Sodium administration in critically ill paediatric patients in Australia and New Zealand: a multicentre point prevalence study

Shailesh Bihari, Marino Festa, Sandra L Peake, Ian M Seppelt, Patricia Williams, Barry Wilkins and Andrew Bersten

Sodium and water balance are affected by daily sodium and water intake and in critical illness are no longer under the direct control of the individual's response to thirst or choice of dietary intake. Isotonic maintenance fluids are often administered to paediatric patients to reduce the risk of hyponatraemia.[1-4] This may increase the risk of sodium and fluid overload, especially in critically ill patients, when a complex interplay of several homoeostatic mechanisms occurs. These include activation of the renin–angiotensin–aldosterone system[5] and impaired activity of dopamine in the proximal tubule of the kidney[6] (dopamine normally inhibits sodium reabsorption[7]), which promote increased sodium retention. An increased level of arginine vasopressin released by the posterior pituitary in acute illness also promotes water reabsorption from the collecting ducts of the kidneys.[8,9]

Data from the Prospective Paediatric Continuous Renal Replacement Therapy (ppCRRT) registry[10,11] and other observational studies[12-14] have shown that positive fluid balance is an independent predictor of mortality in children. The mechanism of the detrimental effects of fluid overload is probably multifactorial, but expansion of extracellular fluid space[15] and increased distance for oxygen diffusion, as well as alterations in cell volume, are likely contributors. Sodium is an extracellular ion and can affect the intracellular and extracellular fluid distribution, with the potential to exacerbate interstitial oedema in the lung and other organs.

A single-centre adult intensive care unit study recently reported that the amount of sodium given to critically ill adults receiving mechanical ventilation for more than 5 days was more than twice the recommended daily intake.[16] The main sources of sodium were intravenous (IV) maintenance fluids, flushes and drugs.[16] These findings were later confirmed in a larger multicentre, point prevalence study in adult ICU patients, in which the main source of administered sodium was IV maintenance fluids, followed by fluid boluses and drug boluses.[17] We have previously shown a significant correlation between sodium balance and respiratory function in adults ventilated in intensive care.[18] The aim of this study was to determine the total administered sodium and its sources, and fluid balance over a single 24-hour period in infants and children in ICU in Australia and New Zealand.

ABSTRACT

Objective: Dysnatraemia and a positive fluid balance are associated with poor outcomes in paediatric intensive care units (PICUs). Our objective was to determine sodium intake and the total daily fluid balance in children in the PICU.

Method: A single-day point prevalence study in 10 Australian and New Zealand PICUs. Patients on free oral diets were excluded. Demographics, 24-hour fluid balance and sodium intake (enteral and parenteral sources) were recorded.

Results: We enrolled 65 patients; 15 were excluded due to having a free oral intake and two patients had incomplete data, leaving 48 children in the study cohort. The 21 infants had a median age of 4 months (interquartile range [IQR], 1–7 months) and a median bodyweight of 5 kg (IQR, 3.5–6.1 kg). The 27 children > 1 year had a median age of 3 years (IQR, 1.5–13 years) and a median bodyweight of 17 kg (IQR, 9.5–47.5 kg). Overall, the median sodium administration on the study day was 4.9 mmol/kg (IQR, 3.2–8 mmol/kg), median fluid administration was 80.8 mL/kg (IQR, 49.8–111.4 mL/kg) and median fluid balance was 9 mL/kg (IQR, –1.4 to 41 mL/kg). For infants, the median sodium administration was 6 mmol/kg (IQR, 3.9–8.1 mmol/kg), and median fluid balance was 20.8 mL/kg (IQR, 3.5–47.2 mL/kg). For children > 1 year, the median sodium administration was 3.5 mmol/kg (IQR, 3.1–7.8 mmol/kg), and median fluid balance was 5.3 mL/kg (IQR, –2.7 to 17.7 mL/kg). Overall, fluid infusions, boluses and catheter flushes together contributed 46.2% of total sodium administered. Drugs contributed substantially to administered sodium (33.3%), with antibiotics accounting for the majority. Enteral feeds contributed 16.2% to overall administered sodium, and were the major source in patients in the PICU for > 10 days.

Conclusion: Daily sodium intake in children in the PICU is high. The contributions of maintenance and bolus intravenous fluids (most commonly as 0.9% sodium chloride), drug infusions and boluses, including antibiotics, and enteral feeds, are significant.

