Fluid balance does not predict estimated sodium balance in critically ill mechanically ventilated patients

Shailesh Bihari, Claire E Baldwin and Andrew D Bersten

ABSTRACT

Background: Distribution of total body water (TBW) depends on local and systemic factors including osmolality, relative sodium content and permeability. Although positive fluid balance has been associated with increased morbidity and mortality in critically ill patients, the mechanisms and relative roles of sodium balance and water distribution are uncertain.

Objective: To track changes in sodium and fluid balance, respiratory function and body composition in patients who required mechanical ventilation for ⩾ 48 hours.

Design, setting and participants: Prospective observational study, set in a tertiary intensive care unit, of 10 patients (seven men) with a mean age of 60 years (standard deviation [SD],12 years) and mean admission Acute Physiology and Chronic Health Evaluation (APACHE) III score of 71 (SD, 26).

Methods: Sodium and fluid balances were estimated daily for up to 5 days, following institution of mechanical ventilation on Day 0. Serum sodium level, oxygenation (PaO_2/FIO_2), body weight, intracellular and extracellular fluid (ECF) distribution (bioelectrical impedance spectroscopy), and blinded chest x-ray oedema scores were performed daily.

Results: After 5 days of mechanical ventilation, the cumulative fluid balance was – 954 mL (SD, 3181 mL) and estimated cumulative sodium balance was 253 mmol (SD, 346 mmol). Serum sodium had increased from 140 mmol/L (SD, 4 mmol/L) to 147 mmol/L (SD, 5 mmol/L). Cumulative sodium balance was weakly correlated with worsening chest x-ray score ($r = 0.35$, $P = 0.004$), a reduction in PaO_2/FIO_2 ratio ($r = -0.52$, $P = 0.001$) and 24-hour urinary sodium ($r = -0.24$, $P = 0.02$). Between Days 1 and 5, body weight decreased (– 2.7 kg; SD, 1.4 kg) and TBW decreased (– 3.4 L; SD, 1.3 L), despite a rise in ECF distribution (1.4% of TBW; SD, 1.9% of TBW).

Conclusions: Fluid balance may not reflect sodium balance in critically ill patients. As sodium balance correlates with respiratory dysfunction and increased extracellular volume, further studies examining sodium balance and morbidity seem warranted.

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A positive fluid balance is associated with poor lung and kidney function,[1,2] delayed return of gastrointestinal function after surgery[3] and increased mortality.[4] The association of a positive fluid balance with adverse outcomes is believed to be due to extracellular compartment expansion, as water distributes to both intracellular and extracellular spaces. However, sodium only distributes into the extracellular space, which may have differential effects on extracellular volumes, cause cellular dehydration and exacerbate interstitial oedema in the systemic and pulmonary circulations.

It is current practice for high amounts of sodium to be administered, but the clinical impact is unknown. In a single-centre study, we reported that critically ill patients were inadvertently administered more than twice[5] the recommended sodium intake of 100 mmol/day,[6] despite achieving a fluid balance consistent with the conservative arm of the Fluids and Catheters Treatment Trial study.[1] This was confirmed in a point prevalence study across 40 intensive care units and 356 patients in Australia and New Zealand, in which the median total sodium administered on the study day was 225 mmol (interquartile range [IQR], 145–368 mmol).[7] However, both studies only observed sodium administration, neither estimated sodium balance, and no clinical correlates were made.

Both sodium and fluid need to be administered in balance and proportionate to the dynamic clinical state. For example, inadequate sodium and fluid administration may exacerbate haemodynamic instability, particularly during stress such as sepsis and mechanical ventilation, and an imbalance may result in hyperosmolality or hypo-osmolality. Furthermore, positive pressure ventilation and positive end-expiratory pressure result in elevated intrathoracic pressure, reduced venous return, and consequent complex neurohumoral responses[8,9] that also lead to sodium and water retention.[10] Although conservative fluid administration may increase ventilator-free days,[1] suggesting a direct effect on respiratory function, the contribution of sodium balance is unknown.

