Fluid Management with CRRT

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Fluid Management with CRRT

Fluid management

Goals

Circuit integrity
- Anticoagulation
  - None
  - Citrate
  - UF heparin
  - LMWH
  - Other
- Filtration fraction

Plasma composition
- Type of fluid
- Content
- Site of administration

Fluid balance
- Removal
- Regulation

Precision CRRT to achieve homeostasis

Monitoring
Practical Issues with Fluid Management for CRRT

- Maintaining the Circuit
- Enabling solute clearances and achieving homeostasis
- Volume control and balance with fluid regulation
- Monitoring for and preventing complications
Hydraulic Circuit for PrismaFlex: Sites for Fluid Administration

External Pumps
- Circuit related
- Non-Circuit

Integrated Pumps
Fluid Delivery in CRRT

Circuit related

- Anticoagulant
  - Saline, Heparin, Citrate, Other

- Substitution fluid
  - Pre-filter Dilution
  - Post-Filter Replacement

- Dialysate

Non-Circuit

- IV
  - Calcium (if Citrate)
  - Maintenance Electrolytes and salts, Base, Blood products; Medications, nutrition

- NG or PEG

Amount and Composition of each of these fluids can be varied to achieve homeostasis
Maintaining the CRRT circuit is crucial for delivering CRRT effectively

- Catheter
- Filter
- Lines
Maintaining the Circuit: Access Issues

- Catheter characteristics
- Placement position
- Dysfunction
  - Clots
  - Kinks
  - Infection
  - Fibrin sheath
KDIGO Guidelines for Vascular Access

- 5.4.1 – Use a non-tunneled temp HD catheter in AKI.

- 5.4.2 – Preferred Insertion Sites: RIJ – Femoral – LIJ – SC

  - Catheter Length

    \[
    \begin{align*}
    \text{RIJ} & : 12-15 \text{ cm} \\
    \text{LJ} & : 15-20 \\
    \text{Fem} & : 19 - 24
    \end{align*}
    \]

- 5.4.3 – Recommendation: Ultrasound guided placement – Maximum barrier precautions – Chlorhexidine (2%) skin antiseptic

- 5.4.4 – Recommendation: Confirm placement of chest catheters with CXR.

- 5.4.5 – We suggest NOT using topical antibiotics over the skin insertion site of a nontunneled HD catheter in ICU patients.

- 5.4.6 – We suggest NOT using antibiotic locks for prevention of Catheter-related infections of nontunneled HD catheters.
Maintaining the Circuit: Filter Integrity

- Catheter
- Filter
  - Down time due to filter clotting is the major reason for reduced RRT dose
Anticoagulation for Extracorporeal Therapies

Scanning electron micrographs of the inner surface of a polysulfone hollow fiber dialyzer membrane during hemodialysis therapy.

LMW Heparin

Scanning electron micrographs of the inner surface of a polysulfone hollow fiber dialyzer membrane during hemodialysis therapy.
Why Citrate?

Citrate and Bleeding

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>citrate Events</th>
<th>citrate Total</th>
<th>control Events</th>
<th>control Total</th>
<th>Weight</th>
<th>Risk Ratio M-H, Fixed, 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Betjes MG 2007</td>
<td>0</td>
<td>21</td>
<td>10</td>
<td>27</td>
<td>19.6%</td>
<td>0.06 [0.00, 0.98]</td>
</tr>
<tr>
<td>Fealy N 2007</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>Not estimable</td>
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</tr>
<tr>
<td>Hetzel GR 2011</td>
<td>5</td>
<td>87</td>
<td>12</td>
<td>83</td>
<td>26.0%</td>
<td>0.40 [0.15, 1.08]</td>
</tr>
<tr>
<td>Kutsogiannis DJ 2005</td>
<td>1</td>
<td>16</td>
<td>8</td>
<td>14</td>
<td>18.1%</td>
<td>0.11 [0.02, 0.77]</td>
</tr>
<tr>
<td>Monchi M 2004</td>
<td>0</td>
<td>25</td>
<td>1</td>
<td>23</td>
<td>3.4%</td>
<td>0.30 [0.01, 6.94]</td>
</tr>
<tr>
<td>Oudemans-van Straaten HM 2009</td>
<td>6</td>
<td>97</td>
<td>16</td>
<td>103</td>
<td>32.9%</td>
<td>0.40 [0.15, 0.98]</td>
</tr>
<tr>
<td>Total (95% CI)</td>
<td>257</td>
<td>260</td>
<td>100.0%</td>
<td></td>
<td></td>
<td>0.28 [0.15, 0.50]</td>
</tr>
</tbody>
</table>

Total events: 47
Heterogeneity: Chi² = 3.16, df = 4 (P = 0.53); I² = 0%
Test for overall effect: Z = 4.27 (P < 0.00001)

Citrate and Circuit Patency

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>citrate Mean</th>
<th>citrate SD</th>
<th>Total</th>
<th>control Mean</th>
<th>control SD</th>
<th>Total</th>
<th>Weight</th>
<th>Mean Difference IV, Random, 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Betjes MG 2007</td>
<td>39</td>
<td>15.7</td>
<td>70</td>
<td>42.3</td>
<td>13.6</td>
<td>72</td>
<td>16.8%</td>
<td>-3.30 [-8.14, 1.54]</td>
</tr>
<tr>
<td>Fealy N 2007</td>
<td>16.3</td>
<td>2.4</td>
<td>10</td>
<td>16.3</td>
<td>6.3</td>
<td>10</td>
<td>16.8%</td>
<td>0.30 [-3.88, 4.48]</td>
</tr>
<tr>
<td>Hetzel GR 2011</td>
<td>37.5</td>
<td>23</td>
<td>87</td>
<td>26.1</td>
<td>19</td>
<td>81</td>
<td>16.7%</td>
<td>11.40 [5.04, 17.76]</td>
</tr>
<tr>
<td>Kutsogiannis DJ 2005</td>
<td>125.5</td>
<td>16.8</td>
<td>36</td>
<td>40.9</td>
<td>9.9</td>
<td>43</td>
<td>16.7%</td>
<td>84.60 [78.37, 90.83]</td>
</tr>
<tr>
<td>Monchi M 2004</td>
<td>81.4</td>
<td>27</td>
<td>26</td>
<td>36.1</td>
<td>8.9</td>
<td>23</td>
<td>16.2%</td>
<td>45.30 [34.30, 56.30]</td>
</tr>
<tr>
<td>Oudemans-van Straaten HM 2009</td>
<td>28.5</td>
<td>8.8</td>
<td>97</td>
<td>27.5</td>
<td>7.2</td>
<td>103</td>
<td>16.9%</td>
<td>1.00 [-1.24, 3.24]</td>
</tr>
<tr>
<td>Total (95% CI)</td>
<td>326</td>
<td>332</td>
<td>100.0%</td>
<td>23.03</td>
<td>[0.45, 45.61]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Heterogeneity: Tau² = 785.58; Chi² = 696.77, df = 5 (P < 0.00001); I² = 99%
Test for overall effect: Z = 2.00 (P = 0.05)
## Recent RCTS for Citrate vs Heparin

<table>
<thead>
<tr>
<th></th>
<th>Shilder et al</th>
<th>Gattas et al</th>
<th>Stucker et al</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year</strong></td>
<td>2014</td>
<td>2015</td>
<td>2015</td>
</tr>
<tr>
<td><strong>Center</strong></td>
<td>Multi</td>
<td>Multi</td>
<td>Single</td>
</tr>
<tr>
<td><strong>No. of patients</strong></td>
<td>C: 66  H: 73</td>
<td>C: 105  H: 107</td>
<td>C: 54  H: 49</td>
</tr>
<tr>
<td><strong>Treatment</strong></td>
<td>Citrate vs. UFH</td>
<td>Citrate vs. heparin/protamine</td>
<td>Citrate vs. UFH</td>
</tr>
<tr>
<td><strong>Circuit lifespan (hrs)</strong></td>
<td>C: 46 (p = 0.02)  H: 32</td>
<td>C: 39.2 (p = 0.004)  H: 22.8</td>
<td>C: 49 (p = 0.004)  H: 28</td>
</tr>
<tr>
<td><strong>Bleeding / Adverse events</strong></td>
<td>C: 0% (p &lt; 0.001)  H:33%</td>
<td>C: 2 (p = 0.011)  H: 11</td>
<td>C: 0  H: 8%</td>
</tr>
<tr>
<td><strong>Metabolic alkalosis (%)</strong></td>
<td>C: 2  H: 0</td>
<td>NR</td>
<td>C: 6  H: 0</td>
</tr>
<tr>
<td><strong>Hypocalcemia</strong></td>
<td>C: 12% (iCa &lt;0.9 mmol/L)  H: NR</td>
<td>NR</td>
<td>C: 11% (severe)  H: 2%</td>
</tr>
<tr>
<td><strong>Mortality</strong></td>
<td>No difference</td>
<td>No difference</td>
<td>No difference</td>
</tr>
</tbody>
</table>
Maintaining the Circuit: Filter Integrity

