In 39 patients, one measured body weight was recorded at midnight along with a calculated daily fluid balance across 2

Table 1
Comparison of baseline characteristics of survivors and nonsurvivors of ICU hospitalisation.

Baseline characteristics	Total	Survivors	Nonsurvivors	P
No. of patients	61	48	13	–
Age, mean (SD), y	56.5 (±18.1)	53.7 (±19.0)	66.8 (±9.2)	.04[a]
Men, n (%)	43 (70.5)	37 (86.0)	6 (14.0)	–
APACHE-II, mean (SD)	27.2 (±8.4)	26.0 (±8.2)	31.6 (±8.0)	.05[a]
Admission diagnosis, n (%)				
Cardiac	13 (21)	10 (21)	3 (23)	–
Gastrointestinal	9 (15)	6 (13)	3 (23)	–
Renal	8 (13)	7 (15)	1 (8)	–
Respiratory	6 (10)	5 (10)	1 (8)	–
Trauma	7 (11)	7 (15)	–	–
Sepsis	11 (18)	7 (15)	4 (31)	–
Other	7 (11)	6 (13)	1 (8)	–
Lowest mean arterial pressure (MAP), median (range), mmHg	65 (35–140)	65 (35–140)	64 (35–79)	–
Received noradrenaline (%)	51 (83.6)	38 (79.2)	13 (100)	–
Highest concentration of noradrenaline, mean (SD), μg/kg/min	0.29 (±0.39)	0.21 (±0.31)	0.45 (±0.49)	<.01[a]
Mechanical ventilation (MV), n (%)	41 (68.3)	29 (70.7)	12 (29.3)	–
MV, median (range), h	134 (6–755)	124.8 (6–755)	150.5 (9–307)	–
Baseline biochemistry				
pH, median (range)	7.3 (7.0–7.6)	7.3 (7.0–7.5)	7.4 (7.2–7.6)	–
Lactate, median (range), mmol/L	1.8 (0.4–8.5)	1.7 (0.4–7.3)	2.9 (1.3–8.5)	–
HCO_3^-, median (range), mmol/L	17 (5–29)	17 (5–29)	16 (12–24)	–
K^+, median (range), mmol/L	4.4 (2.9–8.6)	4.7 (2.9–8.6)	4.4 (3.9–5.6)	–
Na^+, median (range), mmol/L	136 (113–153)	136 (113–150)	137 (130–153)	–
Urea, median (range), mmol/L	18.6 (3.3–90.3)	17.8 (3.3–90.3)	19.4 (8.7–40.3)	–
Creatinine, median (range), μmol/L	355 (58–2560)	386 (58–2560)	314 (128–815)	–
CRRT (CVVHDf), median (range), d	4 (1–32)	4 (1–32)	7 (2–23)	–
ICU LOS, median (range), d	6.0 (1–67)	5.5 (1–67)	6.7 (2–22)	–
Hospital LOS, median (range), d	13.0 (2–131)	16.7 (3–131)	7.7 (2–28)	–

CRRT, continuous renal replacement therapy; CVVHDf, continuous venovenous haemodiafiltration; ICU, intensive care unit; LOS, length of stay; SD, standard deviation.
Data presented as number (%) unless otherwise indicated.
[a] Level of significant difference <.05.

consecutive days. For 30 patients, the recording of two consecutive measurements occurred more than once. This allowed a total of 181 paired comparisons to be made during CRRT of bodyweight changes with the patient's corresponding daily fluid balance. As shown in Fig. 1 scatterplot, correlation between each paired variable was poor (Pearson $r = 0.34$, $p < .0001$). Correlation was worse as shown in Fig. 2 scatterplot when daily fluid balances were corrected for IWL (Pearson $r = 0.32$, $p < .0001$). Figs. 3 and 4 show agreement between daily bodyweight changes and fluid balance by Bland–Altman analysis. Uncorrected fluid balances showed a mean bias of −0.18 kg and 95% agreement interval −8.9 to 8.6 kg. The difference increased when fluid balances corrected for IWL showed a mean bias of −0.99 kg and 95% agreement interval −9.8 to 7.8 kg (Insert Figs. 1–4 near here).