We hypothesised that the pattern of sodium balance in critically ill patients over the first few days following mechanical ventilation would differ from fluid balance, and that a high sodium balance may be associated with greater respiratory dysfunction. Accordingly, our study aimed to prospectively estimate sodium balance, fluid balance and

Table 1. Patient demographics and details at admission to the intensive care unit

Patient no. and diagnosis	Age (years)	Sex	SBL (cm)	Weight (kg)	APACHE II	APACHE III	SAPS II	SOFA score	ICU LOS	Hospital LOS	MV	ICU mortality	CCI
1 Sepsis	68	F	149.8	68.2	19	79	46	10	7.4	57	56	Alive	10
2 Pneumonia	50	M	173.5	59.4	18	62	38	10	8.5	22	122	Alive	4
3 ARDS–aspiration	49	M	174.8	82.2	19	32	60	13	11.5	16	131	Alive	3
4 Sepsis	74	M	171.5	113.8	22	65	46	9	7.0	13	69	Alive	18
5 Cardiogenic shock	61	M	166.8	58.8	14	37	31	2	4.8	8	88	Alive	3
6 Sepsis	39	F	158.5	80.6	20	70	32	14	7.5	7	93	Alive	0
7 Acute liver failure	76	M	181.5	97.4	32	98	66	7	7.0	47	141	Alive	10
8 Pneumonia	63	M	179	98.8	29	113	72	9	26.8	52	138	Alive	4
9 Pneumonia	55	F	164.5	76.2	19	60	33	10	5.5	6	131	Dead	13
10 ARDS–aspiration	60	M	184.8	98.4	25	98	69	12	20.1	26	460	Alive	3
Mean (SD)	60 (12)	NA	170.5 (10.8)	83.4 (18.4)	22 (6)	71 (26)	49 (16)	10 (3)	10.6 (7.2)	25.3 (19.6)	143 (115)	NA	7 (6)

SBL = supine body length. APACHE = Acute Physiology and Chronic Health Evaluation; versions II and III. SAPS = Simplified Acute Physiology Score; version II. SOFA = Sequential Organ Failure Assessment. LOS = length of stay (days). MV = invasive mechanical ventilation (hours). CCI = Charlson comorbidity index; age-adjusted score. F = female. M = male. ARDS = acute respiratory distress syndrome. NA = not applicable.

respiratory function in patients who were anticipated to require mechanical ventilation for at least 48 hours. We also aimed to quantify alterations in body composition.

Methods

Our study protocol was approved by the institutional human research ethics committee (036/11). Patients admitted to a single tertiary ICU were prospectively recruited between April 2011 and December 2011 inclusive. Patients who were anticipated to require invasive mechanical ventilation for at least 48 hours (based on the treating consultant's prediction) were eligible for participation at the time of intubation, providing they did not meet any of the following exclusion criteria:

- < 18 years of age
- history of a chronic haemodialysis requirement
- admission diagnosis of traumatic brain injury
- diabetic ketoacidosis
- hyperglycaemic hyperosmolar syndrome
- surgical ICU admission
- pregnancy or within 2 months postpartum
- anticipated death within 24 hours or designated as not for active treatment.

Surgical patients were excluded in an attempt to minimise other potential sources of fluid and sodium loss. Demographic details were collected, along with ICU admission diagnosis and measures of severity of illness (Acute Physiology and Chronic Health Evaluation [APACHE] versions II and III, Simplified Acute Physiology Score [SAPS II] and Sequential Organ Failure Assessment [SOFA][11]). Outcome data included hours of ventilation, ICU mortality and ICU and hospital lengths of stay. The presence of comorbidity was assessed by the Charlson comorbidity index.[12,13] The day that mechanical ventilation was commenced was designated as Day 0. The following variables were then obtained daily for 5 days or until 24 hours after the day of extubation, whichever occurred first.