- **Catheter**
- **Filter**
  - Down time due to *filter clotting* is the major reason for reduced RRT dose
  - *Concentration polarization* reduces ultrafiltration rate and the filtrate concentrations of several medium / large sized proteins
Mechanisms of Blood Membrane Interactions in Dialysis

Modified from Ronco et al NDT 1998, 13
### Reasons for Discontinuing CRRT and Filter efficacy

#### Table 3. Reasons for stopping CRRT

<table>
<thead>
<tr>
<th>Reasons</th>
<th>Number of Filters</th>
<th>Percentage (%)</th>
<th>FUN/BUN Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factors affecting treatment time without affecting filter function</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D/C for surgical procedures</td>
<td>10</td>
<td>6.3</td>
<td>0.93 (0.92 to 0.99)</td>
</tr>
<tr>
<td>D/C for medical procedures</td>
<td>9</td>
<td>5.7</td>
<td>1.0 (0.95 to 1)</td>
</tr>
<tr>
<td>routine filter changes</td>
<td>16</td>
<td>10.1</td>
<td>0.95 (0.84 to 1.0)</td>
</tr>
<tr>
<td>machine problems</td>
<td>8</td>
<td>5.0</td>
<td>0.97 (0.85 to 1.0)</td>
</tr>
<tr>
<td>transition to IHD</td>
<td>17</td>
<td>10.7</td>
<td>0.96 (0.82 to 0.97)</td>
</tr>
<tr>
<td>venous access clot</td>
<td>6</td>
<td>3.8</td>
<td>0.97 (0.96 to 0.98)</td>
</tr>
<tr>
<td>physician decision</td>
<td>10</td>
<td>6.3</td>
<td>0.98 (0.94 to 1)</td>
</tr>
<tr>
<td>patient or family decision</td>
<td>11</td>
<td>6.9</td>
<td>0.96 (0.94 to 1)</td>
</tr>
<tr>
<td>patient recovery</td>
<td>6</td>
<td>3.8</td>
<td>0.95 (0.92 to 0.99)</td>
</tr>
<tr>
<td>death</td>
<td>3</td>
<td>1.9</td>
<td>0.98 (0.87 to 1.0)</td>
</tr>
<tr>
<td>access change</td>
<td>9</td>
<td>5.7</td>
<td>0.9 (0.87 to 0.95)</td>
</tr>
<tr>
<td>Factors affecting filter function</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>filter clotted</td>
<td>41</td>
<td>25.8</td>
<td>0.89 (0.83 to 0.94)</td>
</tr>
<tr>
<td>filter leak</td>
<td>1</td>
<td>0.63</td>
<td>0.745</td>
</tr>
<tr>
<td>low-sieving concentration polarization</td>
<td>12</td>
<td>7.5</td>
<td>0.86 (0.79 to 1.0)</td>
</tr>
</tbody>
</table>

Claure-Del Granado et al. CJASN, 2011
Dialysis or Blood side Measurements for Dialysis Dose Determination in Continuous Renal Replacement Therapies?

Rolando Claure-Del Granado, MD1, Etienne Macedo, MD1, Sharon Soroko, MS1, Glenn M. Chertow, MD, MPH2, Jonathan Himmelfarb, MD3, T. Alp Ikizler, MD4, Emil P. Paganini, MD5, Ravindra L Mehta, MD1

Program to Improve Care in Acute Renal Disease (PICARD) study

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**Normal filter function**

**Compromised filter function**

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**Time effect**

**Filter efficacy effect**

**Filter duration effect**

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Dialysis or Blood side Measurements for Dialysis Dose Determination in Continuous Renal Replacement Therapies?

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Program to Improve Care in Acute Renal Disease (PICARD) study
Maintaining the Circuit

- **Catheter performance**

- **Filter (CRRT) performance**
  - Down time due to *filter clotting* is the major reason for reduced CRRT dose
  - *Concentration polarization* reduces ultrafiltration rate and the filtrate concentrations of various medium / large sized proteins
  - *High filtration fraction* (high UF + low QB OR post dilution) is associated with both of above
  - Pre-dilution versus post-dilution
Fluid Management in Continuous Renal Replacement Therapy

Pre-Filter vs Post-Filter Replacement Fluid

Modality: CVVH with UFR 1L/hr
Fluid Management in Continuous Renal Replacement Therapy

Pre-Filter vs Post-Filter Replacement Fluid

Modality: CVVH with UFR 1L/hr

Replacement 17 ml/min
Pre-filter
Pre-Pump
BFR 83 ml/min

Blood Pump
BFR 100 ml/min
Hct= 25

Hemofilter

Post-Filter
BFR 100 ml/min
Hct= 31

Ultrafiltrate
17 ml/min
Fluid Management in Continuous Renal Replacement Therapy

Pre-Filter vs Post-Filter Replacement Fluid

Modality: CVVH with UFR 1L/hr

Replacement 17 ml/min

Pre-filter
Post-Pump
BFR 117 ml/min

Blood Pump
BFR 100 ml/min

Hct= 26

Hemofilter

Hct= 31

Ultrafiltrate

17 ml/min

Post-Filter

BFR 100 ml/min

17 ml/min
Pre-Dilution vs Post-Dilution CVVH

Filtration fraction (FF) = ultrafiltration rate/plasma water flow rate

- FF values > 0.20 undesirable due to hemoconcentration-related effects on filter performance
  - major limitation of post-dilution CVVH
  - dependent on blood flow rate ($Q_B$) and hematocrit ($Hct$)
# Fluid Management in CRRT

## Pre-Filter vs Post-Filter Replacement Fluid

<table>
<thead>
<tr>
<th>Modality</th>
<th>Fluid Location</th>
<th>BFR (ml/min)</th>
<th>PF (ml/min)</th>
<th>UF (ml/min)</th>
<th>FF (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVVH 1L/hr</td>
<td>Post-filter</td>
<td>100</td>
<td>70</td>
<td>17</td>
<td>23.9</td>
</tr>
<tr>
<td>CVVH 3L/hr</td>
<td>Post-Filter</td>
<td>200</td>
<td>140</td>
<td>50</td>
<td>35.7</td>
</tr>
<tr>
<td>CVVH 6L/hr</td>
<td>Post-Filter</td>
<td>300</td>
<td>210</td>
<td>100</td>
<td>47.6</td>
</tr>
<tr>
<td>CVVH 1L/hr</td>
<td>Pre-filter pre-pump</td>
<td>83</td>
<td>58.1</td>
<td>17</td>
<td>22.6</td>
</tr>
<tr>
<td>CVVH 3L/hr</td>
<td>Pre-Filter pre-pump</td>
<td>150</td>
<td>105</td>
<td>50</td>
<td>32.2</td>
</tr>
<tr>
<td>CVVH 6L/hr</td>
<td>Pre-Filter pre-pump</td>
<td>200</td>
<td>140</td>
<td>100</td>
<td>41.6</td>
</tr>
<tr>
<td>CVVH 1L/hr</td>
<td>Pre-Filter Post-pump</td>
<td>117</td>
<td>70</td>
<td>17</td>
<td>19.5</td>
</tr>
<tr>
<td>CVVH 3L/hr</td>
<td>Pre-Filter Post Pump</td>
<td>250</td>
<td>140</td>
<td>50</td>
<td>26.3</td>
</tr>
<tr>
<td>CVVH 6L/hr</td>
<td>Pre-Filter Post Pump</td>
<td>400</td>
<td>210</td>
<td>100</td>
<td>32.2</td>
</tr>
<tr>
<td>Hct</td>
<td>Qb</td>
<td>QP</td>
<td>UF</td>
<td>FF</td>
<td></td>
</tr>
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<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>150</td>
<td>112.5</td>
<td>1,000</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>0.35</td>
<td>150</td>
<td>97.5</td>
<td>1,000</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td>150</td>
<td>90</td>
<td>1,000</td>
<td>0.19</td>
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<tr>
<td>0.25</td>
<td>200</td>
<td>150</td>
<td>2,000</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>0.35</td>
<td>200</td>
<td>130</td>
<td>2,000</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td>200</td>
<td>120</td>
<td>2,000</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>150</td>
<td>112.5</td>
<td>2,000</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>0.35</td>
<td>150</td>
<td>97.5</td>
<td>2,000</td>
<td>0.34</td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td>150</td>
<td>90</td>
<td>2,000</td>
<td>0.37</td>
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<tr>
<td>0.25</td>
<td>200</td>
<td>150</td>
<td>1,000</td>
<td>0.11</td>
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</tr>
<tr>
<td>0.35</td>
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<td>130</td>
<td>1,000</td>
<td>0.13</td>
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<td>0.4</td>
<td>200</td>
<td>120</td>
<td>1,000</td>
<td>0.14</td>
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<tr>
<td>0.25</td>
<td>100</td>
<td>75</td>
<td>1,000</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>0.35</td>
<td>100</td>
<td>65</td>
<td>1,000</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td>100</td>
<td>60</td>
<td>1,000</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>100</td>
<td>75</td>
<td>2,000</td>
<td>0.44</td>
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<tr>
<td>0.35</td>
<td>100</td>
<td>65</td>
<td>2,000</td>
<td>0.51</td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td>100</td>
<td>60</td>
<td>2,000</td>
<td>0.56</td>
<td></td>
</tr>
</tbody>
</table>
\[ FF = \frac{\text{UF rate (ml/min)}}{\text{plasma flow rate (Q}_P\text{)} (\text{ml/min})} \]

