Fluids and Resuscitation

Post-Graduate Course:
Critical Care for General Surgeons
Institute of Surgery
St. Luke’s Medical Center – Quezon City
Disclosures

• Worked, partnered and received support from all medical nutritional companies when I started in the practice of clinical nutrition (35 years ago) which continues up to today

• Most of these are in the form of educational and travel grants
Presentation

• Question and answer format
• Principles of adequate fluid therapy and resuscitation
Main Reference
Second printing

Philippine
College of
Surgeons

Handbook
of
Critical Care
and
Surgical Nutrition

First Edition
2015

Committee on
Critical Care and Nutrition

PCS Secretariat
4th floor, PCS Building
992 EDSA, Quezon City (near SM North EDSA)
Nos: (632) 928 1083
(632) 927 4973
(632) 927 4974
Cel: 0920 911 9590
0922 863 2521
0917 547 1936
Fluid management basics
Process of adequate fluid delivery

- Assessment of loss
- Assessment of electrolyte and osmolality status
- Appropriate fluids to use
- Access and delivery
  - Central/peripheral
  - Infusion sets
- Fluid balance
  - Accumulated fluid balance
- Reassess management
### Fluid balance at 23°C room temperature

<table>
<thead>
<tr>
<th>Water intake</th>
<th>ml/day</th>
<th>Water loss</th>
<th>ml/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid</td>
<td>1200</td>
<td>Insensible</td>
<td>700</td>
</tr>
<tr>
<td>In Food</td>
<td>1000</td>
<td>Sweat</td>
<td>100</td>
</tr>
<tr>
<td>From food metabolism</td>
<td>300</td>
<td>Feces</td>
<td>200</td>
</tr>
<tr>
<td>Total</td>
<td>2500</td>
<td>Urine</td>
<td>1500</td>
</tr>
</tbody>
</table>

Total: 2500 ml/day

When do we give fluids?

**Volume Depletion with Depleted Extravascular Compartment**

- Acute blood loss
  - Trauma
  - GI bleed
- Gastrointestinal tract losses (diarrhea, vomiting, fistula)
- Decreased fluid intake due to acute medical conditions
- Diabetic ketoacidosis
- Heat exhaustion
- “Dehydration”

P.E. Marik, Handbook of Evidence-Based Critical Care; Springer Science+Business Media, LLC 2010
When do we give fluids?

**Volume Depletion with Expanded Extravascular Compartment**
- Sepsis
- Pancreatitis
- Trauma
- Surgery
- Burns
- Liver failure
- Cardiac failure

There is a huge component of inflammation:
- Interstitial fluid compartment
- Intracellular fluid compartment
## Assessment of losses

<table>
<thead>
<tr>
<th>Variables</th>
<th>Class I</th>
<th>Class II</th>
<th>Class III</th>
<th>Class IV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pulse Rate</strong></td>
<td>&lt;100</td>
<td>100-120</td>
<td>120-140</td>
<td>&gt;140</td>
</tr>
<tr>
<td><strong>Blood Pressure</strong></td>
<td>Normal</td>
<td>Normal</td>
<td>Decreased</td>
<td>Decreased</td>
</tr>
<tr>
<td><strong>Pulse Pressure (SBP-DBP)</strong></td>
<td>Normal or increased</td>
<td>Decreased</td>
<td>Decreased</td>
<td>Decreased</td>
</tr>
<tr>
<td><strong>Respiratory Rate</strong></td>
<td>14-20</td>
<td>20-30</td>
<td>30-40</td>
<td>&gt;35</td>
</tr>
<tr>
<td><strong>Urine Output (ml/hr)</strong></td>
<td>&gt;30</td>
<td>20-30</td>
<td>5-15</td>
<td>Negligible</td>
</tr>
<tr>
<td><strong>CNS/ Mental Status</strong></td>
<td>Slightly anxious</td>
<td>Mildly anxious</td>
<td>Anxious, confused</td>
<td>Confused, lethargic</td>
</tr>
<tr>
<td><strong>Blood Loss (ml)</strong></td>
<td>Up to 750</td>
<td>750-1500</td>
<td>1500-2000</td>
<td>&gt;2000</td>
</tr>
<tr>
<td><strong>Loss (% blood volume)</strong></td>
<td>Up to 15%</td>
<td>15%-30%</td>
<td>30%-40%</td>
<td>&gt;40%</td>
</tr>
<tr>
<td>Example: 70 kg x 8%: 5.6 L</td>
<td>@800 ml</td>
<td>@800-1600 ml</td>
<td>@1600-2200 ml</td>
<td>@&gt;2200 ml</td>
</tr>
</tbody>
</table>