Estimated sodium and fluid balance

Sodium and fluid inputs were calculated as follows. For all solutions, the type and volume administered over each 24-hour study day was recorded. Intravenous fluid and sodium sources were classified as:

- fluids administered by bolus or infusion for volume expansion or resuscitation, including crystalloids and colloids
- transfusion of blood products including red blood cells, platelets and fresh frozen plasma
- infusions given as maintenance or replacement fluids
- antibiotics administered by a bolus together with their vehicles, as antibiotics significantly contribute to sodium load[5]
- other drugs administered by continuous infusion, with their vehicles
- other drugs administered by a bolus, with their vehicles
- flushes of intravascular lines associated with haemodynamic monitoring, including arterial lines and central venous catheters. Fluid and sodium sources could also be classified as from:

Table 2. Fluid, sodium, respiratory, body composition and other clinical data, by study day*

Parameter	Day 0†	Day 1†	Day 2†	Day 3†	Day 4‡	Day 5§
Fluid and sodium balance						
Total fluid administered (mL)	3563 (2109)	2843 (1089)	2563 (992)	2900 (1126)	2510 (793)	2380 (953)
Urine output (mL)	883 (477)	1796 (1074)	1589 (604)	2061 (603)	2018 (1087)	2098 (1137)
Fluid balance (mL)	1471 (542)	424 (1118)	336 (655)	– 321 (1666)	– 225 (1509)	– 451 (1761)
Total sodium administered (mmol)	488 (399)	198 (86)	149 (46)	135 (66)	112 (46)	94 (34)
Urine sodium (mmol/24 hours)	NA	64 (64)	56 (63)	56 (41)	128 (127)	95 (77)
Highest serum sodium (mmol/L)	140 (4)	141 (4)	142 (5)	145 (6)	146 (5)	147 (5)
Respiratory function						
Lowest Pa_{O_2}/F_{IO_2}	96 (24)	194 (109)	237 (64)	231 (47)	258 (95)	205 (100)
Chest x-ray pulmonary oedema score¶	176 (141)	188 (97)	178 (110)	204 (118)	193 (121)	140 (109)
Body composition						
Body weight (kg)	NA	83 (18)	84 (18)	79 (17)	83 (17)	90 (12)
TBW volume (L)	NA	43 (8)	42 (9)	39 (9)	40 (10)	44 (10)
TBW (% of body weight)	NA	52 (3)	50 (5)	49 (6)	48 (4)	49 (6)
ECF volume (L)	NA	21 (4)	21 (5)	20 (5)	20 (5)	22 (6)
ECF (% of TBW)	NA	50 (4)	50 (4)	50 (4)	50 (5)	51 (3)
Other clinical parameters						
Highest serum creatinine (μmol/L)	89 (54)	95 (36)	87 (30)	84 (27)	62 (21)	69 (28)
Highest serum urea (mmol/L)	5 (4)	12 (6)	11 (5)	11 (5)	11 (5)	12 (7)
Highest serum albumin (g/L)	28 (6)	27 (6)	26 (6)	26 (4)	26 (4)	23 (4)
Total oedema score**	NA	2 (3)	2 (3)	5 (2)	4 (2)	5 (4)
SOFA score	10 (5)	8 (4)	7 (4)	5 (3)	4 (2)	4 (2)

NA = not applicable. TBW = total body water. ECF = extracellular fluid. SOFA = sequential organ failure assessment. * Data are means (SD). † Data for 10 patients. ‡ Data for 7 patients. § Data for 5 patients. ¶ Out of 390. ** Out of 16.

- feeding via enteral nutrition or
- total parenteral nutrition (TPN).

The amount of sodium administered was then calculated based on the published sodium concentration of the sources.[5] Therefore, for drug infusions and boluses, sodium content was calculated from sodium content of both the drug and the type and volume of carrier fluid or diluent. For enteral nutrition, information on the type and volume of feed was recorded and the sodium content calculated accordingly. The sodium content was recorded similarly for custom TPN. No episodes of nasogastric intolerance were recorded in the study cohort.

To estimate sodium output, and therefore balance, each day, urinary sodium concentration was measured from a sample of a 24-hour urine save by the indirect ion selective electrode technique (Roche modular analyser, Hitachi High-Technologies Corporation, Tokyo, Japan). The daily fluid balance, urine output and serum sodium were also collated. Hypernatraemia was defined as a serum sodium level of ⩾ 150 mmol/L.