**Table 3.** Plasma flow and FF for different Q\(_B\)S, UF rates and Hct

<table>
<thead>
<tr>
<th>Hct, %</th>
<th>(Q_B = 150) ml/min</th>
<th>(Q_B = 200) ml/min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Q_P)</td>
<td>FF</td>
</tr>
<tr>
<td>UF = 1,000 ml/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hct = 25</td>
<td>112.5</td>
<td>0.15</td>
</tr>
<tr>
<td>Hct = 35</td>
<td>97.5</td>
<td>0.17</td>
</tr>
<tr>
<td>Hct = 40</td>
<td>90</td>
<td>0.19</td>
</tr>
<tr>
<td>UF = 2,000 ml/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hct = 25</td>
<td>112.5</td>
<td>0.30</td>
</tr>
<tr>
<td>Hct = 35</td>
<td>97.5</td>
<td>0.34</td>
</tr>
<tr>
<td>Hct = 40</td>
<td>90</td>
<td>0.37</td>
</tr>
</tbody>
</table>

\(Q_P\) = Plasma flow rate in ml/min.
\[ FF = \frac{\text{UF rate (ml/min)}}{\text{plasma flow rate (} Q_p \text{)} (\text{ml/min})} \]

**Table 4.** Advantages and disadvantages of pre- and post-filter substitution

<table>
<thead>
<tr>
<th>Pre-filter</th>
<th>Post-filter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td></td>
</tr>
<tr>
<td>UF rate is not limited by } Q_b</td>
<td>Clearance of solutes is directly related to UF rate</td>
</tr>
<tr>
<td>Enhanced elimination of urea from RBC’s</td>
<td>A higher solute clearance rate is produced</td>
</tr>
<tr>
<td>Filter life is increased as the Hct throughout the filter remains low</td>
<td>Delivery of specified solutes and concentrations directly to the solution</td>
</tr>
<tr>
<td>Filter life is increased which may increase filter lifespan and solute clearance, even though hourly solute clearance is decreased</td>
<td></td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
<td></td>
</tr>
<tr>
<td>Solute concentrations are decreased and thus clearance is decreased</td>
<td>UF rate is limited by } Q_b. You cannot order too much UF because the end-filter Hct will be too high</td>
</tr>
<tr>
<td></td>
<td>Because UF rate is limited by FF you may not reach optimal dose</td>
</tr>
<tr>
<td></td>
<td>Filter life may be decreased by high end-filter Hct</td>
</tr>
</tbody>
</table>

RBC = Red blood cell. Adapted from Huang et al. [32].
Maintaining the Circuit: Summary

- Select appropriate size catheter and position for individualized therapy
- For Access requirements > 7 days consider tunnelled catheters
- For CRRT, avoid high filtration fraction and consider pre-dilution to minimize concentration polarization and hemoconcentration
- Select Anticoagulant based on expertise and available resources. Citrate has best results for circuit and filter integrity
- For CRRT, adjust prescription for pre-dilution with either a FUN/BUN ratio or an empirical 15% particularly for CVVH
Practical Issues with CRRT

Maintaining the Circuit

Enabling solute clearances and achieving homeostasis

Volume control and balance with fluid regulation

Monitoring for and preventing complications
Effluent Sieving Coefficient $= \frac{UF}{\text{Plasma concentration of solute}}$ (1 = freely permeable, 0+ not permeable).

Dialysate Diffusive clearance

Ultrafiltrate Convective Clearance

Clearance in CRRT $= SC \times \text{effluent volume (UF, dialysate, UF + dialysate)} + \text{membrane adsorption}$

Effluent

Dialyzer and blood clearance differ based on solute and membrane characteristics
CRRT Operational Characteristics

Summary of Features

- Solute concentration can be manipulated independent of fluid balance
- Plasma composition can be altered by changing composition of dialysate and substitution fluid
- Fluid regulation can occur concurrently with solute removal to maintain patient fluid balance desired
# Regulation of fluid composition

<table>
<thead>
<tr>
<th></th>
<th>CVVHF</th>
<th>CVVHD</th>
<th>CVVHDF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target plasma solute</strong></td>
<td><strong>Composition of Replacement Fluid</strong></td>
<td><strong>Composition of Dialysate</strong></td>
<td><strong>Composition of Dialysate and Replacement Fluid</strong></td>
</tr>
<tr>
<td>concentration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rate of change in plasma concentration</strong></td>
<td><strong>Difference in concentration between Replacement Fluid and plasma</strong></td>
<td><strong>Dialysate Flow Rate (At low (Q_D))</strong></td>
<td><strong>Combined effect of replacement fluid and dialysate fluid rates and composition</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Exchange Rate</strong></td>
<td><strong>Blood Flow Rate (At high (Q_D))</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Sieving coefficient</strong></td>
<td><strong>Dialyzer Size (At high (Q_B))</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Molecular weight</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Dialyzer permeability</strong></td>
<td></td>
</tr>
</tbody>
</table>
Practical Issues with Fluid Management for CRRT

- Maintaining the Circuit
- Enabling solute clearances and achieving homeostasis
- **Volume control and balance with fluid regulation**
- Monitoring for and preventing complications
Fluid Management in the Critically Ill Patient

Strategies for intervention role of CRRT

- Fluid Removal
- Fluid Regulation
Fluid Removal on Dialysis

Refill Rate

Interstitial Space

Capillary Membrane interface for NDF

Vascular Space

Dialyzer

UF

Fig 1. A typical RBV profile obtained in response to a UF pulse showing decay, subsequent refill phase, and measured parameters. Values for $\Delta$RBV in percentage, and for IRR, in percentage per minute. Abbreviation: $\Delta$RBV$_{ref}$, the magnitude of RBV change during the refill phase, in percentage.

Mitra S et al Am J of Kid Dis, 40, 2002
Principles For Fluid Removal with Dialysis

**Removal**
Fluid is primarily removed from intravascular compartment

**Refill**
Plasma refilling rates from interstitial compartment determine rate of change of intravascular blood volume

**Balance**
If ultrafiltration rate exceeds plasma refilling rate decreased blood volume ensues and contributes to hemodynamic instability
Principles For Fluid Management With Intermittent Hemodialysis

Fluid is removed by ultrafiltration governed by transmembrane pressure

Volume of fluid removed is precisely regulated by volumetric balance chambers in machine

Rate of fluid removal dictated by prescription

Maximum fluid removal rate per hour dictated by machine limits (generally 2 L/hr)

Fluid replacement generally not required

Since time is rate limiting factor, goal is to find maximally tolerated ultrafiltration rate
Principles For Fluid Management With Continuous Dialysis

Fluid is removed by ultrafiltration governed by transmembrane pressure.

Volume of fluid removed is precisely regulated by Gravimetric scales outside machine (Prisma, Prismaflex, Aquarius, B. Braun) or Volumetric balancing chamber inside machine (NxStage).

Rate of fluid removal dictated by prescription and operational characteristics.

Maximum fluid removal rate per hour dictated by machine limits (2-12 L/hr).

Fluid replacement is required.