4. Discussion

This study is the first to prospectively compare daily fluid balances with fluid-related changes to body weight in patients receiving CRRT. In achieving our first aim of consecutive daily bodyweight measurements, we found that compliance was moderate but not performed consistently to be considered reliable. This was despite conducting a vigorous education campaign for nursing staff on the requirement for patients to be weighed daily. The second aim was addressed by the study's finding that the relationship between body weight and fluid balance was insufficient to be a trustworthy predictor of change in the fluid status of patients. Evidence from another study supports this finding and suggests that cumulative daily fluid balances become increasingly inaccurate

Table 2
Cumulative daily fluid balances and bodyweight changes for survivors and nonsurvivors.

	Survivors n = 48	Nonsurvivors n = 13	P
	Cumulative balance "uncorrected" for IWL,[a] median (range), mL	Cumulative balance "uncorrected" for IWL,[a] median (range), mL	
Day 1	263 (−4,707 to 5,988)	926 (−1,960 to 2,799)	.560
Start CRRT	779 (−4,707 to 11,095)	2011 (−1,960 to 4,594)	.765
End CRRT	−254 (−19,563 to 8,555)	1,587 (−26,738 to 10,234)	.187
ICU discharge/death	−602 (−18,614 to 24,182)	1,587 (−26,738 to 10,234)	.164
	Cumulative balance "corrected" for IWL,[a] median (range), mL	Cumulative balance "corrected" for IWL,[a] median (range), mL	
Day 1	−649 (−5,282 to 5218)	−30 (−2,895 to 2,084)	.438
Start CRRT	−601 (−7,740 to 5,799)	270 (−7562 to 2745)	.526
End CRRT	−3,518 (−33,683 to 543)	−5,388 (−32,288 to 1,393)	.673
ICU discharge/death	−5,524 (−34,669 to 543)	−5,388 (−34,669 to 1,393)	.333
	Cumulative weight change,[b] median (range), kg	Cumulative weight change,[b] median (range), kg	
Admission weight	81 (42–217)	89.5 (54.5–172)	.788
Start CRRT	0 (−5.5 to 14)	0 (−5 to 11.5)	.769
End CRRT	0 (−23.5 to 30.5)	2.5(−30.5 to 11.5)	.217
ICU discharge/death	−1.5 (−23.5 to 30.5)[c]	2.5 (−30.5 to 11.5)[c]	.085

CRRT, continuous renal replacement therapy; ICU, intensive care unit; IWL, insensible water loss; LOS, length of stay.
[a] Cumulative balance calculated at midnight.
[b] Cumulative weight change at midnight.
[c] Last measured weight before ICU discharge/death.

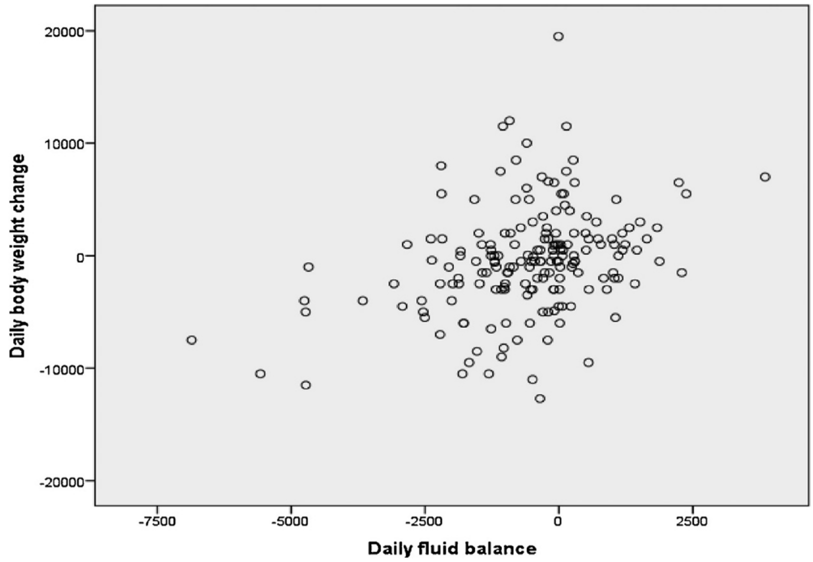

Fig. 1. Correlation plots between 181 changes in body weight and daily fluid balance "uncorrected" for IWL. IWL, insensible water loss.

