Fluid and sodium balance

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Fluid balance in PICU

Cumulative accumulation of fluid results in fluid overload and if severe, may lead to organ dysfunction.

In critically ill children suffering from sepsis and other shock states, the severity and duration of early fluid accumulation is associated with an increased PICU-mortality.

Early achievement of negative fluid balance in critically ill patients is associated with an increased survival.

Fluid overload is associated with impaired oxygenation and morbidity in critically ill children*

Ayse A. Arikan, MD; Michael Zappitelli, MD, MSc; Stuart L. Goldstein, MD; Amrita Naipaul, NP; Larry S. Jefferson, MD; Laura L. Loftis, MD

Higher peak fluid overload predicted higher peak oxygenation index.

Independent of age, gender and degree of illness (PELOD)
Fluid overload (FO) in patients > 1 year

Adjusted OR was 1.03 (1.01-1.05). Suggesting 3% increase in mortality for each 1% increase in severity of fluid overload. When fluid overload was dichotomized to ≥ 20% and ≤ 20% patients with ≥ 20% fluid overload had an adjusted mortality OR 8.5 (2.8-25.7).

Sutherland et al. American Journal of Kidney disease. 2010
Does fluid bolus therapy (FBT) contribute to FO?

- Fluid overload is independently associated with morbidity and mortality in critically ill patients.
- In severe sepsis/septic shock a median of 52.4% of positive fluid balance on the first, 30.8% on the second and 33.2% on the third study day consisted of FBT.
- Negative effects of fluid overload and tissue edema:
  - Impairing oxygen and metabolite diffusion
  - Impeding capillary blood flow and lymphatic drainage
  - Increasing interstitial pressure
  - Impairing pulmonary gas exchange and reducing lung compliance

Bihari et al. Shock (2013) 40; 28-34
• 3141 African children with febrile disease and hypoperfusion randomized to three groups
  • Bolus Albumin 5% + maintenance fluid
  • Bolus Saline + maintenance fluid
  • Only maintenance fluid
  • Primary endpoint: 48h mortality
Effect of an Early Resuscitation Protocol on In-hospital Mortality Among Adults With Sepsis and Hypotension: A Randomized Clinical Trial

Ben Andrews, MD; Matthew W. Somlar, MD, MSc; Levy Muchamwawa, MBChB; Paul Kelly, MD, FRCP; Shabir Lakhi, MBChB; Douglas C. Haimburger, MD, MS; Chikese Mabula, MBChB; Mwango Bwalya, MBChB; Gordon R. Barnard, MD

Figure 2. Kaplan-Meier Plot of the Probability of Survival Until Day 28 After Enrollment

Vital status was known through study day 28 for 194 patients (94.2%). The median duration of follow-up was 28 days (interquartile range, 28-28 days) in both study groups. Vertical ticks on the curves indicate censoring due to loss to follow-up after hospital discharge.
• FBT beneficial to the patients during resuscitation phase. Especially if given early

• FBT should be limited/avoided during optimisation and stabilisation phases due to a considerable risk of harm.

• Fluid resuscitation should include clear limits and individualized end-points to reduce the risk of excessive fluid administration

• Avoid fluid bolus to non-responders

• Do not give fluid bolus any faster than you need

• Initiate vasopressors and hemodynamic monitoring after > 30 ml/kg fluid resuscitation if hypotension persists while continuing fluid therapy with hemodynamic monitoring.

FBT-negative effects

- Associated with FO
- Increased capillary pressure – faster filtration?
- Degradation of glycocalyx – increased vascular permeability?
Glycocalyx

- Covers the capillary endothelial surface
- Web of membrane-bound glycoproteins, proteoglycans and glucosamnioglycans
- Binds plasmaproteins and fluid – Endothelial surface layer (ESL)

Woodcock et al. BJA (2012) 108; 384-94
Glycocalyx and ESL:

• Barrier preventing leakage of plasma proteins

• Albumin is an important part of the ESL

• Non-circulating part of the intravascular volume

• Is compromised in critical illness, systemic inflammation, diabetes, sepsis, trauma, hypervolemia
The 10-N pediatric anesthesia Quality checklist

1. No fear
2. Normovolemia
3. Normotension
4. Normocardia
5. Normoxemia
6. Normocapnia
7. Normonatremia
8. Normoglycemia
9. Normothermia
10. No pain
Normal fluid losses
(per hour)