As procedure is continuous, goal is to target ultrafiltration to achieve fluid balance over time.
# Comparisons of Fluid Management Capability

<table>
<thead>
<tr>
<th></th>
<th>Normal Kidney</th>
<th>Intermittent HD*</th>
<th>Peritoneal Dialysis</th>
<th>CRRT#</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ultrafiltration (ml/min)</strong></td>
<td>120</td>
<td>34</td>
<td>14</td>
<td>100</td>
</tr>
<tr>
<td><strong>Volume of Filtrate /day (L)</strong></td>
<td>173</td>
<td>8</td>
<td>14</td>
<td>144</td>
</tr>
<tr>
<td><strong>Volume removed /Day (L)</strong></td>
<td>0.1-1.5</td>
<td>0-8</td>
<td>0-14</td>
<td>0-100</td>
</tr>
</tbody>
</table>

**Net Ultrafiltration capacity**
# Comparisons of Fluid Management Capability

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<td>0.1-1.5</td>
<td>0-8</td>
<td>0-14</td>
<td>0-100</td>
</tr>
<tr>
<td><strong>Regulatory mechanism</strong></td>
<td>GFR Control</td>
<td>UFR Control</td>
<td>UFR control</td>
<td>UFR Control</td>
</tr>
<tr>
<td></td>
<td>Reabsorption</td>
<td>-</td>
<td>-</td>
<td>Replacement Fluid</td>
</tr>
<tr>
<td><strong>Sensing mechanism</strong></td>
<td>Hemodynamic</td>
<td>-</td>
<td>-</td>
<td>- ? hemodynamic</td>
</tr>
<tr>
<td></td>
<td>Volume status</td>
<td>-</td>
<td>-</td>
<td>? volume status</td>
</tr>
</tbody>
</table>

* 4 hours /day

# High volume HF 6L/hr
# Fluid Management Comparisons

<table>
<thead>
<tr>
<th></th>
<th>Fluid Removal</th>
<th>Fluid Regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Kidney</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>IHD</td>
<td>+++</td>
<td>-</td>
</tr>
<tr>
<td>PD</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td>CRRT</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>Characteristics</td>
<td>Fluid removal</td>
<td>Fluid regulation</td>
</tr>
<tr>
<td>----------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>------------------------------------------------------</td>
</tr>
<tr>
<td>UF rate</td>
<td>To meet anticipated needs based upon static weight at beginning of treatment as compared to target weight</td>
<td>Variable and reassessed frequently depending upon patient needs and goals of therapy</td>
</tr>
<tr>
<td>Fluid management</td>
<td>Adjust UF</td>
<td>Adjust amount of replacement fluid and/or UF</td>
</tr>
<tr>
<td>Fluid balance</td>
<td>Even or negative</td>
<td>Positive, even, or negative</td>
</tr>
<tr>
<td>Volume removed</td>
<td>Based on physician estimate</td>
<td>Driven by patient characteristics and goals</td>
</tr>
<tr>
<td>Application</td>
<td>Easy, similar to IHD</td>
<td>Requires specific tools and training</td>
</tr>
</tbody>
</table>

**IHD = Intermittent hemodialysis.**
Principles of Fluid Management in CRRT

CRRT Fluid Balance
Provides a mechanism for achieving the patient fluid balance goals
Two approaches
• Fluid removal
• Fluid regulation

Patient Fluid Balance
Depends on goals for patient
Goals may range from removing fluid, keeping even or giving fluid.
Fluid balance goals require adjustment frequently and will often determine the operational parameters.
### Principles of Fluid Management with CRRT

<table>
<thead>
<tr>
<th><strong>UF</strong></th>
<th><strong>Replacement</strong></th>
<th><strong>CRRT Fluid Balance</strong></th>
<th><strong>Patient Fluid Balance</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>UF is used to remove fluid and UF rate can be controlled</td>
<td>Replacement fluid may be used to replace varying amounts of the fluid removed</td>
<td>Fluid balance for the CRRT device is computed as the difference between UF removed and replacement fluid given for any given period of time</td>
<td>Depends on the difference between all intakes and outputs including CRRT for any given period of time</td>
</tr>
<tr>
<td>UF removes fluid with composition close to plasma water</td>
<td>Composition of the replacement fluid can be varied</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solutes removed to varying degrees depending upon membrane characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fluid regulation**
Approaches to Fluid Balance with CRRT

**Fluid Regulation**

**Patient Balance**
- BC
- Drug
- Nutrient

**Machine Balance**
- $Q_{TR}^{PRE/POS}$
- $Q_D$

**Fluid Management**

$Q_{EFF} = Q_{R}^{PRE/POST} + Q_{OUT} + Q_{UF}^{NET} + UO$
Approaches to Fluid Balance with CRRT Principles

**Intakes**
- Oral; IV

**Outputs**
- Urine; GI
- Drains; Insensible

**Patient Balance**
- At any given point in time depends on the difference in intakes and outputs
- Plasma composition determined by underlying pathophysiologic processes and process of care (amount and types of fluids given)
Approaches to Fluid Balance with CRRT Fluid Removal

- **Patient Balance**
  - At any given point in time depends on the difference in intakes and outputs
  - Plasma composition determined by underlying pathophysiologic processes and process of care (amount and types of fluids given)

- **Intakes**
  - Oral; IV

- **Outputs**
  - Urine; GI
  - Drains; Insensible

- **CRRT Addition**
  - Provides a new source of fluid removal that can be adjusted

- **CRRT Balance**
  - Negative if fluid removal rate > replacement fluid rate
  - Zero if no fluid removed and no replacement given (CVVHD)
  - fluid removal rate = replacement fluid rate

Key is to integrate CRRT balance with patient fluid balance
Approaches to Fluid Balance with CRRT

Fluid Regulation

- Adjust patient fluid balance using CRRT as a tool for fluid management
- Goal is to adjust fluid removal/administration to achieve patient needs

Substitution Fluid

Ultrafiltrate

Common Strategy
Approaches to Fluid Balance with CRRT

Fluid Regulation

Substitution

Fluid

Ultrafiltrate

Common Strategy

UF is Varied

Alternate Strategy

UF is fixed
Replacement is varied
### Approaches to Fluid Balance with CRRT

**Fluid Removal vs. Regulation**

**Table 6. Two different methods for fluid balance in CRRT**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Ultrafiltration technique</th>
<th>Replacement fluid technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid balance</td>
<td>Achieved by varying UF rate</td>
<td>Achieved by adjusting amount of replacement fluids</td>
</tr>
<tr>
<td>Differences</td>
<td>Output is varied to accommodate changes in intake and output to reach a fluid removal goal</td>
<td>Output is fixed to achieve solute clearance goal and replacement fluid rates are changed to allow flexibility in reaching net fluid balance goals</td>
</tr>
<tr>
<td>Advantages</td>
<td>Familiar strategy from intermittent HD Can allow for fluid balance calculations over an extended period with calculation of a rate per unit time</td>
<td>Allows for constant solute clearance Dissociates clearance parameters from fluid balance</td>
</tr>
<tr>
<td>Disadvantages</td>
<td>Solute clearance may fluctuate Requires frequent interactions with CRRT machine to adjust UF rates to meet patient needs</td>
<td>Requires hourly calculations of the amount of replacement fluid to be given with risk for fluid imbalance if rate not calculated correctly with clear appreciation of all of the inputs and outputs for the patient</td>
</tr>
</tbody>
</table>
Case:

74 yo HF was admitted with 25% total body surface area burns in a structure fire, smoke inhalation.

She was in the structure fire for unknown time, her husband died in the fire.

She has burn injury to face, dorsum of both arms and legs.

She received large volume resuscitation and is about 40 L + since admission.

She is intubated and sedated in the burn unit on a fentanyl and versed drip.

HR 90, BP 135/80, Temp 99, FiO2 70%

Burns on face, back, arms

S1S2, Lungs bilateral diffuse rhonchi

Abdomen obese marked edema and bowel sounds present

Legs marked edema to thighs

Labs: Sodium 146, Potassium 4, Chloride 109, Bicarb 35, BUN 18, Creatinine 0.54, Glucose 154, Calcium 8.6

WBC 9.7, hemoglobin 9, platelet 144
Case:

<table>
<thead>
<tr>
<th>Area</th>
<th>% S2</th>
<th>% S3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body</td>
<td>63.5</td>
<td>36.5</td>
</tr>
<tr>
<td>Left arm</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Right arm</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Back</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

Lund & Browder Chart - estimate is the correct TBSA

 RTS: 18.5%
Case:
Case:

Dec 29

Jan 1
Case:

Temp

Heart Rate

BP
**Case:**

<table>
<thead>
<tr>
<th></th>
<th>12/29/12 0600 - 12/30/12 0559</th>
<th>12/30/12 0600 - 12/31/12 0559</th>
<th>12/31/12 0600 - 01/01/13 0559</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IN</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0600</td>
<td>11,643</td>
<td>7,309</td>
<td>4,076.5</td>
</tr>
<tr>
<td>1800</td>
<td>8,735</td>
<td>4,564</td>
<td>3,454</td>
</tr>
<tr>
<td><strong>Daily</strong></td>
<td>20,428</td>
<td>11,873</td>
<td>7,530.5</td>
</tr>
<tr>
<td><strong>OUT</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0600</td>
<td>770</td>
<td>799</td>
<td>712</td>
</tr>
<tr>
<td>1800</td>
<td>1,740</td>
<td>1,000</td>
<td>799</td>
</tr>
<tr>
<td><strong>Net</strong></td>
<td>+18,666</td>
<td>+6,540</td>
<td>-3,364.5</td>
</tr>
<tr>
<td><strong>Wt</strong></td>
<td>122.7 kg (270 lb 8.1 oz)</td>
<td>127 kg (279 lb 15.6 oz)</td>
<td>137.8 kg (303 lb 12.7 oz)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>131.9 kg (290 lb 12.6 oz)</td>
<td></td>
</tr>
</tbody>
</table>
## Case Study

<table>
<thead>
<tr>
<th>Date Range</th>
<th>IN</th>
<th>OUT</th>
<th>Net</th>
<th>Wt</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/29/12 - 12/30</td>
<td>11,640</td>
<td>8,785</td>
<td>2,855</td>
<td>122.7 kg (270 lb 8.1 oz)</td>
</tr>
<tr>
<td>12/30/12 - 12/31</td>
<td>7,303</td>
<td>4,564</td>
<td>2,739</td>
<td>127 kg (279 lb 15.8 oz)</td>
</tr>
<tr>
<td>12/31/12 - 01/01</td>
<td>4,676.5</td>
<td>3,454</td>
<td>1,222.5</td>
<td>131.8 kg (290 lb 12.6 oz)</td>
</tr>
<tr>
<td>Daily</td>
<td>20,428</td>
<td>1,740</td>
<td>18,688</td>
<td>137.8 kg (303 lb 12.7 oz)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date Range</th>
<th>IN</th>
<th>OUT</th>
<th>Net</th>
<th>Wt</th>
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<td>12/30/12 - 12/31</td>
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<td>131.8 kg (290 lb 12.6 oz)</td>
</tr>
<tr>
<td>Daily</td>
<td>18,688</td>
<td>1,740</td>
<td>16,948</td>
<td>137.8 kg (303 lb 12.7 oz)</td>
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</tbody>
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<tr>
<td>01/01/12 - 01/02</td>
<td>3,454</td>
<td>1,511</td>
<td>1,943</td>
<td>137.8 kg (303 lb 12.7 oz)</td>
</tr>
<tr>
<td>Daily</td>
<td>7,530.5</td>
<td>1,511</td>
<td>6,019.5</td>
<td>137.8 kg (303 lb 12.7 oz)</td>
</tr>
</tbody>
</table>
What should you do for fluid management at this time?

A. Start a vasopressor to optimize BP
B. Start a diuretic drip
C. Stop IV fluids
D. Start IHD
E. Start PD
F. Start CRRT
G. Talk to the family and withdraw care
Optimizing Renal Support for Fluid Management with CRRT

- Desired fluid balance
- Fluid management strategy (removal, even, positive balance)
- Adjustments: Frequency
- Goals of Therapy

Patient Assessment

Goals of therapy
- Short term
- Long term

CRRT Operational Parameters
- Effluent volume
- Pump settings
- Solutions rate
- Measurements
Fluid Management in CRRT

Key Decisions

- How much UF volume is required to provide solute clearance
- How much UF is needed to achieve fluid balance
- What fluid composition is needed to replace fluid removed

Practical Issues

- Prescription
- Implementing fluid management with different pumped systems
- Monitoring and charting
- Roles and responsibilities
Fluid management in CRRT
Prescription

Step 1: Determine the effluent rate (dialysate and/or ultrafiltrate) needed to meet clearance goals (recommend starting at 30 ml/kg/h)
- Monitor clearance
- Adjust effluent rate to meet clearance goals
- Monitor hemofilter performance (FUN/BUN)

Step 2: Determine fluid balance needs for the patient and determine the iBalance by incorporating machine and patient fluid balance to determine net goals
- Monitor hemodynamic response to fluid removal
- Frequent clinical assessment of fluid removal goal
- Flow sheets to monitor machine/patient balance
- Consider measures of dynamic fluid assessment

Step 3: Determine composition of replacement and/or dialysate solutions to meet goals of maintaining electrolyte and acid-base homeostasis
- Monitor serum electrolytes
- Monitor acid-base status
- Adjust fluids accordingly to meet goals

Step 4: Determine the timing for achievement of goal and monitoring parameters
- Timing based upon hemodynamic stability and imperatives based upon clinical goals
- Set fluid removal rate
- Determine best method to monitor changes
Fluid Management in CRRT

Prescription Elements

- **Modality**
  - CVVH
  - CVVHD
  - CVVHDF

- **Operational Characteristics**
  - Solute removal
    - Membrane
    - Blood flow
    - Effluent volume (Dialysate, Ultrafiltrate)
  - Fluid Balance
    - Ultrafiltrate
    - Substitution fluid
    - Dilution fluid
    - Replacement fluid
  - Circuit
    - Anticoagulation
    - Filtration fraction
    - Monitoring

- **Plasma Composition**
  - Solution content
  - Flow rates
  - Monitoring

- **Organ Support**
  - High Volume
  - High cut off membranes and sorbents
  - Temperature control
Fluid management in CRRT Prescription

**Desired solute clearance**
- Effluent volume
- Dialysate
- Ultrafiltrate

**Desired Fluid balance**
- Fluid removal
- Fluid regulation

**Operational and safety parameters**
- Monitoring and charting
- Problem avoidance and recognition
Fluid management in CRRT

Prescription

**How much solute clearance?**
- Based on patient characteristics (catabolic state, nutritional support, underlying renal function etc)
- Calculated as desired clearance ml/min and expressed as L/hr

**Compute minimal effluent volume**
- Clearance requirement in L/hr = minimal effluent volume/hr
- Amount of dialysate and ultrafiltrate to meet minimal effluent volume (modality dependent)
\[ FF = \frac{\text{UF rate (ml/min)}}{\text{plasma flow rate (}Q_P\text{)(ml/min)}} \]

**Table 3.** Plasma flow and FF for different \(Q_B\)s, UF rates and Hct

<table>
<thead>
<tr>
<th>Hct, %</th>
<th>(Q_B = 150\text{ ml/min})</th>
<th>(Q_B = 200\text{ ml/min})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Q_P)</td>
<td>FF</td>
</tr>
<tr>
<td>UF = 1,000 ml/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hct = 25</td>
<td>112.5</td>
<td>0.15</td>
</tr>
<tr>
<td>Hct = 35</td>
<td>97.5</td>
<td>0.17</td>
</tr>
<tr>
<td>Hct = 40</td>
<td>90</td>
<td>0.19</td>
</tr>
<tr>
<td>UF = 2,000 ml/h</td>
<td></td>
<td></td>
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<tr>
<td>Hct = 25</td>
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<td>Hct = 35</td>
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<tr>
<td>Hct = 40</td>
<td>90</td>
<td>0.37</td>
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</table>

\(Q_P\) = Plasma flow rate in ml/min.
Fluid management in CRRT Prescription

**How much solute clearance?**
- Based on patient characteristics (catabolic state, nutritional support, underlying renal function etc)
- Calculated as desired clearance ml/min and expressed as L/hr

**Compute minimal effluent volume**
- Clearance requirement in L/hr = minimal effluent volume / hr
- Amount of dialysate and ultrafiltrate to meet minimal effluent volume (modality dependent)

**UF volume needed for fluid balance needs**
- Define patient fluid balance requirements and estimate net (intake - output) amount of fluid to be removed
- Define intakes obligated to CRRT therapy e.g. citrate and calcium required for anticoagulation
- Add total fluid to be removed every hour to achieve goals
- Compute UF required for fluid balance = total fluid to be removed
Fluid management in CRRT

Prescription

For example:
CVVHDF Effluent volume 2700 ml/hr
Dialysate 1000 ml/hr
Ultrafiltrate needs
  Fluid needs 500 ml/hr
  Dilution fluids 700 ml/hr (500 pre-filter and 200 post filter)
  Safety factor 500 ml/hr
Total UF vol needed
Total UF volume needed = 1700 ml
Net UF = (1700-700 (dilution fluid)) = 1000 ml/hr
Thus final effluent volume = UF 1700 ml + dialysate 1000 ml = 2700 ml/hr
Fluid management in CRRT Prescription

- Target is to achieve final effluent volume without increasing filtration fraction (FF) > 20%
- Set BFR so that UF/plasma flow /min = < 20%
- Set dialysate flow rate
- Ascertain that effluent volume

For Example

a) Compute UF volume /min
b) Set UF flow rate
c) UF vol = 1000 ml/hr = 17 ml/min
d) Minimum plasma flow to achieve <20%
   FF = 17 x 5 = 85 ml/min
e) Minimum blood flow rate = plasma flow / (1 - Hct)
f) = 85/.75 (for Hct 25 ) = 114 ml/min
g) Set BFR at 120 ml/min
h) Set dialysate flow rate at 1000 ml/hr
i) Set Dilution fluids at 700 ml/hr
j) UF rate at 1000 ml/hr
k) Effluent volume = 2700 ml/hr
Fluid management in CRRT Prescription

- Determine net fluid balance goal e.g. negative, zero or positive
- Determine CRRT fluid balance very hour
- Set replacement fluid rate or UFR to achieve patient fluid balance goal
Role of CRRT in Fluid Management
How is it Done?