Crit Care Resusc 2014; 16: 112–118

Table 1. Patient characteristics

Characteristic	Data ($n = 48$)
Infants, *n* (%)	21 (44%)
Age, months*	4 (1–7)
Weight, kg*†	5 (3.5–6.1)
Children > 1 year, *n* (%)	27 (56%)
Age, years*	3 (1.5–13)
Weight, kg*†	17 (9.5–47.5)
Male, *n* (%)	24 (50%)
ICU admission source, *n* (%)	
Operating theatre	21 (44%)
Elective surgery	20 (42%)
Emergency surgery	1 (2%)
After cardiopulmonary bypass	9 (19%)
Transfer from other ICU	10 (21%)
Transfer from other hospital	7 (15%)
Hospital ward	6 (12%)
Emergency department	4 (8%)
ANZPICR diagnostic categories, *n* (%)	
Injury	5 (10%)
Respiratory	13 (27%)
Cardiovascular	7 (15%)
Neurological	1 (2%)
PIM risk of death*	0.02 (0.01–0.06)
High-risk PIM, *n* (%)	7 (15%)
Low-risk PIM, *n* (%)	5 (10%)
SOFA respiratory score*	2 (0–3)
Trauma, *n* (%)	3 (6%)
Burns, *n* (%)	1 (2%)
Sepsis on study day, *n* (%)	7 (15%)
ALI/ARDS on study day, *n* (%)	6 (12%)
Renal replacement therapy, *n* (%)	1 (2%)
Mechanically ventilated in first hour, *n* (%)	34 (71%)
Discharged from ICU at 28 days, *n* (%)	38 (79%)
Discharged from hospital at 28 days, *n* (%)	27 (56%)
28-day ICU mortality, *n* (%)	2 (4%)

ICU = intensive care unit. ANZPICR = Australian and New Zealand Paediatric Intensive Care Registry. PIM = paediatric index of mortality. SOFA = sequential organ failure assessment. ALI = acute lung injury. ARDS = acute respiratory distress syndrome. * Median and interquartile range. † Weight estimated or actual (38 patients measured [79%]).

Methods

We undertook a multicentre, single-day, point prevalence study in collaboration with the Paediatric Study Group (PSG) of the Australian and New Zealand Intensive Care Society (ANZICS) Clinical Trials Group (CTG). Ten ICUs (eight dedicated paediatric ICUs [PICUs] and two mixed adult and paediatric ICUs) caring for most of the critically ill or injured infants and children in Australia and New Zealand participated in our study (see Appendix), conducted on either of two study dates (21 September or 19 October 2011). Neonatal ICUs, defined as units caring solely for newborn infants, were excluded from our study. Approval was obtained from individual participating site research ethics committees, with the requirement for individual subject consent waived at all sites. This ensured recruitment of all patients < 16 years present in the ICU at 10 am on the study day.

Demographic and descriptive data including age, sex, weight (estimated and measured), admission paediatric index of mortality (PIM) II score,[19] admission diagnosis and specific diagnoses on the study day (eg, acute lung injury, acute respiratory distress syndrome and sepsis) were documented. Data on major treatment interventions (eg, invasive mechanical ventilation and renal replacement therapy) on the study day were also collected, as well as the respiratory component of the sequential organ failure assessment (SOFA) score.[20] The highest and lowest serum sodium levels on the study day were recorded and patients were categorised as having normal serum sodium levels, hypernatraemia (serum sodium level ⩾ 150 mmol/L[21]) or hyponatraemia (serum sodium level < 130 mmol/L[22]).

Patients receiving a normal oral diet who did not receive prescribed formula feed (enteral or parenteral) at any time during the study day were described as having free oral intake and were excluded from the study analysis. Data on all sources of administered sodium (excluding any non-prescribed oral diet) were recorded for the remaining patients. The absolute and relative contributions of potential sources of administered sodium were categorised as:

- IV bolus
- IV infusions (maintenance or replacement fluids)
- blood products (red blood cells, platelets or fresh frozen plasma)
- IV drug boluses including fluid given as a diluent or a vehicle for administration
- IV drug infusions including fluid given as a diluent or a vehicle for administration
- IV flushes associated with haemodynamic monitoring of arterial or central venous catheters
- prescribed enteral nutrition
- prescribed parenteral nutrition.