Respiratory function

The chest x-ray was evaluated for pulmonary oedema by a blinded assessor and assigned a score of 0–390, using a scoring system validated by Halperin et al,[14] with 0 representing no oedema and high scores representing severe oedema. More specifically, the chest x-ray score was calculated by the summation of subscores from 0 (normal) to 65 (alveolar oedema involving entire pulmonary region) assigned to each of six lung regions. The highest and lowest Pa_{O_2}/F_{IO_2} ratio was also calculated from routinely performed arterial blood gas analysis (ABL700 series, Radiometer Medical ApS, Brønshøj, Denmark).

Body composition

Body weight was measured to the nearest 0.1 kg at the same time each day using a Jordan frame attachment to a patient lifter with a weigh scale (IPL 150em lifter, Invacare), which enabled patients to remain in a stable supine position. Care was taken to ensure that there was no additional weight of attachments or linen that had not been factored into the calculations and procedure for this measurement. Supine body length was also recorded to the nearest 0.1 cm using a tape measure (W606PM Executive Thinline, Lufkin) as a proxy measurement of height[15,16] on the initial test day.

Body composition analysis was then performed with bioelectrical impedance spectroscopy, using a tetrapolar device (SFB7, ImpediMed) and a previously described technique.[16] Participants rested supine, with the medial surfaces of their limbs abducted, resting away from and not touching the body. Single-use gel electrodes (ImpediMed) were placed on the dorsal hand and foot of one side of the body,

Table 3. Sources of sodium administered during Days 0–5*

Sodium source	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5
Resuscitation	305 (62.5%) (58.7–65.1)	35 (17.7%) (15.9–19.1)	7 (4.8%) (4.4–5.2)	9 (6.5%) (5.9–7.1)	3 (2.8%) (2.3–3.2)	0
Transfusion	40 (8.1%) (7.8–9.4)	0	3 (1.8%) (1.6–2.1)	2 (1.4%) (1.1–1.8)	3 (2.5%) (2.2–3.0)	0
Infusion	34 (7.0%) (6.2–7.9)	18 (8.9%) (8.1–9.9)	3 (1.9%) (1.6–2.2)	4 (2.6%) (2.2–2.9)	3 (2.5%) (2.2–3.0)	0
Drug infusion	17 (3.4%) (3.1–3.8)	42 (21.1%) (19.2–22.3)	15 (10.3%) (9.2–11.0)	14 (10.5%) (9.1–12.1)	1 (1.3%) (0.9–1.5)	15 (15.5%) (14.1–17.1)
Drug bolus	0	2 (1.0%) (0.7–1.5)	8 (5.3%) (4.9–5.8)	3 (2.0%) (1.5–2.6)	23 (20.1%) (18.8–22.3)	0
Antibiotics	53 (10.8%) (9.4–11.9)	34 (17.0%) (15.9–18.1)	32 (21.4%) (20.0–23.2)	34 (24.9%) (22.9–26.4)	23 (20.1%) (18.9–22.3)	17 (17.8%) (15.9–19.1)
Feeds	0	26 (12.9%) (11.5–14.1)	35 (23.7%) (21.5–25.5)	28 (20.8%) (19.7–22.5)	28 (25.4%) (23.8–27.4)	22 (23.2%) (21.3–25.1)
TPN	5 (1.1%) (0.9–1.3)	5 (2.5%) (1.9–3.3)	13 (8.4%) (7.9–9.1)	2 (1.8%) (1.2–2.4)	4 (3.2%) (2.2–4.4)	7 (7.3%) (5.9–8.8)
Flush	36 (7.3%) (6.9–7.9)	37 (18.6%) (17.1–19.9)	34 (22.5%) (20.9–23.9)	40 (29.6%) (27.6–32.1)	36 (31.8%) (29.8–34.2)	34 (36.2%) (33.7–39.9)

TPN = total parenteral nutrition. * Data expressed as mmol and (% of total administered sodium) (95% CI).

to form the tetrapolar electrode arrangement. Data were uploaded to Bioimp software (v. 5.3.1.1, ImpediMed), and inbuilt prediction algorithms using Cole–Cole modelling with details of weight, height, age and sex were used to approximate the volumes of the total body water (TBW), extracellular fluid (ECF) and intracellular fluid (ICF) compartments. The relative volume of ECF was then expressed as a percentage of TBW.