<table>
<thead>
<tr>
<th></th>
<th>Preterm</th>
<th>Infant</th>
<th>Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perspiratio insensibilis</td>
<td>2-3 ml/kg</td>
<td>1 ml/kg</td>
<td>0,5 ml/kg</td>
</tr>
<tr>
<td>Diures</td>
<td>2-3 ml/kg</td>
<td>2 ml/kg</td>
<td>1 ml/kg</td>
</tr>
</tbody>
</table>
Fluid turnover (per day)

- Adults: Approximately 20%
- Infants: Approximately 5%
## Fluid requirement: maintenance

<table>
<thead>
<tr>
<th>Weight</th>
<th>Fluid per day</th>
<th>Fluid per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-10 kg</td>
<td>100 ml/kg</td>
<td>4 ml/kg</td>
</tr>
<tr>
<td>10-20 kg</td>
<td>1000 ml + 50 ml</td>
<td>3-4 ml/kg</td>
</tr>
<tr>
<td></td>
<td>for every kg &gt;10</td>
<td></td>
</tr>
<tr>
<td>&gt; 20 kg</td>
<td>1500 ml + 20 ml/kg</td>
<td>2-3 ml/kg</td>
</tr>
<tr>
<td></td>
<td>every kg over 20.</td>
<td></td>
</tr>
</tbody>
</table>

In critically illness during the acute phase: provide 60-70 % of volumes above.
Example ECV losses: difference children/adults

- A 70 kg adult loose 3 litres/day (urine, faeces and perspiratio). Constitutes 20 % of ECV

- The corresponding losses in an infant weighing 7 kg is 0,7 litres/day. This constitutes 40 % of ECV.

- If additional ongoing fluid losses due to diarrhea is present – severe dehydration can develop fast.
Perioperative acute hyponatremia
Hyponatremic encephalopathy (HE)

• Acute hyponatremia results in increased inflow of water from ECV to ICV which leads to cell swelling and possibly cerebral edema and encephalopathy.

• If plasma-\( \text{Na}^+ \) decrease to < 125 mmol/L, there is a considerable risk of development of hyponatremic encephalopathy.
Hyponatremic encephalopathy (HE) cont

- Children have an increased risk of developing HE as compared to adults.

- Large brain relative to skull.

- Adult size of the brain at 6 years of age, whereas the skull reaches adult size at 16 years of age.

- On average, children develop HE at a plasma sodium concentration of 120 mmol/L, at 111 in adults.
Case reports