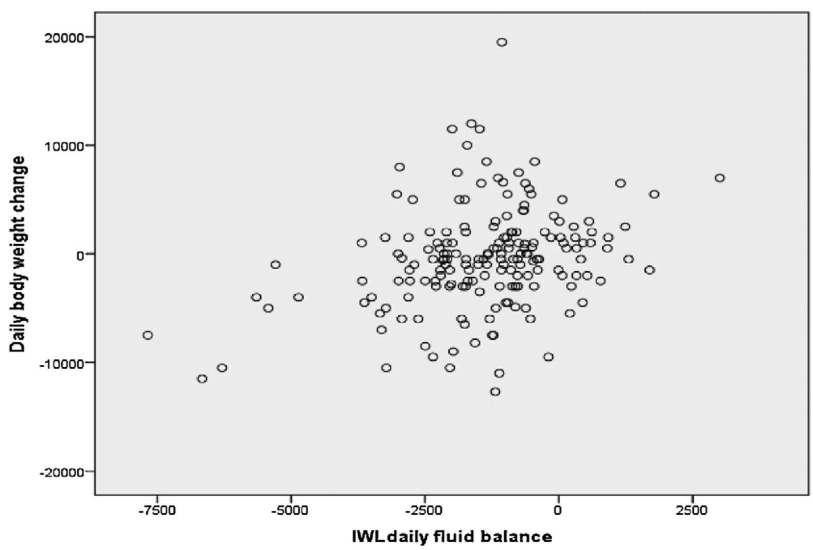

Fig. 2. Correlation plots between 181 changes in body weight and daily fluid balance "corrected" for IWL. IWL, insensible water loss.

and underestimate fluid gain compared with bodyweight changes even when corrected for IWL.[7]

The charting of daily and cumulative fluid balance has been shown to be vulnerable to calculation and documentation errors.[4–6,18] This is despite efforts to minimise the margin of error by improvements in the design of fluid balance charts and use of pocket calculators to reduce mathematical errors. Some improvement in reducing the number of calculation errors may be possible by the use of clinical information systems with electronic spreadsheets, but the problem of documentation error remains when manual data entry is required.[19] The incidence of errors in fluid balance calculations using paper-based charting was observed in 27% (164/603) of charts reviewed. Despite a daily median discrepancy of 58 ml, the difference varied considerably each day to clinically significant volumes (range, 1–1,464 ml). This was similar to cumulative totals when calculations were checked for accuracy with a median discrepancy of 131 ml but possibility of larger differences on ICU discharge or death (range, 1–2,402 ml).

Even if errors in fluid balance calculations could be eliminated, does fluid balance charting provide the best way for estimating body fluid status? The charting of inputs and outputs fails to account for fluid shifts that occur in critical illness when fluid is dispersed throughout the body until fluid is able to be drawn back into the intravascular space for removal by diuretics or dialysis. Output from IWL is another confounder that plays a significant part on fluid loss in the ICU patient and cannot be predicted accurately relying instead on a calculated value rather than one that is measured if used at all.

The second method for estimating body fluid status most commonly used in the ICU is by measuring changes in body weight. Over a short period of time (less than a week), changes in body weight are almost entirely the result of alterations in body fluid volume.[20] The utility of using bodyweight changes to monitor body

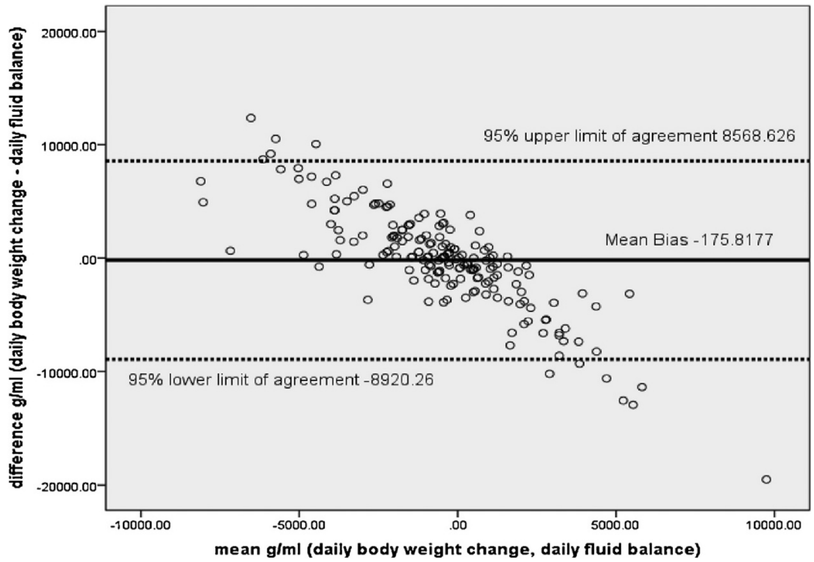

Fig. 3. Bland–Altman plot between 181 changes in body weight and daily fluid balance "uncorrected" for IWL. IWL, insensible water loss.