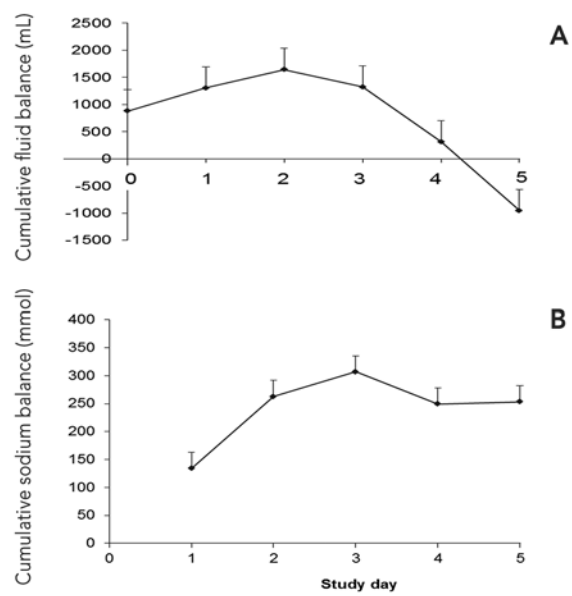
Other clinical parameters

Other clinical parameters recorded from routine monitoring and investigations included serum creatinine, urea and albumin levels. The use of a-priori selected therapies, including diuretics, steroids and renal replacement therapy, were noted. Peripheral oedema was scored by a blinded and independent assessor, by summation of subscores from the pedal, lateral chest wall, hand and sacral regions (individually scored from 0–4) to form a total oedema score from 0–16 with high scores representing greater oedema.[17] A SOFA score was also calculated daily.[11]

Statistical analysis

Data are reported as means with SD, or median with IQR, as appropriate for the distribution of each variable. Analysis was performed using SPSS version 19.0 (SPSS Inc). Differences between variables over time were analysed by a repeated-measures analysis of variance (ANOVA) and correlations were analysed using the Pearson correlation coefficient (*r*). Cumulative fluid balance and sodium balance were correlated with next day's chest x-ray score and the lowest PaO_2/FIO_2 ratios. A conventional alpha level of < 0.05 was used for all significance testing.

Figure 1. Cumulative fluid balance (A) and estimated cumulative sodium balance (B) during intensive care unit stay in 10 mechanically ventilated patients*



* Data points are means. Vertical lines = standard error of means.

Figure 2. Correlations between cumulative sodium balance and next day's chest x-ray score (A), and cumulative sodium balance and next day's lowest $Pa{O_2}/F{IO_2}$ ratio (B)