**Prescription**
- Machine PRISMAFLEX
- Filter HF-1000 filter set
- Mode: CVVHDF
- BFR: 100 ml/min
- Dialysate flow rate: 1000 ml/hr
- Patient fluid removal 1000 ml/hr
- Pre-filter replacement: 500 ml/hr
- Post-Filter dilution 200 ml/hr
- **Effluent volume 2700 ml/hr**

**Anticoagulation: Regional citrate**
- 4% tri-sodium citrate at 180 ml/hr
- Calcium chloride 40 ml/hr
- Monitoring: peripheral and post-filter ionized calcium

**Solutions:**
- Dialysate: Prisma sate 32 bicarb + Mg 2 meq/L + K 4.0 meq/L
- Pre-filter fluid for dilution: 0.9% saline
- Post-filter for circuit patency: 0.9% saline
- Post-filter replacement: to achieve target fluid balance: Prisma sol 32
Fluid Management in CRRT

Orders

- Components
- Standardization
## UCSD Medical Center Citrate CRRT Orders

### Solutions and Flow Rate:

11. Blood flow: ☐ 100 mls/min ☐ Other ______ mls/min (Max: 450 mls/min)

12. (1B) Dialysate - Base solution: 0.45% NaCl

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<tr>
<th></th>
<th>mEq/L</th>
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<tr>
<td>NaCl</td>
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<td>NaHCO₃</td>
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<tr>
<td>KCl</td>
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<tr>
<td>Magnesium Sulfate</td>
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<tr>
<td>Dextrose (0.1-1%)</td>
<td>%</td>
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<tr>
<td>Other 1</td>
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<tr>
<td>Other 2</td>
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</table>

*Total NaCl/HCO3 should equal 40 mEq/L

<table>
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<tr>
<th>FLOW RATES</th>
<th>Standard (mLs/hr)</th>
<th>Other (mLs/hr)</th>
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<tr>
<td>(1A) Total Effluent (total of all fluids)</td>
<td>2700</td>
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<tr>
<td>(1B) Dialysate</td>
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<tr>
<td>(1C) Post filter (deaeration chamber via replacement pump)</td>
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<tr>
<td>(1D) Pre filter (via Pre Blood Pump)</td>
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<tr>
<td>(3A) Patient fluid removal (Max 2000 mls/hr)</td>
<td>1000</td>
<td></td>
</tr>
</tbody>
</table>

() refers to form D6037

14. (1C) Post filter: ☐ Normal Saline ☐ Other: ________________________

15. (1D) Pre filter: ☐ Normal Saline ☐ Other: ________________________
14. Replacement fluid composition: □ 0.9% sodium chloride
   □ Other 1: ____________________________  □ Other 2: ____________________________

15. Replacement fluid flow rates: Choose one method below to maintain net fluid balance:
   □ Set hourly fluid removal rate:
     □ Net negative ________ mL/hour for ________ hours.
     □ Keep even for ________ hours.
     □ Net positive ________ mL/hour for ________ hours.

   □ Sliding scale (below):
     Parameters:
     ○ MAP  ○ PAWP
     ○ CVP  ○ Other ________
     Suggested Hourly Fluid Target Parameters  OTHER Hourly Fluid Target Parameters
     + 200 mL  
     + 150 mL  
     + 100 mL  
     + 50 mL  
     EVEN  
     - 50 mL  
     - 100 mL  
     - 150 mL  
     - 200 mL  

NOTE: For all machines other than PRISMA: infuse fluid into replacement fluid line (prefilter, postpump).
     For PRISMA: give replacement fluid postfilter via venous return line.
Fluid Management in CRRT

UF pump setting

- UF pump can be set independent of other pumps (Diapact, BM25)
- UF pump rate dictated by other pump settings (PRISMA, Aquarius, Prismaflex)

CRRT fluid balance computation

- Fluids hung on scale
- Fluids outside of system
Hydraulic Circuit for PrismaFlex
Machine Programming Components:
Modality: CVVH, CVVHD, CVVHDF
Negative fluid balance desired (Fluid removal rate)
Replacement fluid pre vs post filter
Dialysate flow rate
Anticoagulant flow rate
Machine Programming Components:
Modality: CVVH, CVVHD, CVVHDF
Negative fluid balance desired (Fluid removal rate)
Replacement fluid pre vs post filter
Dialysate flow rate
Anticoagulant flow rate

Effluent Pump Speed = RF + DF + AC + Flod removal
Citrate CVVHDF: UCSD Protocol

Substitution Fluid varying rate 200-1000 ml/hr (Prismasol, custom solution NaCl/NaHCO3)

CaCl₂ 0.1 meq/ml 40-80 ml/hr
Adjusted based on Peripheral Ionized Ca

4% Trisodium Citrate 120-200ml/hr
Citrate flow adjusted based on post filter Ionized Calcium

Hydraulic Circuit for PrismaFlex

Dialysate
Prismasate with Calcium and added Magnesium and Potassium

Effluent Pump
2700 ml/hr (net UFR 1000 ml/hr)

Post Dilution Fluid
NaCl 200 ml/hr

Pre Dilution Fluid
NaCl 500 ml/hr
Fluid Management in CRRT

Orders
- Components
- Standardization

Charting
- CRRT Balance
- Patient Balance
- Where and how often is it charted
Approaches to Fluid Balance with CRRT
Fluid Regulation
# UCSD MEDICAL CENTER CRRT FLOWSHEET

## Case Study 46 yr old woman with MOF

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<th>06</th>
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## UCSD MEDICAL CENTER CRRT FLOWSHEET

### Case Study 46 yr old woman with MOF

#### Level 3 fluid management

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## UCSD Medical Center CRRT Flowsheet

### Continuous Renal Replacement Therapy (CRRT) Flowsheet

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</tbody>
</table>

### Patient Identification

<table>
<thead>
<tr>
<th>Name</th>
<th>MR#</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>008</td>
</tr>
</tbody>
</table>

### Data Entries

- Effluent (Total of all fluids)
- Prefilter solution (Internal pump)
- Dialysate infused
- Patient fluid removal (EF)
- Additional output (urine, fluid from drains)
- Total output
- All intake, IV or all except replacement
- Hours fluid balance
- Desired output + ORT -
- Fluid balance given
- Central venous fluid balance
- CVP, PAWP, MAP
- Access pressure, PA
- Access pressure, PA
- Return pressure, PA
- Blood flow, connections, check central, peripheral
- Ionized calcium, post
- Calcium chloride, flow
- Nitrogenous
| CRRT Flow sheets in EMR |
Case Study
Case Study

Creatinine
## Case Study

<table>
<thead>
<tr>
<th>Date</th>
<th>IN</th>
<th>OUT</th>
<th>Net</th>
<th>Wt</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/03/13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/04/13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/05/13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **IN**:
  - 0600: 11,130
  - 1800: 10,864
  - Daily: 21,994

- **OUT**:
  - 0600: 12,400
  - 1800: 12,004
  - Daily: 24,404

- **Net**:
  - 0600: -1,350
  - 1800: -1,800
  - Daily: -3,150

- **Wt**:
  - 134.3 kg (296 lb 1.2 oz)
  - 130.2 kg (287 lb 0.6 oz)
  - 127.7 kg (281 lb 8.4 oz)
Case Study
**Case Study**

<table>
<thead>
<tr>
<th>Date Range</th>
<th>IN</th>
<th>OUT</th>
<th>Net</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/07/13 0900 - 01/08/13 0600</td>
<td>11,313</td>
<td>12,163</td>
<td>-850</td>
<td>116.3 kg (257 lb 9 oz)</td>
</tr>
<tr>
<td>01/07/13 0900 - 01/08/13 0600</td>
<td>12,235</td>
<td>11,937</td>
<td>-500</td>
<td>117.2 kg (259 lb 6.1 oz)</td>
</tr>
<tr>
<td>01/09/13 0900 - 01/10/13 0600</td>
<td>11,497</td>
<td>11,607</td>
<td>-500</td>
<td>115.5 kg (255 lb 13.4 oz)</td>
</tr>
<tr>
<td>01/09/13 0900 - 01/10/13 0600</td>
<td>12,235</td>
<td>12,235</td>
<td>-500</td>
<td>114.1 kg (251 lb 6.7 oz)</td>
</tr>
</tbody>
</table>