SBP = systolic blood pressure, DBP = diastolic blood pressure

In the resuscitation phase what type and how much fluids will you give?

- Have you reviewed your BLS and ATLS protocols?
- Not ABC, but CAB (=establish perfusion first to reach the microcirculation then oxygenation and the rest follows)
- Ventilation: bag > mask > intubate
- Establish intravenous line when possible (large bore needle) > central line is ideal if possible
- Crystalloids: first line > give as much as 2-3 liters fast (500 ml bolus every 15-20 minutes) | Don’t forget the values in the previous slide
- Colloids: given as blood volume deficits
- Blood: Hb? Hct? what level?
- Medications: inotropes

What to measure during resuscitation?

• Clinical
  • Urine output
  • Heart rate

• Laboratory
  • Urine sodium and osmolarity
  • BUN
  • Lactate

• Arterial pressure measurements:
  • Mean arterial pressure (cerebral and abdominal perfusion pressure)
  • PPV (or SVV)

• Arterial pH, BE, and HCO3
  • Mixed venous oxygen saturation SmvO2 or ScvO2
  • Mixed venous pCO2
  • Tissue pCO2 (sublingual capnometery or equivalent)

• Others:
  • Gastric impedance spectroscopy
  • Skeletal muscle tissue oxygenation StO2 as measured by NIRS
  • Extravascular lung water
  • Intra-abdominal pressure
What to measure during resuscitation?

• **Clinical**
  • Urine output
  • Heart rate

• **Laboratory**
  • Urine sodium and osmolarity
  • BUN
  • Lactate

• Arterial pressure measurements:
  • Mean arterial pressure (cerebral and abdominal perfusion pressure)
  • PPV (or SVV)

• Arterial pH, BE, and HCO3
  • Mixed venous oxygen saturation SmvO2 or ScvO2
  • Mixed venous pCO2
  • Tissue pCO2 (sublingual capnometery or equivalent)

• Others:
  • Gastric impedance spectroscopy
  • Skeletal muscle tissue oxygenation StO2 as measured by NIRS
  • Extravascular lung water
  • **Intra-abdominal pressure**
MAP = Mean Arterial Pressure
CVP = Central Venous Pressure
ScvO2 = central venous oxygen saturation

Goals of resuscitation (within 6 hours):
- CVP 8–12 mm Hg
- MAP ≥ 65 mm Hg
- Urine output ≥ 0.5 mL/kg/hr
- Scvo2 ≥ 70%.
What are the measures of intravascular volume status?

• Static measures of intravascular volume:
  • CVP: Central Venous Pressure
  • PCWP: Pulmonary Capillary Wedge Pressure

• Dynamic measures of intravascular volume:
  • SVV: Stroke Volume Variation
  • PVV: Pulse Pressure Variation
How do we know we are within the normal bounds of fluid delivery?