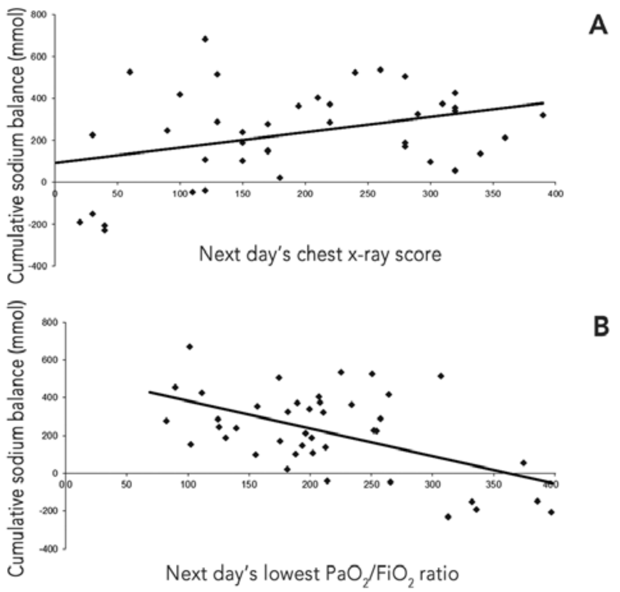
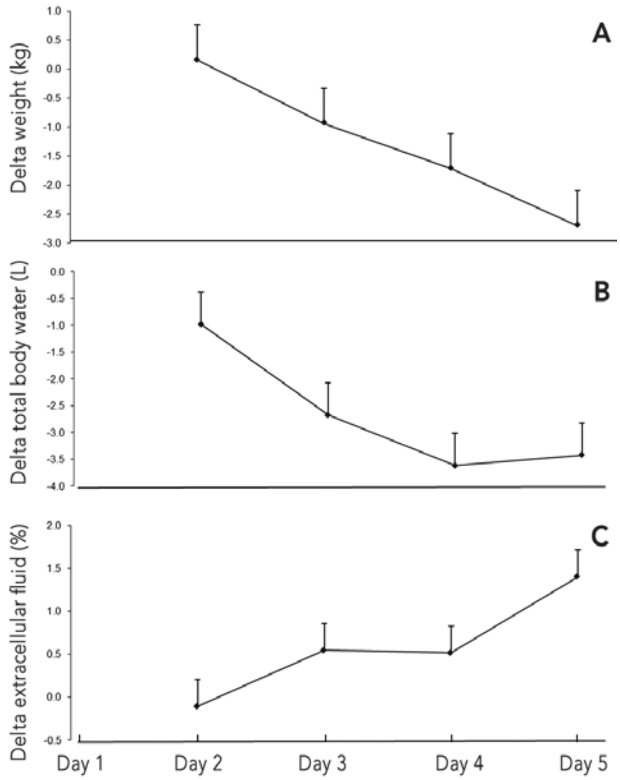


Figure 3. Delta* body weight (A), delta* total body water (B) and delta* extracellular fluid (% of total body water) (C), compared with Day 1†



* Delta = difference in measurement on study day compared with Day 1. † Data points are means. Vertical lines = standard error of means.

Results

Ten patients with a mean age of 60 years (SD, 12 years) participated for a median of 4.5 days (IQR, 3.2–5.0 days), with all patients completing the study protocol. Other demographic details and characteristics at ICU admission are outlined in Table 1. No patient required renal replacement therapy, and all patients were included in the study within 24 hours of initiation of mechanical ventilation.

Fluid, sodium, respiratory function, body composition and other clinical parameters are listed by study day in Table 2. Patients achieved only a relatively modest positive fluid balance, which was negative by Day 3. It took until Day 5 for the cumulative fluid balance to become negative, at – 954 mL (SD, 3181 mL) (Figure 1A). Conversely, sodium administration was considered high throughout the study period, although it did progressively decrease each day (Table 2). On Day 0, resuscitation fluids were the predominant source of sodium administration, with fluctuations in the contribution of other sources, shown in Table 3. While four patients met the criteria for hypernatraemia, the highest serum sodium steadily increased from Day 0 to Day 5 ($P = 0.046$). Furthermore, after 5 days of mechanical ventilation, patients had an estimated cumulative sodium balance of 253 mmol (SD, 346 mmol) (Figure 1B). The increase in serum sodium was mirrored by an increase in serum urea, but there was a decrease in serum creatinine and albumin between Days 0 and 5 (Table 2). Patients who received diuretics during the study period (a total of 15 diuretic days) achieved a better urine output ($P = 0.04$) but did not achieve a higher or lower natriuresis when compared with patients who did not receive diuretics ($P = 0.11$). There was no difference in the urine output ($P = 0.44$) or natriuresis ($P = 0.54$) with intravenous steroids (a total of 25 steroid days).