Patients were categorised by the number of completed days in ICU at the onset of the study day (< 24 hours versus ⩾ 24 hours, and < 10 days versus ⩾ 10 days). For patients in the ICU < 24 hours at the time of the study census, data for individual patients were reported by cohort regardless of the exact number of hours spent in the ICU. For all parenteral fluids and blood products, the types and volumes administered over the previous 24-hour period were recorded and the amounts of sodium administered were

Table 2. Sodium and fluid administration and daily fluid balance, by days in paediatric intensive care unit (PICU)*

PICUDay	*n*	Sodium, mmol/kg	Fluid, mL/kg	Fluid balance, mL/kg
< 1†	5	3.3 (1.2–5)	33 (25.3–48.2)	9 (5.3–17.7)
2–10	29	4.6 (3.2–7.9)	81.6 (53.9–106.2)	18.5 (1.1–41.3)
> 10	14	6.1 (3.5–10.7)	106.5 (66.7–126.4)	0.5 (–10.4 to –19.5)
Total	48	4.9 (3.2–8)	80.8 (49.8–111.4)	9 (–1.4 to –41)

* Expressed as median and interquartile range (IQR). † Median stay, 14 hours; IQR, 11–18 hours.

calculated based on the published sodium concentrations.[16] For drug infusions and boluses, sodium contents were calculated from the the sodium content of the drug and the type and volume of carrier fluid or diluent. Antibiotics are reported as a subgroup of all drug boluses or infusions, as it is known that they contribute a significant sodium load in adults in the ICU.[16,17] For prescribed enteral and parenteral nutrition, information on the type and volume of feed was recorded and the sodium content was calculated. For custom parenteral nutrition, the sodium content was recorded. No data on sodium from oral intake were collected. Data were collected using REDCap software (under a non-profit end-user license from Vanderbilt University).

Statistical analysis

Variables are reported as mean and standard deviation, or median and interquartile range (IQR), and compared using the student *t* test or Mann–Whitney *U* test as appropriate. Sodium administration from each source is reported as a percentage of the total administered sodium with the 95% confidence interval.

The Pearson correlation was used to describe the association between administered sodium (log transformed for normal distribution) and the following variables: age, weight, day of ICU stay, SOFA respiratory score, serum sodium level, fluid administered and 24-hour fluid balance on the study day. Predictor variables for sodium administration were analysed using multiple linear regression (the stepwise method) (SPSS version 2.0 [SPSS Inc]). Day 1 data were not included in the model, as 24-hour data were incomplete (median ICU length of stay, 14 hours [IQR, 11–18 hours]).

Data for infants and older children were also analysed separately as they may have had different sources of fluid and sodium, and infant kidneys may still be developing.[23] For all analyses, $P < 0.05$ was considered statistically significant.

Results

Patient characteristics

We screened 65 patients from 10 participating PICUs on a single study day. Seventeen patients (26%) were excluded from the study because they had free oral feeds (15 [23%]) or had data missing (two [3%]).

Of the remaining 48 patients (24 boys and 24 girls), the mean number of children studied at each site was four (SD, 1–9 children). Twenty-one patients were infants (44%) with a median age of 4 months (IQR, 1–7 months), whose mean bodyweight was 5 kg (SD, 3.5–6.1 kg). Twenty-seven children (56%) were aged > 1 year (mean, 3 years; SD, 1.5–13 years), and their mean bodyweight was 17 kg (SD, 9.5–

Table 3. Sodium and fluid administration and daily fluid balance, by diagnostic category on study day*

Diagnostic category	*n* (%)	Sodium, mmol/kg	Fluid, mL/kg	Fluid balance, mL/kg
Elective admission†	21 (43.8%)	3.9 (2.9–6.9)	80 (43.4–121.2)	18.5 (–2.7 to 56.4)
Trauma†	3 (6.3%)	8.9 (4.6–18)	56 (63.7–115.1)	19.5 (20.4 to 84.1)
After cardiac bypass surgery†	9 (18.8%)	3.4 (2.9–6.2)	63.7 (43.4–94.9)	16.5 (–20.5 to 33.1)
Sepsis‡	7 (14.6%)	6.8 (3.3–16.1)	73.2 (46.4–103.4)	5.3 (–10.4 to 24.3)
Burns†	1 (2.1%)	18	115.1	84.1
ALI/ARDS‡	6 (10.6%)	5.4 (3.3–12.4)	60.9 (42.2–101.2)	–4.3 (–23.5 to 5.2)
Other	22 (45.8%)	5 (3.1–7.8)	90.1 (58.9–125)	9 (0.3 to 48.3)
High-risk PIM	7 (14.6%)	3.5 (3.2–7.9)	67.6 (50–73.6)	17.7 (0.5 to 24.3)
Low-risk PIM	5 (10.4%)	3.9 (1.6–6.3)	63.4 (33.9–91.8)	17.7 (8.9 to 31.7)
PIM ROD (top 50%)	NA	5.6 (3.5–10.8)	87.7 (56.5–117.3)	7 (0.5 to 24.3)
PIM ROD (bottom 50%)	NA	3.9 (2.7–7.2)	75.1 (41.4–103.2)	13.4 (–5.9 to 43.5)

ALI = acute lung injury. ARDS = acute respiratory distress syndrome. PIM = paediatric index of mortality. ROD = risk of death. ICU = intensive care unit.
* Expressed as median and interquartile range. † Category at ICU admission. ‡ Category on study day.