**Notes:**
- Daily values reflect the difference between IN and OUT for each time period.
- Weight values are given in kilograms and pounds.
# Case Study

<table>
<thead>
<tr>
<th>Date Range</th>
<th>01/09/13 0600 - 01/10/13 0559</th>
<th>01/10/13 0600 - 01/11/13 0559</th>
<th>01/11/13 0600 - 01/12/13 0559</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IN</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0600</td>
<td>11,718</td>
<td>9,744</td>
<td>1,537</td>
</tr>
<tr>
<td>1800</td>
<td>11,885</td>
<td>5,833</td>
<td>2,495.2</td>
</tr>
<tr>
<td><strong>OUT</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0600</td>
<td>12,315</td>
<td>10,259</td>
<td>950</td>
</tr>
<tr>
<td>1800</td>
<td>12,485</td>
<td>10,483</td>
<td>1,335</td>
</tr>
<tr>
<td><strong>Daily</strong></td>
<td>23,603</td>
<td>19,667</td>
<td>4,032.2</td>
</tr>
<tr>
<td><strong>Net</strong></td>
<td>-597</td>
<td>-516</td>
<td>+487</td>
</tr>
<tr>
<td><strong>Wt</strong></td>
<td>114.1 kg (251 lb 8.7 oz)</td>
<td>111.7 kg (246 lb 4.1 oz)</td>
<td></td>
</tr>
</tbody>
</table>

*Note: The table includes daily net weight changes for a specified period.*
Case Study

Creatinine
## Case Study

<table>
<thead>
<tr>
<th>Date</th>
<th>IN</th>
<th>OUT</th>
<th>Daily</th>
<th>Net</th>
<th>Wt</th>
<th>Previous Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/12/13 0600</td>
<td>1,631.5</td>
<td>1,958</td>
<td>-326.5</td>
<td>-1,793</td>
<td>113 kg (243.6 oz)</td>
<td>111.7 kg (246 lb 4.1 oz) at 01/11/13 0600</td>
</tr>
<tr>
<td>01/13/13 0600</td>
<td>2,182</td>
<td>360</td>
<td>2,522</td>
<td>1,466.5</td>
<td>111.6 kg (246 lb 0.5 oz)</td>
<td>111.3 kg (246 lb 5.9 oz)</td>
</tr>
<tr>
<td>01/14/13 0600</td>
<td>1,522</td>
<td>1,666</td>
<td>-143</td>
<td>+347</td>
<td>1,738</td>
<td>110 kg (242 lb 8.1 oz)</td>
</tr>
<tr>
<td>01/15/13 0600</td>
<td>2,654</td>
<td>385</td>
<td>2,269</td>
<td>+204</td>
<td>2,624.5</td>
<td>4,087</td>
</tr>
</tbody>
</table>

**Note:** The data provided is for illustrative purposes and should be verified with actual records.
Case Study
Achieving Fluid Balance with CRRT

- Targeted Fluid management
  - Hemodynamic parameters
  - TBW and compartmental distribution parameters
SVV to Guide Fluid Management in CRRT
SVV to Guide Fluid Management in CRRT
Practical Issues with Fluid Management for CRRT

- Maintaining the Circuit
- Enabling solute clearances and achieving homeostasis
- Volume control and balance with fluid regulation
- Monitoring for and preventing complications
CRRT Fluid Management Preventing Complications

- **Prescription**
  - Modality
  - Blood flow rate
  - Filtration fraction
  - Fluid Balance Goal
  - Quantity to be Removed
  - Fluid removal rate
  - Substitution fluid
  - Pre-dilution (Rate/hr)
  - Post-Dilution (Rate/hr)
  - Dialysate rate
  - Fluid composition
  - Substitution
  - Dialysate
  - Warmer Temperature
  - External Pumps
  - In Circuit

- **Parameter**
  - Inappropriate Goal
  - Amount of fluid removed
  - Rate of fluid removal

- **Complication**
  - Volume depletion
  - Fluid Overload
  - Hypotension
  - Hemodynamic instability
Differing clinical circumstances demand different rates of fluid removal

CRRT: communication is crucial

**Doctor**
- Inserts line
- Prescribes anticoagulant
- Prescribes modality, dose and fluid removal

**Nurse**
- Sets up & provides therapy
- Adjusts settings to achieve goals
- Measures and adjusts anticoagulant
- Makes chart entries
- Monitors for complications and responds appropriately
Fluid Management with CRRT
What can we do?

**Need**

- Utilize dialysis for fluid regulation instead of fluid removal only
- Late utilization when fluid redistribution into large compartments has already occurred
- Develop guidelines based on demonstrated best practices
- Recognize importance of fluid retention on outcome

**Strategy**

- CRRT can continuously adjust fluid balance in critically ill patients
- Initiate RRT at earlier time points to prevent fluid accumulation
- Protocol based standardization of approach
- Implement calculators to track fluid accumulation and fluid overload
Current Knowledge

Fluid therapy is common in patients at risk for AKI.

Prolonged fluid resuscitation leads to edema of kidney and other organs and can contribute to AKI.

Fluid overload > 10% body weight is associated with increased morbidity and mortality.

Intervention Strategies

An early transition to a fluid restrictive strategy may be beneficial in patients with AKI.

Fluid removal in patients with or at risk for AKI should be implemented with appropriate monitoring.

CRRT allows continuous fluid regulation to support patients.

Areas for Research

Is fluid accumulation a mediator of adverse outcomes from AKI?

Role of endothelial glycocalyx.

Biomarkers/ novel fluid assessment tools to allow safer fluid management.

At what level of volume retention should therapy be started?

Can dialysis provide a safety net in pts with compromised renal function?
Extra slides
Overview

- CRRT Fluid composition and electrolyte and acid base Mx
- Fluid Overload and its treatment with CRRT
- Precision CRRT and individualization of treatment
- Monitoring and complications during CRRT
- Quality metrics and benchmarking
Maximum Ultrafiltration Rate (in L/hr) Achieved at 20% (30%) Filtration Fraction in Post-Dilution CVVH

<table>
<thead>
<tr>
<th>QB = 150 mL/min</th>
<th>QB = 200 mL/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hct = 0.30</td>
<td>1.3 (1.9)</td>
</tr>
<tr>
<td>Hct = 0.40</td>
<td>1.1 (1.6)</td>
</tr>
</tbody>
</table>
Blood flow requirements for CRRT to maintain filtration fraction at 25%

**FF(%) = (UFR x 100) / Q_p**

**Q_p = BFR x (1-Hct)**

When BFR = 100ml/min, Hct = 0.3 Q_p = 70ml/min

If FF > 30%, promote filter clotting

If FF = 30%, BFR of 100 ml/min, UF = 21ml/min

<table>
<thead>
<tr>
<th>Ultrafiltration rate (mls/hr)</th>
<th>Minimum Q_b/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500</td>
<td>100</td>
</tr>
<tr>
<td>2000</td>
<td>130</td>
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<tr>
<td>2500</td>
<td>155</td>
</tr>
<tr>
<td>3000</td>
<td>200</td>
</tr>
<tr>
<td>4000</td>
<td>265</td>
</tr>
</tbody>
</table>
Pathological effects of fluid overload in organ systems

Too much fluid is bad...


---

**Normal**
- Slower loss of fluid from vasculature
- Normal glycocalyx, Extra-cellular Matrix & Lymphatic drainage
- Normal interstitium
- ECM disrupted
- Low interstitial pressure
- Hydrated Glycosaminoglycans
- Fluid accumulation
  - Increased capillary permeability
  - Plasma protein loss
  - Impaired lymphatic function
  - Increased interstitial capacity

**Intact Glycocalyx**
- Lymphatic return = Fluid loss to Interstitium
- Fluid therapy
- Ultrafiltration
- Lymphatic return < Fluid loss to Interstitium
- ECM disrupted
- Low interstitial pressure
- Hydrated Glycosaminoglycans
- Rapid loss of fluid from vasculature

**Degraded Glycocalyx**
- Systemic Inflammation
- ANP
- TNFα
- LPS
- Hyperglycemia
- Oxidative Stress
Fluid overload is associated with an increased risk for 90-day mortality in critically ill patients with renal replacement therapy: data from the prospective FINNAKI study

Suvi T Vaara¹, Anna-Maija Korhonen¹, Kirsi-Maija Kaukonen¹, Sara Nisula¹, Outi Inkinen³, Sanna Hoppu³, Jouko J Laurila⁴, Leena Mildh¹, Matti Reinikainen⁵, Vesa Lund⁶, Ilkka Pariainen⁷ and Ville Pettitš⁸, for The FINNAKI study group

Vaara et al. Critical Care 2012, 16:R197
http://ccforum.com/content/16/5/R197

Figure 3 Ninety-day mortality according to the percentage of fluid accumulation prior to renal replacement therapy initiation.
*Comparison across groups P < 0.001.
Resolution of Fluid Overload with RRT and Survival

An observational study fluid balance and patient outcomes in the randomized evaluation of normal vs. augmented level of replacement therapy trial*

The RENAL Replacement Therapy Study Investigators

Crit Care Med 2012 Vol. 40, No. 6
Fluid overload and interstitial oedema may contribute to the maintenance of AKI.