When we used the data at each measurement point for each patient, the cumulative sodium balance weakly correlated with: the next day's worsening (higher) chest x-ray scores ($r = 0.35$, $P = 0.004$) (Figure 2A); a next day's reduction in the lowest $Pa{O_2}/F{IO_2}$ ratio ($r = -0.52$, $P = 0.001$) (Figure 2B); and lower urinary sodium ($r = -0.24$, $P = 0.02$). However, there was not a significant association between the cumulative fluid balance and either the next day's chest x-ray scores ($P = 0.24$) or the next day's $Pa{O_2}/F{IO_2}$ ratios ($P = 0.44$). Neither was there an association between the cumulative sodium balance and either total oedema ($P = 0.28$) or SOFA scores ($P = 0.11$).

Body weight (Table 2) decreased between Days 1 and 5 (mean change, – 2.7 kg; SD, 1.4 kg; $P = 0.03$) (Figure 3A), and TBW volume decreased (mean change, – 3.4 L; SD, 1.3 L; $P = 0.05$) (Figure 3B). However, the distribution of body water tended to increase in the ECF compartment (mean change, 1.4% of TBW; SD, 0.9% of TBW; $P = 0.08$) (Figure 3C). Delta ECF (the difference in ECF on the study day compared with Day 1) had a positive correlation with total sodium administered ($r = 0.47$, $P = 0.008$) and cumulative sodium balance ($r = 0.42$, $P = 0.02$), a negative correlation with highest serum albumin ($r = -0.56$, $P = 0.001$) and no correlation with daily fluid balance ($P = 0.59$) or cumulative fluid balance ($P = 0.11$).

Discussion

We sampled a small group of mechanically ventilated patients with moderately severe illness at ICU admission. Despite achieving a negative fluid balance over the first 5 days of mechanical ventilation, estimated sodium balance remained positive, with a tendency to increase. A more positive estimated sodium balance was weakly associated with lower oxygenation, measured as the Pa_{O_2}/F_{IO_2} ratio, and more severe pulmonary oedema, measured as the chest x-ray score. There was also a rise in serum sodium, an increase in the relative ECF volume, and losses in body weight and body water over the study period.

In previous studies of critically ill patients, sodium balance has not been separated from fluid balance in those who may be at high risk of sodium retention. Following shock, pulmonary interstitial collagen may have an increased propensity for sodium absorption associated with interstitial oedema, as suggested by studies of primate lungs by Moss et al.[18-20] This can lead to intracellular dehydration, which may explain recent reports of an association of conservative fluid balance with cognitive impairment in patients with acute lung injury.[21] Despite the pilot nature of our study, we also found novel associations between estimated sodium balance and clinically relevant parameters.

Hypernatraemia,[22] which has been associated with poor outcomes in critically ill patients,[23,24] may result from sodium retention and inadvertent sodium loading during conservative fluid management. In our study, except for Day 0, sodium administration was at the lower end of the practice spectrum[7] in our research locale, and the management of fluid balance in our study patients would be classified as conservative. Even so, four patients met criteria for hypernatraemia at some point during the study, and serum sodium steadily increased. While the measured negative fluid balance only partly (about 3 mmol/L) accounts for the increase in serum sodium of 7 mmol/L, this is fully accounted for when faecal and skin losses are considered. We measured an average weight loss of around 3 kg with a corresponding loss in TBW, consistent with the cumulative negative fluid balance (– 950 mL), plus an approximate (unmeasured) fluid loss from faeces (– 200 mL/day), skin (– 500 mL/day) and net metabolic water production (+350 mL/day).[8] This suggests that the positive sodium balance we estimated was not accounted for or incompletely accounted for by standard measures of fluid balance and serum sodium.