Table 4. Source and contribution to total sodium administered, by intensive care unit day, % (95% CI)

Sodium source	ICU stay < 10 days*† (*n* = 29)	ICU stay > 10 days* (*n* = 14)	Total (*N* = 48)
Fluid boluses	27.4 (25.5–29.3)	7.8 (6.4–9.2)	17.9 (16.7–19.1)
Fluid infusions‡	25.4 (23.5–27.2)	17.6 (15.6–19.5)	23.9 (22.5–25.2)
Blood products	2.2 (1.6–2.8)	5.2 (4–6.3)	3.1 (2.5–3.6)
Drug boluses	13.9 (12.5–15.4)	9.4 (7.9–10.9)	14.9 (13.7–16)
Antibiotics	10.1 (8.8–11.3)	10.9 (9.2–12.5)	10.5 (9.5–11.4)
Drug infusions	4.2 (3.3–5)	15.3 (13.4–17.1)	7.9 (7.1–8.7)
Catheter flushes	5.9 (4.9–6.9)	3.1 (2.1–3.9)	4.4 (3.8–5)
Enteral feeds	10.6 (9.3–11.9)	27.6 (25.3–29.9)	16.2 (15.1–17.3)
Parenteral nutrition	0	3.1 (2.1–3.9)	1.1 (0.8–1.4)

* On the study day. † Excludes children staying in the ICU < 24 hours. ‡ Maintenance or replacement fluids.

47.5 kg). The reasons for PICU admission and other characteristics are shown in Table 1, and the profile was found to be typical of PICU patients.[24]

Administered sodium and 24-hour fluid balance

The median administered sodium and fluid and fluid balance and in the 48 patients on the study day are shown in Table 2. The 24-hour administered sodium and fluid and fluid balance, according to the length of stay in the ICU on the study day (Table 2), were not significantly different between patients in the ICU for fewer than 10 days compared with patients in the ICU for 10 days or more (sodium, $P = 0.18$; fluid, $P = 0.39$; fluid balance, $P = 0.67$). The median urine output was 44 mL/kg (IQR, 24–78 mL/kg on the study day.

For the 21 infants, the 24-hour administered sodium was 6 mmol/kg (IQR, 3.9–8.1 mmol/kg), fluid was 102.6 mL/kg (IQR, 80–127.7 mL/kg) and fluid balance was 20.8 mL/kg (IQR, 3.5–47.2 mL/kg); for the 27 children > 1 year, the 24-hour administered sodium was 3.5 mmol/kg (IQR, 3.1–7.8 mmol/kg), fluid was 58.1 mL/kg (IQR, 35.7–85.7 mL/kg) and fluid balance was 5.3 mL/kg (IQR, −2.7 to 17.7 mL/kg). Although the total administered fluid volume recorded on the study day was greater in infants ($P < 0.001$), the administered sodium and 24-hour fluid balance were not statistically different between infants ($P = 0.53$) and children > 1 year of age ($P = 0.08$).

The 24-hour administered sodium and fluid and fluid balance, by diagnostic category, are shown in Table 3. The median administered sodium in children with sepsis was 6.8 mmol/kg (IQR, 3.3–16.1 mmol/kg) and in children admitted with trauma was 8.9 mmol/kg (IQR, 4.6–18 mmol/kg). The median sodium administration across sites was 5.3 mmol/kg (IQR, 3.2–6.9 mmol/kg) and was not different between them.

Sodium administration on the study day was correlated with the day of stay in the ICU ($P = 0.003$, $\rho = 0.47$), age ($P = 0.005$, $\rho = -0.44$), 24-hour administered fluid/kg ($P < 0.001$, $\rho = 0.68$) and weight ($P = 0.013$, $\rho = -0.38$). Using multiple linear regression modelling ($R^2 = 0.46$), administered sodium was only associated with 24-hour administered fluid/kg (unstandardised β coefficient, 0.08 [SE, 0.02], $P < 0.001$).

Fourteen patients (29.2%) had only one serum sodium reading for the study day, so we reported the mean highest available serum sodium level on the study day, which was 143.2 mmol/L (SD, 6.6 mmol/L). Twelve patients (25%) had a serum sodium level of ⩾ 145 mmol/L, three had hypernatraemia and one had hyponatraemia on the study day.