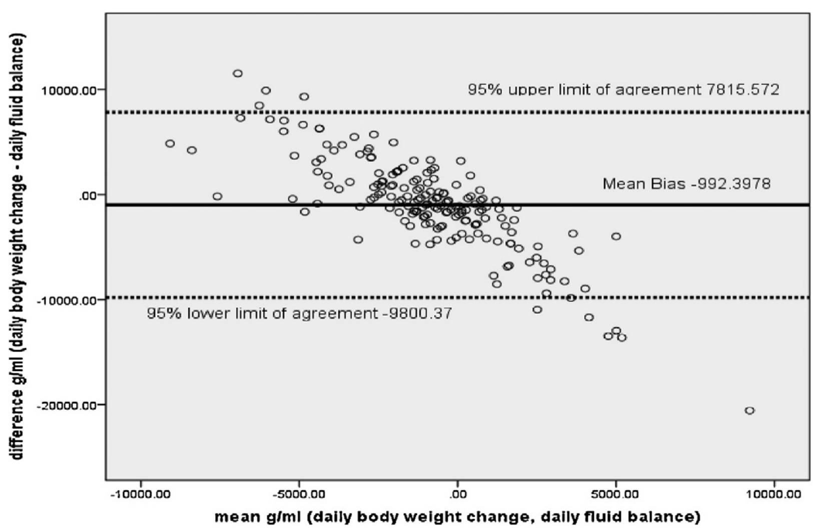

Fig. 4. Bland–Altman plot between 181 changes in body weight and daily fluid balance "corrected" for IWL. IWL, insensible water loss.

fluid status is consistent across this time frame with a reported mean ICU LOS of 8.7 days for severe acute kidney injury[21] and a median treatment duration of 5 days reported for patients requiring CRRT.[22,23] Because the median ICU LOS in this study was 6 days, it can be confidently predicted that for the majority of patients, changes in body weight was likely to have been fluid related. In patients whose LOS was greater than 6 days, the role that catabolic metabolism played in the changes we observed is unclear.

Since the introduction of "smart" beds at the study site, the task of weighing incapacitated patients who require CRRT has been made easier. No incidents were reported during the study that jeopardised the safety of patients or nursing staff when body weight was measured using electronic bed scales. Compliance with measuring body weight at midnight while patients were receiving CRRT was 71% (286/403). This was better than reported elsewhere.[12] It is uncertain why gaps occurred in the collection of consecutive measurements as this was not part of the investigation, but nurses may have not been made aware of changes in practice regarding increased frequency and timing of when patients were required to be weighed. A decision may have been made to withhold weighing the patient if not considered clinically appropriate, or competing demands on nursing time may have been another issue why body weight had not been measured.

This study also looked at compliance of nurses with protocols to achieve accuracy in the weighing of patients. A checklist was provided as a reminder for nurses on what to include or remove from the bed when first tarred and for this to be repeated once the patient was placed on the bed ready to be weighed. Furthermore, it required measurements to be double-checked by a second nurse, which is suggested as one way to reduce uncertainties over accuracy.[7] Although strict quality control measures were implemented during the study, it did not eliminate the uncertainty in 1 case (a daily weight change of 19.5 kg). This represented a 0.3% (1/286) error in the recording/documenting of daily bodyweight changes but lower than the 3.1% (8/257) reported elsewhere for uncertainty over changes in body weight greater than 15 kg.[13]

Our study confirms that a calculated fluid balance is not predictive of a similar change in body weight. This is based on the assumption that a 1-L calculated fluid gain or loss will be matched by a similar measured weight gain or loss of 1 kg. As shown in Table 2, a negative fluid balance or weight loss at the end of CRRT and on ICU discharge was associated with ICU survival when compared with nonsurvivors who had a positive fluid balance and weight gain on death. The variability that Table 2 shows in the cumulative losses or gains in fluid balances or bodyweight changes at different stages of ICU admission suggests that they cannot be viewed as the same. Although not significant, the P value of 0.085 on discharge or death could suggest that changes in body weight between survivors and nonsurvivors was an independent factor and is possibly a more reliable method than the charting of cumulative fluid balances for monitoring fluid overload.