- Accurate fluid balance record
- Accumulated fluid balance record

- Accurate measurement of input
  - Oral
  - Tube feeds (includes flushing)
  - Intravenous
  - Water from food metabolism

- Accurate measurement of output:
  - Urine
  - Drains
  - Stool
  - Insensible water loss (10 ml/kg/per day: 2/3 skin, 1/3 lungs)
# NUTRIENT AND FLUID BALANCE SHEET

Patient Name ___________________________ File Number ___________ PIN ___________
Age ______ Sex ______ Attending MD ________________________________
Height (meter) ___________ Weight (kg) ___________

## Fluid Intake Record

<table>
<thead>
<tr>
<th>Date</th>
<th>Unit</th>
<th>Oral</th>
<th>Enteral</th>
<th>Tube Flush</th>
<th>Parenteral</th>
<th>IVDex</th>
<th>IVF2</th>
<th>Others</th>
<th>Total Intake</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Fluid Output Record

<table>
<thead>
<tr>
<th>Date</th>
<th>Unit</th>
<th>Urine</th>
<th>Drain1</th>
<th>Drain2</th>
<th>Stool</th>
<th>Insensible</th>
<th>Total Output</th>
<th>Fluid Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
How do we know we are within the normal bounds of fluid delivery?

<table>
<thead>
<tr>
<th>Compartment</th>
<th>% of weight</th>
<th>70 kg patient (Liters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total body fluid 1</td>
<td>60%</td>
<td>42 L = 70 kg x 60%</td>
</tr>
<tr>
<td>ICF 1</td>
<td>40%</td>
<td>28 L = 70 kg x 40%</td>
</tr>
<tr>
<td>ECF 1</td>
<td>20%</td>
<td>14 L = 70 kg x 20%</td>
</tr>
<tr>
<td>Plasma 1</td>
<td>5%</td>
<td>3.5 L = 70 kg x 5%</td>
</tr>
<tr>
<td>Blood volume (BV) 1</td>
<td>8%</td>
<td>5.6 L = 70 kg x 8%</td>
</tr>
<tr>
<td>Interstitial fluid volume (IFV) 2</td>
<td>12%</td>
<td>8.4 L = ECF – BV = 14 L – 5.6 L</td>
</tr>
<tr>
<td>Accumulated fluid balance 2</td>
<td>&lt; 80% IFV</td>
<td>6.7 L = 8.4 L x 80% / or 10% of weight</td>
</tr>
</tbody>
</table>

Fluid management
What crystalloid am I going to give?

<table>
<thead>
<tr>
<th></th>
<th>Plasma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>135-145</td>
</tr>
<tr>
<td>K</td>
<td>3.5-5.3</td>
</tr>
<tr>
<td>Ca</td>
<td>2.2-2.6</td>
</tr>
<tr>
<td>Mg</td>
<td>0.7-1.2</td>
</tr>
<tr>
<td>Cl</td>
<td>95-105</td>
</tr>
<tr>
<td>Bicarb precursor</td>
<td>24-32</td>
</tr>
<tr>
<td>Na:Cl ratio</td>
<td>1.28-1.45:1</td>
</tr>
<tr>
<td>Osmolality</td>
<td>275-295</td>
</tr>
</tbody>
</table>
What crystalloid am I going to give?

<table>
<thead>
<tr>
<th></th>
<th>Plasma</th>
<th>0.9% Saline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>135-145</td>
<td>154</td>
</tr>
<tr>
<td>K</td>
<td>3.5-5.3</td>
<td>-</td>
</tr>
<tr>
<td>Ca</td>
<td>2.2-2.6</td>
<td>-</td>
</tr>
<tr>
<td>Mg</td>
<td>0.7-1.2</td>
<td>-</td>
</tr>
<tr>
<td>Cl</td>
<td>95-105</td>
<td>154</td>
</tr>
<tr>
<td>Bicarb precursor</td>
<td>24-32</td>
<td>-</td>
</tr>
<tr>
<td>Na:Cl ratio</td>
<td>1.28-1.45:1</td>
<td>1:1</td>
</tr>
<tr>
<td>Osmolality</td>
<td>275-295</td>
<td>308</td>
</tr>
</tbody>
</table>
Hyperchloremic acidosis

- Depress myocardial function
  - reduced cardiac output
  - reduce renal and intestinal perfusion
- Altered coagulation: increased bleeding
- Mislead the clinician:
  - to think patient is hypovolemic, or has a surgical cause for their acidosis leading to inappropriate management
  - Further administration of saline-based fluids will exacerbate the condition
- Diagnosis: just check the serum chloride and monitor

What crystalloid am I going to give?