<table>
<thead>
<tr>
<th>Time (h)</th>
<th>Condition</th>
<th>Treatment</th>
<th>Temperature (°F)</th>
<th>Outcome</th>
</tr>
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<tbody>
<tr>
<td>0.15</td>
<td>Meningitis</td>
<td>0.18% NaCl</td>
<td>137 to 131</td>
<td>Cerebral edema, dilated pupil, 2 deaths</td>
</tr>
<tr>
<td>ND</td>
<td>ND</td>
<td>Hypotonic</td>
<td>&lt;130</td>
<td>Death, cerebral edema</td>
</tr>
<tr>
<td>1.5</td>
<td>Influenza</td>
<td>D&lt;sub&gt;5&lt;/sub&gt; water</td>
<td>120</td>
<td>Death, cerebral edema</td>
</tr>
<tr>
<td>3</td>
<td>Meningitis</td>
<td>D&lt;sub&gt;5&lt;/sub&gt; water</td>
<td>128</td>
<td>Death, cerebral edema</td>
</tr>
<tr>
<td>3</td>
<td>Dehydration</td>
<td>D&lt;sub&gt;5&lt;/sub&gt; water</td>
<td>133 to 114</td>
<td>Death, cerebral edema</td>
</tr>
<tr>
<td>2</td>
<td>Hip surgery</td>
<td>Hypotonic</td>
<td>112</td>
<td>Death, cerebral edema</td>
</tr>
<tr>
<td>4</td>
<td>Gastroenteritis</td>
<td>D&lt;sub&gt;5&lt;/sub&gt; 0.45% NaCl</td>
<td>136 to 118</td>
<td>Respiratory arrest, seizure, cerebral demyelination, Death, cerebral edema, cardiac arrest</td>
</tr>
<tr>
<td>ND</td>
<td>ND</td>
<td>Hypotonic</td>
<td>142–128</td>
<td>Death, cerebral edema, quadriplegia</td>
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<tr>
<td>3.5</td>
<td>Tonsillitis</td>
<td>Hypotonic</td>
<td>139 to 114</td>
<td>Quadriplegia</td>
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<tr>
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<td>Tonsillectomy</td>
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<td>141 to 123</td>
<td>Death</td>
</tr>
<tr>
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<td>Tonsillectomy</td>
<td></td>
<td>139 to 115</td>
<td>Death</td>
</tr>
<tr>
<td>15</td>
<td>Tonsillectomy</td>
<td></td>
<td>141 to 101</td>
<td>Death</td>
</tr>
<tr>
<td>3.5</td>
<td>Tonsillectomy</td>
<td></td>
<td>138 to 121</td>
<td>Death</td>
</tr>
<tr>
<td>12</td>
<td>Fracture setting</td>
<td></td>
<td>137 to 120</td>
<td>Mental retardation</td>
</tr>
<tr>
<td>4</td>
<td>Fracture setting</td>
<td></td>
<td>139 to 118</td>
<td>Death</td>
</tr>
<tr>
<td>3</td>
<td>Tonsillectomy</td>
<td></td>
<td>137 to 113</td>
<td>Death</td>
</tr>
<tr>
<td>1.5</td>
<td>VP shunt</td>
<td></td>
<td>137 to 114</td>
<td>Vegetative</td>
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<tr>
<td>9</td>
<td>Fracture setting</td>
<td></td>
<td>137 to 120</td>
<td>Vegetative</td>
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<tr>
<td>15</td>
<td>Fracture setting</td>
<td></td>
<td>138 to 102</td>
<td>Vegetative</td>
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<tr>
<td>4</td>
<td>Tonsillectomy</td>
<td></td>
<td>138 to 107</td>
<td>Death</td>
</tr>
<tr>
<td>2</td>
<td>Orchiopexy</td>
<td></td>
<td>138 to 116</td>
<td>Death</td>
</tr>
<tr>
<td>6</td>
<td>Nasal packing</td>
<td></td>
<td>138 to 119</td>
<td>Death</td>
</tr>
<tr>
<td>12</td>
<td>Appendectomy</td>
<td></td>
<td>137 to 123</td>
<td>Death</td>
</tr>
<tr>
<td>12</td>
<td>Pneumonia</td>
<td></td>
<td>134 to 116</td>
<td>Vegetative</td>
</tr>
</tbody>
</table>

Arieff et al. BMJ (1992) 304; 1218-22
Acute hyponatremia

Main defence against hyponatremia is the capacity of the kidneys to dilute urine and excrete free water.

If free water is given in excess in parallel with decreased capacity of the kidneys to excrete free water, hyponatremia will ensue.

Arginin vasopressin (AVP) inhibit the kidneys to excrete free water. AVP regulates osmolarity and intravascular volume

SIAD(H)

- Common cause of the development of acute hyponatremia in the perioperative phase.
- Increased secretion of AVP, especially during surgery.
- Desalination (RAAS, ANP, BNP)
Diseases/conditions associated with SIAD

- Perioperative
- Malignancy
- Bronchiolitis, asthma, pneumonia
- Meningitis, encephalitis, head trauma
- Drugs (ADH-analogue, NSAID, chemotherapy, opioids anaesthetic gas).
- Mechanical ventilation
Additional causes for increased for AVP secretion

- Nausea - vomiting
- Pain
How to prevent acute hyponatremia?

- Avoid hypotonic solutions (not newborns before adaptation).
- Never use hypotonic solution for rehydration
- Avoid large volumes (hypervolemia)
- Monitor plasma sodium concentration
A novel isotonic-balanced electrolyte solution with 1% glucose for intraoperative fluid therapy in children: results of a prospective multicentre observational post-authorization safety study (PASS)

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European consensus statement for intraoperative fluid therapy in children
Robert Sümpelmann, Karin Becke, Peter Crean, Martin Jöhr, Per-Arne Lönnqvist, Jochen M. Strauss and Francis Veyckemans
140 mmol/L of sodium versus 77 mmol/L of sodium in maintenance intravenous fluid therapy for children in hospital (PIMS): a randomised controlled double-blind trial

Sarah McNab, Trevor Duke, Mike South, Franz E Babl, Katherine J Lee, Sarah J Arnup, Simon Young, Hannah Turner, Andrew Davidson
Time to hyponatremia
Thank you for your attention!