Table 5. Maintenance and replacement fluids used on the study day (*N* = 34 patients)

Fluid type	Number of patients (%)
0.9% Sodium chloride	8 (16.7%)
5% Dextrose + ½ sodium chloride	6 (12.5%)
10% Dextrose + ½ sodium chloride	5 (10.4%)
2.5% Dextrose + ½ sodium chloride	5 (10.4%)
0.45% Sodium chloride	4 (8.3%)
Hartmann's solution	2 (4.2%)
4% Dextrose + ⅕ sodium chloride	2 (4.2%)
5% Dextrose	1 (2.1%)
3% Sodium chloride	1 (2.1%)

Sources of administered sodium

The contributions to the total sodium administered in all 48 patients are shown in Table 4. Fluid infusions, boluses and catheter flushes together contributed 46.2% of total sodium administered. Drugs, including antibiotics administered by IV bolus or infusion, also contributed substantially (33.3%) to administered sodium, with antibiotics accounting for most sodium administered as drugs.

Table 4 shows subgroup analysis of patients by their length of stay in the ICU. For the 29 infants and children in the ICU > 1 day and < 10 days, IV fluid administered as a bolus or an infusion was the biggest contributor to administered sodium, but in the 14 infants and children who were in the ICU > 10 days, the greatest proportion of administered sodium was via enteral feeds.

IV maintenance or replacement fluid was administered to 34 patients (71%) in the study cohort on the study day. The types of fluid used for maintenance or replacement IV infusions are shown in Table 5. As well as being the most commonly used maintenance and replacement fluid, 0.9% sodium chloride was also the fluid used most commonly as a vehicle for IV drug boluses and infusions (65.8% and 68.2% respectively). Heparinised 0.9% sodium chloride was the most common IV or intra-arterial flush fluid (97.1%).

Sources of sodium administration such as drug infusions, drug boluses and intravascular flushes together inadvertently provide a high burden of daily administered sodium load (27.2%).

Discussion

Our study shows that children in the PICU were administered much more sodium than expected. The median administered sodium was far greater than recommendations based on the nutrient reference value guidelines for Australia and New Zealand,[25] with more than 75% of the study cohort receiving over 3 mmol/kg of sodium on the study day. It is noteworthy that although the main source of sodium changed, with increased enteral sodium administration observed in patients in the PICU for more than 10 days, the overall sodium intake remained high throughout the PICU admission.

The major source of sodium administration was IV fluid, mainly in the form of maintenance and replacement IV fluid infusions, as well as IV drug infusions, boluses and flushes. This finding is similar to a single-centre study of an adult ICU[16] and one on adult cardiac patients,[26] but has not been previously reported in the PICU population. It is noteworthy that 0.9% sodium chloride was the most common IV infusion fluid used as a vehicle for administration of drugs, as infusions and boluses and for flushing intravascular catheters, and contributed substantially to the high levels of administered sodium in children in this study. There is evidence to suggest that parenteral maintenance solutions with a high sodium concentration may be significantly safer than hypotonic solutions in protecting against acute postoperative hyponatraemia in children. However, in adults, recent studies have shown that excretion of water and sodium is slower after a bolus of 0.9% sodium chloride compared with balanced solutions[27] and may result in reductions in renal blood flow velocity and renal cortical tissue perfusion.[28]

The most commonly used IV fluid in our study was 0.9% sodium chloride. Chloride administration is a recognised cause of normal anion gap acidosis in paediatric intensive care,[29] and implementation of a chloride-restrictive strategy may have less deleterious effects, ie, kidney injury and requirement for dialysis.[30]

Although a portion of the administered sodium is inevitably required for the management of critically ill children, eg, in bolus and maintenance fluids, some of the administered sodium, such as that present in the vehicle used for drug infusion, boluses and intravascular flushes, inadvertently provide more than one-quarter of the administered sodium load, and are largely avoidable. Attention to minimising these inadvertent sources of sodium is a possible target for a sodium restriction strategy.

Fluid balance was also positive in most patients, with 25% of patients in the cohort recorded to be more than 40 mL/kg fluid-positive over the 24-hour study period. Compared with older children, infants younger than 1 year received more sodium/kg bodyweight and had a more positive fluid balance, with 75% of the infants in the cohort recorded to have received more than 80 mL/kg of fluid on the study day. A positive fluid balance in adults and children in the ICU has previously been shown to be associated with poor lung and kidney function,[31-33] delayed return of gastrointestinal function after surgery[34] and an increased risk of death.[10-14,35] Valentine and colleagues have reported that a positive and increasing fluid balance on Day 3 of an ICU stay, in children with acute lung injury in PICUs, was independently associated with fewer ventilator-free days.[36] The adverse effects of a positive fluid balance may be due to extracellular fluid expansion. A positive fluid balance coupled with high sodium administration, as seen in many of the patients in our study, can also potentially lead to cellular dehydration and interstitial oedema in the lungs[18] and the systemic circulation. This is postulated to be a potential mechanism contributing to abnormal neurocognitive effects in patients with lung injury managed with conservative fluid balance.[37]