<table>
<thead>
<tr>
<th></th>
<th>Plasma</th>
<th>0.9% Saline</th>
<th>Ringer’s Lactate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>135-145</td>
<td>154</td>
<td>131</td>
</tr>
<tr>
<td>K</td>
<td>3.5-5.3</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Ca</td>
<td>2.2-2.6</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Mg</td>
<td>0.7-1.2</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Cl</td>
<td>95-105</td>
<td>154</td>
<td>111</td>
</tr>
<tr>
<td>Bicarb precursor</td>
<td>24-32</td>
<td>-</td>
<td>Lactate 29</td>
</tr>
<tr>
<td>Na:Cl ratio</td>
<td>1.28-1.45:1</td>
<td>1:1</td>
<td>1.18:1</td>
</tr>
<tr>
<td>Osmolality</td>
<td>275-295</td>
<td>308</td>
<td>276</td>
</tr>
</tbody>
</table>

- Hypotonic
- Hyponatremia
- Hypomagnesemia
What crystalloid am I going to give?

<table>
<thead>
<tr>
<th></th>
<th>Plasma</th>
<th>0.9% Saline</th>
<th>Ringer’s Lactate</th>
<th>Sterofundin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>135-145</td>
<td>154</td>
<td>131</td>
<td>140</td>
</tr>
<tr>
<td>K</td>
<td>3.5-5.3</td>
<td>-</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Ca</td>
<td>2.2-2.6</td>
<td>-</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Mg</td>
<td>0.7-1.2</td>
<td>-</td>
<td>0</td>
<td>1.5</td>
</tr>
<tr>
<td>Cl</td>
<td>95-105</td>
<td>154</td>
<td>111</td>
<td>98</td>
</tr>
<tr>
<td>Bicarb precursor</td>
<td>24-32</td>
<td>-</td>
<td>Lactate 29</td>
<td>Acetate 27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gluconate 23</td>
</tr>
<tr>
<td>Na:Cl ratio</td>
<td>1.28-1.45:1</td>
<td>1:1</td>
<td>1.18:1</td>
<td>1.43:1</td>
</tr>
<tr>
<td>Osmolality</td>
<td>275-295</td>
<td>308</td>
<td>276</td>
<td>294</td>
</tr>
</tbody>
</table>

• Balanced electrolyte solution

When you add dextrose to all of the above > HYPO-OSMOLAR
Why hypo-osmolar?

GLUT4 cells (skeletal and fat tissues) 2/3 of all cells of the body
How to compute for plasma osmolality

Osmolality = $2 \times [\text{Na}] + \frac{[\text{glucose}]}{18} + \frac{[\text{BUN}]}{2.8}$

Na = 140 mmol/L  
Glucose = 110 mg/dL  
BUN = 20 mg/dL

Osmolality = $(2 \times 140) + \left(\frac{110}{18}\right) + \left(\frac{20}{2.8}\right)$