Prowle, Kirwan, Bellomo *Nat Rev Nephrol* 2013
Questions

- To what extent is fluid overload a marker of illness severity (measure of unknown confounders) and to what extent an avoidable cause of iatrogenic morbidity and mortality?

- Does fluid overload itself contribute to the initiation or persistence of AKI?
  - Can we treat this?

- Does the avoidance or treatment of fluid overload with RRT (or diuretics) improve outcomes?
  - If so when?
Section 5: Dialysis Interventions for Treatment of AKI

5.1.1: Initiate RRT emergently when life-threatening changes in fluid, electrolyte, and acid-base balance exist. (Not Graded)

5.1.2: Consider the broader clinical context, the presence of conditions that can be modified with RRT, and trends of laboratory tests—rather than single BUN and creatinine thresholds alone—when making the decision to start RRT. (Not Graded)

5.2.1: Discontinue RRT when it is no longer required, either because intrinsic kidney function has recovered to the point that it is adequate to meet patient needs, or because RRT is no longer consistent with the goals of care. (Not Graded)

5.2.2: We suggest not using diuretics to enhance kidney function recovery, or to reduce the duration or frequency of RRT. (2B)

5.8.2: Provide RRT to achieve the goals of electrolyte, acid-base, solute, and fluid balance that will meet the patient’s needs. (Not Graded)

5.8.3: We recommend delivering a Kt/V of 3.9 per week when using intermittent or extended RRT in AKI. (1A)

5.8.4: We recommend delivering an effluent volume of 20–25 ml/kg/h for CRRT in AKI (1A). This will usually require a higher prescription of effluent volume. (Not Graded)
Systematic approach to fluid management in critical illness

- Resuscitate appropriately early
- Avoid need for removal as much as possible by then appropriately limiting intake
- Ultrafiltration as a component in an active fluid management strategy
Goals in mechanical fluid removal

- Resolve fluid overload and its adverse effects on organ function
- Allow necessary interventions
  - Nutrition
  - Drugs
- Prevent overt hypovolaemia
  - Secondary ischaemic injury
  - Adverse neuroendocrine responses
- Avoid complications of RRT
Quantification of fluid overload

- Clinical Examination
- Serial Weights
- Cumulative Fluid Balance
- Chest X-ray
- Oxygenation indices
- Lung Ultrasound
- Intra-abdominal pressure
- Echocardiography
- Bioimpedance body composition analysis
Decisions in prescribing ultrafiltration

- **Goal (Long term)**
  - Extent of fluid overload
  - “Euvolaemia”

- **Tolerance of fluid removal (Short term)**
  - Rate of removal
  - Rate of vascular refilling
  - Ability of circulation to tolerate transient reduction in intravascular volume
Differing clinical circumstances demand different rates of fluid removal

British journal of anaesthesia 113: 764-771
## Approaches to Fluid Balance with CRRT

### Fluid Regulation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Common</th>
<th>Alternate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intake</td>
<td>Variable</td>
<td>Variable</td>
</tr>
<tr>
<td>Non-CRRT output</td>
<td>Variable</td>
<td>Variable</td>
</tr>
<tr>
<td>Ultrafiltration rate</td>
<td>Variable to achieve fluid balance</td>
<td>Fixed to achieve target effluent volume</td>
</tr>
<tr>
<td>Substitution fluid rate</td>
<td>Fixed = or &lt; UFR</td>
<td>Varies to achieve negative, zero, or positive fluid balance</td>
</tr>
<tr>
<td>Fluid balance</td>
<td>Achieved by varying UF rate</td>
<td>Fluid balance is achieved by adjusting amount of substitution fluid</td>
</tr>
<tr>
<td>Key difference</td>
<td>Output is varied to accommodate changes in intake and fluid balance goals</td>
<td>Output is fixed to achieve desired solute clearance and allow flexibility in accommodating varying intake</td>
</tr>
<tr>
<td>Advantages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient factors</td>
<td>Similar to strategy for fluid removal in intermittent dialysis</td>
<td>Keeps solute clearance constant. Allows for variation in intake. Individualizes prescription</td>
</tr>
<tr>
<td>CRRT factors</td>
<td>Fluid balance calculations can be deferred to longer intervals (e.g., every 8–12 hours)</td>
<td>Therapy parameters dissociate clearance requirements from fluid balance. Reduces interactions with CRRT pump to adjust UF rates. Simplifies regimen for caregiver. First step to utilizing CRRT for fluid regulation</td>
</tr>
<tr>
<td>Disadvantages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient factors</td>
<td>Assumes patient in static state. Mimics ESRD prescription. Intake may fluctuate. Fluid boluses not accounted for. Over- or undershoot common. Solute clearances fluctuate, particularly if dependent on convection</td>
<td>Requires hourly calculations for amount of replacement fluid to be given. Potential for fluid imbalances if a balance sheet is not used</td>
</tr>
<tr>
<td>CRRT factors</td>
<td>Requires frequent interactions with CRRT pump to adjust UF rates. Underutilizes CRRT for fluid removal only</td>
<td>May require use of an external pump to achieve fluid regulation</td>
</tr>
</tbody>
</table>

---

Mehta, Kidney Int 2005
Approaches to Fluid Balance with CRRT

**Fluid Regulation**

**Patient Balance**
- BC
- Drug
- Nutrient

**Machine Balance**
- $Q_{\text{TR}}^{\text{PRE/POS}}$
- $Q_D$

**FLUID MANAGEMENT**

$Q_{\text{EFF}} = Q_{\text{TR}}^{\text{PRE/POST}} + Q_{\text{UF NET}}$

- UO
- Drainage
- Insensible Loss
### CRRT: Operating Characteristics

#### Fluid removal vs Fluid regulation

<table>
<thead>
<tr>
<th></th>
<th>Fluid removal</th>
<th>Fluid regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UF Rate</strong></td>
<td>To meet anticipated needs</td>
<td>Greater than anticipated needs</td>
</tr>
<tr>
<td><strong>Fluid Management</strong></td>
<td>Adjust UFR</td>
<td>Adjust amount of replacement fluid</td>
</tr>
<tr>
<td><strong>Fluid Balance</strong></td>
<td>Zero or negative balance</td>
<td>Positive, negative or zero balance</td>
</tr>
<tr>
<td><strong>Volume removed</strong></td>
<td>Based on physician estimate</td>
<td>Driven by patient characteristics</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Easy, similar to IHD</td>
<td>Requires specific tools and training</td>
</tr>
</tbody>
</table>
Principles of Fluid Management in CRRT

**Ultrafiltrate**
- UF is used to remove fluid and UF rate can be controlled.
- UF removes fluid with composition close to plasma water.
- Solutes removed to varying degrees depending upon membrane characteristic.

**Replacement**
- Replacement fluid may be used to replace varying amounts of the fluid removed.
- Composition of the replacement fluid can be varied.

**CRRT Fluid Balance**
- Fluid balance for the CRRT device is computed as the difference between UF removed and replacement fluid given for any given period of time.

**Patient Fluid Balance**
- Depends on the difference between all intakes and outputs including CRRT for any given period of time.
Principles For Fluid Management With Continuous Dialysis

- Fluid is removed by ultrafiltration governed by transmembrane pressure.
- Volume of fluid removed is precisely regulated by Gravimetric scales outside machine (Prisma, Prismaflex, Aquarius, B. Braun) or Volumetric balancing chamber inside machine (NxStage).
- Rate of fluid removal dictated by prescription and operational characteristics.
- Maximum fluid removal rate per hour dictated by machine limits (2-12 L/hr).
- Fluid replacement is required.
Fluid Control Units on CRRT Machines

Figure 3: Dialysis
Dialyzer and Blood Circuit Added to Loop
Net Removal Pump = Patient Fluid Removed