The serum sodium levels observed in our study are similar to those in studies performed in neonates.[4] The prevalence of observed hypernatraemia is consistent with the literature[38] and has been associated with poor outcomes.[39]

Study limitations

Our data are from a single study day across multiple PICUs in Australia and New Zealand and thus represent a snapshot of current practice. Despite our best efforts (multiple pilot trials) to record all IV and enteral fluids administered, errors in data collection cannot be excluded. We also excluded patients who had free oral intake, as it was difficult to ascertain the sodium content of all oral feeds with the current study design. Despite this, some of the included patients were allowed oral feeds, hence the total administered sodium might be an underestimate. Indications for the prescription of high sodium-containing fluids such as

0.9% sodium chloride were not recorded and they may have been used as a therapeutic modality. Our observations are based on the calculated fluid balance in the study cohort; we did not weigh the patients before and after the study day as this was beyond the scope of our study. In addition, as sodium intake (calculated as volume × concentration for IV and enteral fluids) was the main aim of our study, fluid balance had some advantages over weighing of patients, as it is internally consistent with fluid intake and losses.

Future directions

We show high levels of administered sodium in our cohort of PICU patients. Our results should be confirmed in a longitudinal study in a larger group of patients. Future studies should include measurement of the estimated sodium balance from measured urinary sodium and examine this effect on oxygenation, serum sodium and patient-related outcomes (length of ICU stay and mortality). Similarly, serum chloride and total chloride administration should be measured and the effect on body pH should be examined. Specific subgroups such as children with renal failure and respiratory failure should be examined separately.

As the current level of administered sodium is high, future studies should examine strategies to decrease the amount of sodium administered via inadvertent sources, such as vehicles for drug infusions and drug boluses and flushes for intravascular catheters, and should examine the effect of such strategies on sodium balance and clinical outcomes.

Conclusion

Our study shows high levels of administered sodium and a positive fluid balance in most of a cohort of PICU patients across Australia and New Zealand. The contributions of maintenance and bolus IV fluids (most commonly 0.9% sodium chloride), drug infusions and boluses, including antibiotics, and enteral feeds are significant. Future studies should evaluate the effect of this practice on overall sodium balance and patient outcomes.

Competing interests

None declared.

Author details

Shailesh Bihari, Lecturer,[1] and Intensivist[2]
Marino Festa, Paediatric Intensive Care Specialist[3]
Sandra L Peake, Associate Professor,[4] Adjunct Associate Professor,[5] and Senior Staff Specialist, Department of Intensive Care Medicine[6]
Ian M Seppelt, Senior Staff Specialist,[7] Clinical Lecturer,[8] and Senior Research Fellow[9]
Patricia Williams, Affiliate Lecturer, Discipline of Acute Care,[4] Adjunct Research Fellow, School of Public Health and Preventive Medicine, Department of Epidemiology and Preventive Medicine,[5] and Research Manager[6]
Barry Wilkins, Paediatric Intensive Care Specialist[10]
Andrew Bersten, Professor,[1] and Head of Department[2]

1 Department of Critical Care Medicine, Flinders University, Adelaide, SA, Australia.
2 Department of Intensive Care Medicine, Flinders Medical Centre, Adelaide, SA, Australia.
3 Kids Research Institute, Children's Hospital at Westmead, Sydney, NSW, Australia.
4 School of Medicine, University of Adelaide, Adelaide, SA, Australia.
5 ANZIC Research Centre, Monash University, Melbourne, VIC, Australia.
6 The Queen Elizabeth Hospital, Adelaide, SA, Australia.
7 Department of Intensive Care Medicine, Nepean Hospital, Sydney, NSW, Australia.
8 Sydney Medical School, Nepean, University of Sydney, Sydney, NSW, Australia.
9 George Institute for Global Health, Sydney, NSW, Australia.
10 Children's Hospital at Westmead, Sydney, NSW, Australia.
Correspondence: biharishailesh@gmail.com