Osmolality = 280 + 6.1 + 7.1

Osmolality = 293.2 mmol/L
Increasing blood volume by 1 liter

IVFV | ECFV | ICFV
---|---|---
5L | 12L | 30L

9.4L D5W

5L 0.9% NaCl

1L 6% HES

Capillary membrane

Cell membrane

CEREBRAL EDEMA

## Effect of excessive use of crystalloids

<table>
<thead>
<tr>
<th>Trauma patients</th>
<th>7L/24h</th>
<th>13L/24h</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAH (intra-abdominal hypertension: IAP ≥ 12 mmHg)</td>
<td></td>
<td>2x in 42%</td>
</tr>
<tr>
<td>ACS (abdominal compartment syndrome: IAP &gt; 20 mmHg)</td>
<td></td>
<td>2x in 16%</td>
</tr>
<tr>
<td>MOF (multiple organ failure)</td>
<td></td>
<td>2x in 22%</td>
</tr>
<tr>
<td>Mortality</td>
<td></td>
<td>11%  27%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Medical patients</th>
<th>6.9L mean (+) fluid balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAH (intra-abdominal hypertension)</td>
<td>85%</td>
</tr>
<tr>
<td>ACS (abdominal compartment syndrome)</td>
<td>25%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Burn patients (30% surface area)</th>
<th>Survived</th>
<th>Dead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume infused during treatment</td>
<td>45 L</td>
<td>61 L</td>
</tr>
</tbody>
</table>

IAP = Intra-Abdominal Pressure; normal = 5-7 mmHg

How to measure intra-abdominal pressure
# Colloids

<table>
<thead>
<tr>
<th>Electrolytes</th>
<th>Plasma</th>
<th>Tetraspan 6%</th>
<th>HES in 0.9% saline</th>
<th>Albumin 5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na (mmo/L)</td>
<td>142</td>
<td>140</td>
<td>154</td>
<td>130-160</td>
</tr>
<tr>
<td>K (mmo/L)</td>
<td>4.5</td>
<td>4</td>
<td>-</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>Ca (mmo/L)</td>
<td>2.5</td>
<td>2.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mg (mmo/L)</td>
<td>0.85</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cl (mmo/L)</td>
<td>103</td>
<td>118</td>
<td>154</td>
<td>-</td>
</tr>
<tr>
<td>HCO3 (mmo/L)</td>
<td>24</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lactate (mmo/L)</td>
<td>1.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Acetate (mmo/L)</td>
<td>-</td>
<td>24</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Colloid (g/L)</td>
<td>Albumin = 30-52</td>
<td>Starch = 60</td>
<td>Starch = 60</td>
<td>Albumin = 50</td>
</tr>
</tbody>
</table>

Blood

• Hemoglobin in Critical Illness

“RESTRICTIVE” TRANSFUSION POLICY
(NEJM 1999)

Hb = 7-9 g/dL

LOWER MORTALITY

(Hb = 10-12 g/dL)
Restrictive policy (Hb: 7-9) vs. liberal policy (Hb: 10-12)

30 day mortality rate
- APACHE < 20: 8.7% vs. 16.1%
- <55y/o: 5.7% vs. 13%
- During hospitalization: 22% vs. 28%, p < 0.05

Conclusions
A restrictive strategy of red-cell transfusion is at least as effective as and possibly superior to a liberal transfusion strategy in critically ill patients, with the possible exception of patients with acute myocardial infarction and unstable angina.

Blood

- Hemoglobin in Critical Illness

  “RESTRICTIVE” TRANSFUSION POLICY
  (NEJM 1999)

  \[ Hb = 7-9 \text{ g/dL} \]

  LOWER MORTALITY

  \( (Hb = 10-12 \text{ g/dL}) \)

- Massive Blood Transfusion Protocol: 8-10 units of blood delivered within 12 hours
Surgery
What are the fluid dynamics during surgery?

<table>
<thead>
<tr>
<th>Fluid Loss</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Insensible perspiration</td>
<td>• 10 ml/kg/day - 2/3 skin, 1/3 lungs <strong>(700 ml)</strong></td>
</tr>
<tr>
<td></td>
<td>• Ventilation with 100% water = almost zero loss</td>
</tr>
<tr>
<td></td>
<td>• Ventilation in dry air = 0.5 ml/kg/day</td>
</tr>
<tr>
<td>Evaporative loss</td>
<td>• minor incisions with slightly exposed but non-exteriorised viscera = 2 ml/hour</td>
</tr>
<tr>
<td></td>
<td>• moderate incisions with partly exposed but non-exteriorised viscera = 8 ml/hour</td>
</tr>
<tr>
<td></td>
<td>• major incisions with completely exposed and exteriorised viscera = 32 ml/hour <strong>(120 ml in 3-4 hrs)</strong></td>
</tr>
<tr>
<td></td>
<td>• Loss from completely exteriorised viscera decreases by 50% after 20 minutes</td>
</tr>
<tr>
<td></td>
<td>• Wrapping the exteriorised viscera in plastic reduces the evaporation loss by 87.5%.</td>
</tr>
</tbody>
</table>

What are the fluid dynamics during surgery?