The weak correlation we observed from 181 paired comparisons of daily fluid balances and changes in body weight ($r = 0.34$) is consistent with the findings of other studies.[5,12,13,24,25] No improvement arose in the relationship when the same statistical test was repeated after fluid balances were corrected for IWL ($r = 0.32$). Pearson correlation of the 181 paired measurements as shown in the scatterplots for Figs. 1 and 2 are concentrated around zero where agreement between the variables occurred when smaller values were compared. This only shows agreement in terms of a linear relationship and not the degree of differences as an indicator of agreement.[26] To assess this, we used Bland–Altman analysis by measuring the differences between each pair and plotting it against the mean of the 2 measurements. The average difference between daily fluid balances and corresponding weight change did not represent a large discrepancy (mean bias of −0.18 kg), but the scatterplot in Fig. 3 shows that there were wide limits of agreement around the mean bias line among the 181 paired measurements (−8.9 to 8.6 kg). Studies that have provided information on IWL have not shown that inclusion of corrected values reduces the degree of difference between fluid balance and bodyweight changes.[7,13] As shown in Fig. 4, the mean bias increased (−0.99 kg), and limits of agreement remained wide (−9.8 to 7.8 kg). On-going agreement between fluid balances and bodyweight changes irrespective of correction for IWL has been shown to gradually worsen with the discrepancy widening the longer the patient stays in ICU.[7]

The strength of this study was that patients were weighed after fluid balance was calculated at midnight. This allowed for daily changes between the two variables to be compared at the same time. Uncertainty over recorded measurements was evaluated by double-checking fluid balance charting, and weighing procedures were repeated by a second person. The reliability of the relationship between the two variables was also evaluated by comparing bodyweight changes with fluid balance charts corrected for IWL.

Although weighing of patients at midnight was considered a strength, it was not an ideal time to weigh patients due to reduced capacity of nurses to receive assistance compared to if the activity had been conducted during the day. The possibility that compliance was affected by the timing of when patients were weighed was nevertheless mitigated by the use of beds with built-in scales. This allowed patients to remain in bed while a weight was recorded at midnight without having to resort to the traditional method of using slings and hoists to weigh patients where additional assistance would have possibly been required.

The study has several other limitations. It was a single-centre study where the composition of patients and procedures followed may have influenced the results. Accuracy of the fluid balance chart was affected by movement of the patient when procedures were performed outside ICU, with fluid given or lost not always charted when the patient returned. Comparisons between daily fluid balances and bodyweight changes were not matched with physical signs of fluid overload such as the presence of dependent oedema. The possibility of overestimating output when fluid balances were corrected for IWL may have occurred which increased the average difference with bodyweight changes. The possibility remains that in the absence of a statistical difference between cumulative changes in fluid balance and body weight, the sample size for this study may not have been sufficiently powered to have shown a difference.

5. Conclusion

The importance of undertaking regular assessment of body fluid status and recognition of fluid overload has gained recent attention due to an unequivocal link to poorer outcomes in critically ill patients, a finding that did seem to be consistent with outcomes from this study. Patients who require CRRT are particularly vulnerable to the adverse effect of fluid overload on the body, and this is an independent risk factor of mortality.[27,28] The charting of fluid balance and measurement of changes in body weight are two methods most commonly used in the ICU. This study identified problems with both methods in monitoring fluid overload in the body during CRRT. It confirmed the findings from other studies that paper-based charting is vulnerable to calculation errors in the monitoring of inputs and outputs. Studies that rely on daily charting of fluid balances as a measured variable should give consideration to the possibility of errors when interpreting the findings of studies investigating the effects of fluid volume on the body. Similar consideration should be given to the accuracy of changes in body weight which include explanations on what steps were taken to reduce uncertainties over recorded measurements. The effect of gaps in the frequency of when patients were weighed should be reported as this can also impact the interpretation of results. A strong relationship was not found between fluid balance and body weight with the magnitude of some differences clinically significant irrespective of whether fluid balances were corrected for IWL. This confirms that caution is required in comparing calculated fluid balances with bodyweight changes and underscores the importance of physical examination when assessing body fluid status in patients receiving CRRT.

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To answer the Continuing Professional Development Questions - go to page 90 http://dx.doi.org/10.1016/S1036-7314(19)30035-9

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