References

1 Choong K, Arora S, Cheng J, et al. Hypotonic versus isotonic maintenance fluids after surgery for children: a randomized controlled trial. *Pediatrics* 2011; 128: 857-66.
2 Coulthard MG, Long DA, Ullman AJ, Ware RS. A randomised controlled trial of Hartmann's solution versus half normal saline in postoperative paediatric spinal instrumentation and craniotomy patients. *Arch Dis Child* 2012; 97: 491-6.
3 Moritz ML, Ayus JC. Intravenous fluid management for the acutely ill child. *Curr Opin Pediatr* 2011; 23: 186-93.
4 Balasubramanian K, Kumar P, Saini SS, et al. Isotonic versus hypotonic fluid supplementation in term neonates with severe hyperbilirubinemia – a double blind, randomized, controlled trial. *Acta Paediatr* 2012; 101: 236-41.
5 Jungmann E, Schifferdecker E, Rümelin A, et al. [Plasma renin activity and aldosterone behavior in critically ill patients] [German]. *Klin Wochenschr* 1987; 65: 87-91.
6 Seri I, Kone BC, Gullans SR, et al. Locally formed dopamine inhibits Na+-K+-ATPase activity in rat renal cortical tubule cells. *Am J Physiol* 1988; 255 (4 Pt 2): F666-73.
7 Seri I, Kone BC, Gullans SR, et al. Influence of Na+ intake on dopamine-induced inhibition of renal cortical Na(+)-K(+)-ATPase. *Am J Physiol* 1990; 258 (1 Pt 2): F52-60.
8 Holmes CL, Patel BM, Russell JA, Walley KR. Physiology of vasopressin relevant to management of septic shock. *Chest* 2001; 120: 989-1002.
9 Iwasaki Y, Gaskill MB, Robertson GL. Adaptive resetting of the volume control of vasopressin secretion during sustained hypovolemia. *Am J Physiol* 1995; 268 (2 Pt 2): R349-57.
10 Goldstein SL, Somers MJ, Brophy PD, et al. The Prospective Pediatric Continuous Renal Replacement Therapy (ppCRRT) Registry: design, development and data assessed. *Int J Artif Organs* 2004; 27: 9-14.
11 Symons JM, Chua AN, Somers MJ, et al. Demographic characteristics of pediatric continuous renal replacement therapy: a report of the prospective pediatric continuous renal replacement therapy registry. *Clin J Am Soc Nephrol* 2007; 2: 732-8.