## Fluid Loss

<table>
<thead>
<tr>
<th>Third space loss:</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) pathological fluid accumulations</td>
</tr>
<tr>
<td>• 2.5–5 mL may accumulate around a large bowel anastomosis if no fluid is administered <em>(5 ml)</em></td>
</tr>
<tr>
<td>• 5–10 mL may accumulate if 15 mL/kg/hour fluid is given;</td>
</tr>
<tr>
<td>• Edematous entire colon, the accumulation would be 150–300 mL, depending on the volume/type of IVF <em>(300)</em></td>
</tr>
<tr>
<td>b) non-anatomical third space loss</td>
</tr>
<tr>
<td>• Volumes up to 15 mL/kg/hour are recommended in the first hour of abdominal surgery, with decreasing volumes in subsequent hours. <em>(1L first hr then + 1L 2-3hrs)</em></td>
</tr>
</tbody>
</table>

Total Water Loss = 120+305+1000+1000 = 2.3L in 2-3h

What is the usual practice of fluid management?

• Average perioperative fluid infusion:
  • Intra-op = 3.5 to 7 liters
  • 3 liters/day for the next 3 to 4 days
  • Average gain post-op = 3 to 6 kg weight gain (4%-8% in a 70 kg patient)

• Do we have local data on the usual fluids (type and volume) delivered during surgery?

Fluid overload and mortality

• Overload criteria: > 10% weight gain from pre-admission weight

• Weight gain and mortality:
  • 5% weight gain -> 10% mortality
  • 15% weight gain -> 20% mortality
  • 32% weight gain -> 100% mortality

The effect of fluid overload

<table>
<thead>
<tr>
<th></th>
<th>Restricted Group (n=69)</th>
<th>Standard Group (n=72)</th>
<th>$\rho$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overall complications</strong></td>
<td>21</td>
<td>40</td>
<td>0.003</td>
</tr>
<tr>
<td><strong>Major complications</strong></td>
<td>8</td>
<td>18</td>
<td>0.040</td>
</tr>
<tr>
<td><strong>Minor complications</strong></td>
<td>15</td>
<td>36</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Tissue-healing complications</strong></td>
<td>11</td>
<td>22</td>
<td>0.040</td>
</tr>
<tr>
<td><strong>Cardiopulmonary complications</strong></td>
<td>11</td>
<td>22</td>
<td>0.007</td>
</tr>
<tr>
<td><strong>Deaths</strong></td>
<td>0</td>
<td>4</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Plasma protein changes after injury

• The transcapillary escape rate of albumin from the circulation into the interstitial space increases from 5 to 15%/hr after major surgery and may take up to 10 days to return to normal (effect of inflammatory status post-injury on the microcirculation)

• Sepsis and other complications may prolong this period

• This, and the vasodilatory effects of anaesthetic agents which increase the intravascular volume requirement (i.e. decrease the effective circulatory volume), have important therapeutic implications
The effect of surgery, anesthesia and hypotonic fluids

INJURY = SURGERY

- Inflammatory mediators
  - $\uparrow$K+ release from cells
  - $\downarrow$K+ and $\uparrow$ Na intracellular
  - Sick cell syndrome of critical illness

- $\uparrow$VASODILATION EFFECT OF ANESTHETIC AGENTS
  - $\uparrow$Albumin escape from intravascular space