The association of estimated sodium balance with both a lower Pa_{O_2}/F_{IO_2} ratio and a higher chest x-ray score may have been due to the distribution of sodium to extracellular spaces and the volume expansion of this compartment. Our body composition analysis results suggested that there was an increase in the relative volume of fluid distributed to the extracellular compartment. This was despite a reduction in TBW, reflected by changes in body weight. This observation is consistent with our previous work[16] and other longitudinal observations of haemodynamically stable, mechanically ventilated, critically ill patients early in the course of illness.[25-27] From these studies, it seems that fluctuations in body weight can mostly be attributed to changes in body water, while progressive cellular dehydration and fluctuations in extracellular overhydration occur at the whole-body level[25-27] and at the tissue level.[28] The rise in the ECF compartment correlated with the cumulative sodium balance but not with the cumulative fluid balance. In relation to the lung, a small fractional rise in ECF compartment volume appears insufficient to explain the measured deterioration in Pa_{O_2}/F_{IO_2} ratio and chest x-ray score. Perhaps the propensity of interstitial collagen to retain sodium during mechanical ventilation, combined with a critical illness, may lead to a ventilation–perfusion mismatch, which may lead to worsening of the Pa_{O_2}/F_{IO_2} ratio and chest x-ray score, with interstitial collagen possibly acting as a sink for sodium. While the lack of association between fluid balance and these variables in our study may seem unexpected, it is consistent with the physiological concept that the primary determinant of extracellular volume is sodium, in which case achieving a negative fluid balance without consideration of the sodium balance may be of little benefit.

The lack of effect of diuretics in producing natriuresis may seem surprising, but critically ill patients are at risk of sodium retention as a result of activation of the renin–angiotensin–aldosterone system.[3] Such patients also have impaired activity of dopamine in the proximal tubule of the kidney,[29] which normally inhibits sodium reabsorption.[30] Similar findings have been reported for chronic heart failure.[31]

Clinical implications of our study include support for the suggestion of Trubuhovich[32] that sodium balance should be considered daily in routine management of critically ill patients, especially as it cannot be assumed that cumulative fluid balance reflects sodium balance. As positive sodium balance may be affected by the amount administered, it may also be important for clinicians to recognise the variety of sources from which inadvertent sodium loading can occur, and how this may change over the course of illness and recovery.

Limitations

The findings of our study need to be considered in the light of several limitations. First, our sample was small and represents medical ICU patients. Although the small sample size limits our conclusions, we believe this is the first clinical study to correlate sodium balance and measures of respiratory function. This provides a basis to increase the sample size and examine sodium balance and body composition parameters with more objective and technically challenging measures, including other measures of oxygenation and lung function, extravascular lung water and cognitive function. Recruitment was limited to medical patients rather than surgical ones in an attempt to minimise other potential sources of fluid and sodium loss, particularly through the gastrointestinal system. While we were able to be accurate in our calculation of sodium administration, sodium balance was only estimated from urine loss, and did not include other gastrointestinal or incidental losses. Similar limitations apply to estimates of water balance. The difference between the calculated water balance and both body weight and TBW likely reflects unmeasured losses from the gastrointestinal tract and skin. Also, as patients were only followed for up to 5 days and there was some attrition by Day 4 and Day 5 due to extubation, the data were incomplete, and the pattern of sodium balance after 5 days remains unknown.

We did not use "gold standard" isotope dilution methods for measurement of body composition variables, due to the technical and equipment expertise required, particularly for measurements in the critically ill. Bioelectrical impedance spectroscopy may be used; it has been reported to have good agreement with the bromide dilution method for monitoring changes over time in ICU patients, despite underestimating ECF volumes by about 2–4 L, mostly in patients with sepsis.[25,33] Only three of our patients had sepsis, and the average fluid balance of all patients at enrolment was about 1.5 L, far less than in previous studies in which fluid balance was about 12.5 L.[25,26] With the greatest inaccuracies of bioelectrical impedance analysis evident in a severely fluid-overloaded state and in patients with sepsis, we suggest that we would still have been able to map a trend in changes over time using bioelectrical impedance spectroscopy, and that inaccuracies would have been minimised in our sample. The comparatively small magnitude of body water fluctuations that we observed over the study period may also have reflected a relatively modest fluid excess in the first place.

Conclusions

Our study related clinical sequelae to estimated positive sodium balance in mechanically ventilated, critically ill patients who had a conservative fluid balance. As there may be other clinically important and differential effects of sodium balance, further research is required in ICU patients to delineate the optimal balance of fluid and sodium.

Competing interests

None declared.

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