12 Goldstein SL, Somers MJ, Baum MA, et al. Pediatric patients with multi-organ dysfunction syndrome receiving continuous renal replacement therapy. *Kidney Int* 2005; 67: 653-8.
13 Michael M, Kuehnle I, Goldstein SL. Fluid overload and acute renal failure in pediatric stem cell transplant patients. *Pediatr Nephrol* 2004; 19: 91-5.
14 Foland JA, Fortenberry JD, Warshaw BL, et al. Fluid overload before continuous hemofiltration and survival in critically ill children: a retrospective analysis. *Crit Care Med* 2004; 32: 1771-6.
15 Jacob M, Chappell D, Rehm M. The 'third space' – fact or fiction? *Best Pract Res Clin Anaesthesiol* 2009; 23: 145-57.
16 Bihari S, Ou J, Holt AW, Bersten AD. Inadvertent sodium loading in critically ill patients. *Crit Care Resusc* 2012; 14: 33-7.
17 Bihari S, Peake SL, Seppelt I, et al. Sodium administration in critically ill patients in Australia and New Zealand: a multicentre point prevalence study. *Crit Care Resusc* 2013; 15: 294-300.
18 Bihari S, Baldwin CE, Bersten AD. Fluid balance does not predict estimated sodium balance in critically ill mechanically ventilated patients. *Crit Care Resusc* 2013; 15: 89-96.
19 Baghurst PA, Norton L, Slater A; ANZICS Paediatric Study Group. The application of risk-adjusted control charts using the Paediatric Index of Mortality 2 for monitoring paediatric intensive care performance in Australia and New Zealand. *Intensive Care Med* 2008; 34: 1281-8.
20 Vincent JL, Moreno R, Takala J, et al; Working Group on Sepsis-Related Problems of the European Society of Intensive Care Medicine. The SOFA (Sepsis-related Organ Failure Assessment) score to describe organ dysfunction/failure. *Intensive Care Med* 1996; 22: 707-10.
21 Lindner G, Kneidinger N, Holzinger U, et al. Tonicity balance in patients with hypernatremia acquired in the intensive care unit. *Am J Kidney Dis* 2009; 54: 674-9.
22 Asadollahi K, Beeching N, Gill G. Hyponatraemia as a risk factor for hospital mortality. *QJM* 2006; 99: 877-80.
23 Quigley R. Developmental changes in renal function. *Curr Opin Pediatr* 2012; 24: 184-90.
24 Australian and New Zealand Intensive Care Society. Report of the Australian and New Zealand Paediatric Intensive Care Registry. 2010. http://www.anzics.com.au/downloads/doc_download/567-2010-anzpic-registry-annual-report (accessed Sep 2013).
25 National Health and Medical Research Council. Sodium. In: Nutrient reference values for Australia and New Zealand including recommended dietary intakes. Canberra: Commonwealth of Australia, 2006: 229-34. http://www.nrv.gov.au/resources/_files/n35-sodium.pdf (accessed Aug 2013).
26 Tafreshi J, Hoang TM, Grigorian T, et al. Impact of iatrogenic, excessive, nondietary sodium administration in patients with acute heart failure exacerbation on hospital length of stay. *Pharmacotherapy* 2011; 31: 58-61.
27 Reid F, Lobo DN, Williams RN, et al. (Ab)normal saline and physiological Hartmann's solution: a randomized double-blind crossover study. *Clin Sci (Lond)* 2003; 104: 17-24.
28 Chowdhury AH, Cox EF, Francis ST, Lobo DN. A randomized, controlled, double-blind crossover study on the effects of 2-L infusions of 0.9% saline and plasma-lyte® 148 on renal blood flow velocity and renal cortical tissue perfusion in healthy volunteers. *Ann Surg* 2012; 256: 18-24.
29 Taylor D, Durward A, Tibby SM, et al. The influence of hyperchloraemia on acid base interpretation in diabetic ketoacidosis. *Intensive Care Med* 2006; 32: 295-301.
30 Yunos NM, Bellomo R, Hegarty C, et al. Association between a chloride-liberal vs chloride-restrictive intravenous fluid administration strategy and kidney injury in critically ill adults. *JAMA* 2012; 308: 1566-72.
31 National Heart, Lung, and Blood Institute Acute Respiratory Distress Syndrome (ARDS) Clinical Trials Network; Wiedemann HP, Wheeler AP, Bernard GR, et al. Comparison of two fluid-management strategies in acute lung injury. *N Engl J Med* 2006; 354: 2564-75.
32 Arikan AA, Zappitelli M, Goldstein SL, et al. Fluid overload is associated with impaired oxygenation and morbidity in critically ill children. *Pediatr Crit Care Med* 2012; 13: 253-8.
33 Bouchard J, Soroko SB, Chertow GM, et al; Program to Improve Care in Acute Renal Disease (PICARD) Study Group. Fluid accumulation, survival and recovery of kidney function in critically ill patients with acute kidney Injury. *Kidney Int* 2009; 76: 422-7.
34 Lobo DN, Bostock KA, Neal KR, et al. Effect of salt and water balance on recovery of gastrointestinal function after elective colonic resection: a randomised controlled trial. *Lancet* 2002; 359: 1812-8.
35 Boyd JH, Forbes J, Nakada TA, et al. Fluid resuscitation in septic shock: a positive fluid balance and elevated central venous pressure are associated with increased mortality. *Crit Care Med* 2011; 39: 259-65.
36 Valentine SL, Sapru A, Higgerson RA, et al; Pediatric Acute Lung Injury and Sepsis Investigator's (PALISI) Network; Acute Respiratory Distress Syndrome Clinical Research Network (ARDSNet). Fluid balance in critically ill children with acute lung injury. *Crit Care Med* 2012; 40: 2883-9.
37 Mikkelsen ME, Christie JD, Lanken PN, et al. The adult respiratory distress syndrome cognitive outcomes study: long-term neuropsychological function in survivors of acute lung injury. *Am J Respir Crit Care Med* 2012; 185: 1307-15.
38 Forman S, Crofton P, Huang H, et al. The epidemiology of hypernatraemia in hospitalised children in Lothian: a 10-year study showing differences between dehydration, osmoregulatory dysfunction and salt poisoning. *Arch Dis Child* 2012; 97: 502-7.
39 Holliday MA, Segar WE, Friedman A. Reducing errors in fluid therapy management. *Pediatrics* 2003; 111: 424-5. ❑

Appendix. Participating sites and investigators (in Australia unless otherwise stated)

- Children's Hospital at Westmead, NSW: M Festa
- John Hunter Children's Hospital, NSW: P Harrigan, M Hardie
- Princess Margaret Hospital for Children, Perth, WA: S Erickson, J Abe
- Royal Children's Hospital, Brisbane, QLD: A Slater, D Long, S Kendall
- Royal Children's Hospital, Melbourne, VIC: W Butt, C Delzoppo
- Royal Darwin Hospital, Darwin, NT: D Stephens, J Thomas, M Fletcher
- Royal Hobart Hospital, Hobart, TAS: A Turner, D Cooper, R McAllister
- Starship Children's Hospital, Auckland, New Zealand: J Beca, L Segedin, C Sherring, M Rea
- Sydney Children's Hospital, Sydney, NSW: ML Morritt, G Williams, J Young
- Women's and Children's Hospital, Adelaide, SA: M Yung, G Letton