- $\uparrow$HYPTONIC FLUID INFUSION
  - 90% cause of hyponatremia in surgery

Fluid Retention + Electrolyte Imbalance

The effect of water and salt overload

Salt and water overload

↑ intra-abdominal pressure

↓ mesentery blood flow

STAT3 activation
↓ myosin phosphorylation

↓ muscle contractility

ILEUS

Intestinal edema

↓ tissue OH-proline

Intramucosal acidosis

Impaired wound healing

DEHISCENCE

### Key factors to be checked pre/post surgery

<table>
<thead>
<tr>
<th>Factor</th>
<th>Assessment data</th>
<th>To do</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severely malnourished</td>
<td>Modified SGA “C”</td>
<td>Correct malnutrition</td>
</tr>
<tr>
<td>Oncotic pressure</td>
<td>Albumin &lt; 3</td>
<td>Need to infuse albumin? Colloid?</td>
</tr>
<tr>
<td>Pulmonary capillary pressure</td>
<td>• &gt;12 mm Hg</td>
<td>Anti-inflammatory, antibiotics, immunonutrition (fish oils, glutamine)</td>
</tr>
<tr>
<td></td>
<td>• Inflammatory condition of the lung</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cardiac and/or renal causes</td>
<td>c/o cardiologist/nephrologist</td>
</tr>
<tr>
<td>Electrolyte status</td>
<td>Low normal to hypo levels</td>
<td>Correct; avoid D5W &gt; “refeeding syndrome”</td>
</tr>
<tr>
<td>Lymphatic flow</td>
<td>Inflammatory conditions involving lymphatic flow (sepsis, critical care, tumor obstruction)</td>
<td>Critical care management Oncologist</td>
</tr>
<tr>
<td>Fluid infusion</td>
<td>80%-84% of computed plasma volume</td>
<td>Protocol on fluid infusion e.g. maximum 24 h net volume; infusion rate/h</td>
</tr>
<tr>
<td>Type of fluid infused (=crystalloid)</td>
<td>0.9% NaCl?, lactated Ringer’s?</td>
<td>Balanced electrolyte solution</td>
</tr>
</tbody>
</table>
Early Recovery After Surgery

• Pre-operative phase
  • Nutrition build-up (if needed)
  • Carbohydrate loading 2 hours before surgery

• Intra-operative phase
  • Epidural anesthesia (early mobility and ↓ inflammatory response)
  • Zero to almost none fluid balance

• Post-operative phase
  • Oral feeding as early as 24 hours
  • Good pain control
  • Early mobilization
  • Restricted and appropriate fluid management
  • Adequate intake
Effect of fluid overloading and use of saline

Slower gastric emptying and bowel movements

Passage of gas: 2 days faster; stools: 3 days faster

Lobo D, Lancet 2002: 359; 1812-1818
Critical Care
What are the conditions for fluid management?

**Volume Depletion with Expanded Extravascular Compartment**

- Sepsis
- Pancreatitis
- Trauma
- Surgery
- Burns
- Liver failure
- Cardiac failure

There is a huge component of inflammation:

- Interstitial fluid compartment
- Intracellular fluid compartment
Factors inducing intercellular edema

PULMONARY/GUT EDEMA

1. Oncotic pressure
   Albumin level < 3
2. Pulmonary capillary pressure
   > 12 mm Hg
3. Lymphatic flow
   < 2L/day flow
4. Fluid infusion volume

Why lungs and gut only?

• Skeletal muscle contraction keeps the lymphatic fluid flow in the muscle tissues normal thus maintaining normal interstitial fluid volume in these areas
• This mechanism is minimally present in the lungs and gut
The major factor that influences rapid pulmonary edema development is **colloid oncotic pressure**.

---

**Interrelationship between oncotic pressure, pulmonary capillary pressure and infusion volume in the development of pulmonary edema**

<table>
<thead>
<tr>
<th>Pulmonary capillary pressure</th>
<th>Colloid oncotic pressure</th>
<th>Development of pulmonary edema</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 25 mm Hg</td>
<td>Normal</td>
<td>Within 30 – 180 minutes</td>
</tr>
<tr>
<td>12 mm Hg</td>
<td>Reduced by 1/2</td>
<td>Immediate</td>
</tr>
</tbody>
</table>

Saline, colloid and free water resuscitation on development of pulmonary edema

<table>
<thead>
<tr>
<th>Fluid type</th>
<th>Mean volume</th>
<th>COP mm Hg</th>
<th>PCP mm Hg</th>
<th>COP-PCP difference</th>
<th>% edema</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 0.9% NaCl (crystalloid)</td>
<td>8.6L</td>
<td>14.7</td>
<td>12.7</td>
<td>2 mm Hg</td>
<td>88%</td>
</tr>
<tr>
<td>1 HES (colloid)</td>
<td>5.2L</td>
<td>23.5</td>
<td>16.8</td>
<td>6.7 mm Hg</td>
<td>22%</td>
</tr>
<tr>
<td>2 RL (crystalloid)</td>
<td>8.4L</td>
<td>12</td>
<td>6</td>
<td>6 mm Hg</td>
<td>0%</td>
</tr>
</tbody>
</table>

Two major factors that hasten development of pulmonary edema:
- **Drop in colloid oncotic pressure** > narrow colloid oncotic pressure and pulmonary capillary pressure difference
- **Presence of sodium chloride in the infused solution**

Albumin

Liver: the only organ that synthesizes albumin

Synthesis

13.6 g day\(^{-1}\)

(3.8\% day\(^{-1}\))

Intravascular

118 g

45%

Loss

13.3 g day\(^{-1}\)

(3.7\% day\(^{-1}\))

Albumin synthesis:

Synthesis rate = 12-25 g/day

The liver can only increase albumin synthesis rate 2-2x above normal

300\% in sepsis

Trans-Capillary Exchange Rate

TCER

4.5\% day\(^{-1}\)

lymphatics

Extravascular

55%

242 g

Exchangeable

177 g

Remote

65 g

Loss

0.3 g day\(^{-1}\)


Fig 4 Typical albumin distribution in a healthy 70 kg adult.
Albumin

In critical illness, the albumin level lowers, and it will only go back to normal when recovery starts.

The role of albumin in critical illness

<table>
<thead>
<tr>
<th>Organ</th>
<th>Fraction of extracellular albumin (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin</td>
<td>40</td>
</tr>
<tr>
<td>Muscle</td>
<td>40</td>
</tr>
<tr>
<td>Gut</td>
<td>40</td>
</tr>
<tr>
<td>Liver</td>
<td>4.1</td>
</tr>
<tr>
<td>Subcutaneous, etc.</td>
<td>8</td>
</tr>
</tbody>
</table>

Prognostic value of albumin: estimated increase in the odds of death from 24%-56% for each 2.5 g litre⁻¹ decrease in serum albumin concentration.
Suggested steps

• Fluid delivery
  • When albumin is low, decide when to give albumin infusion
    • This is needed in pre-/post-operative critical care patients
  • Recommended fluid replacement = balanced electrolyte solutions
  • Correct electrolyte abnormalities

• Fluid balance
  • Should be “zero” or minimum
  • Replace only what is lost
  • Edema will occur if 24h fluid balance exceeds 80% of the intravascular plasma volume or 195 ml/hr fluid delivery (or >80% of interstitial fluid volume)
Suggested steps

• In conditions where the pulmonary capillary pressure is elevated (e.g. pneumonia, inflammatory state, sepsis, congestive heart failure, renal failure)
  • Improve oncotic pressure by giving:
    • Adequate nutrition (= BCAA, protein or lean body mass build-up boosters: HMB)
    • Albumin (=2 g/dL)
    • Other colloids
  • Immunonutrition (fish oils, glutamine, antioxidants) > reduce the inflammatory load

• Monitoring:
  • Always monitor fluid, electrolyte and acid base status (strict)
  • Get patient’s weight regularly if possible (Ferenczi et al. Int J Surg 2007; 5: 408-12)
Thank You