Not Your Parents' CRRT:
Advanced Pediatric-Specific Techniques

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Introduction

• Pediatric CRRT is no longer a “novel” therapy
  – Many years of experience
  – Literature to support our approach
• Each patient presents unique challenges
  – Adapting standards to clinical situations
  – Adjusting approach to address complications
• Each program faces its own issues
  – Technology, support, staffing, acuity, etc.
Format for the Session

• Present a clinical case or question
• Discuss as a group
• Review our perspective
  – Case resolution
  – Points illustrated
  – Data/literature review where available
• Summarize at the end
Case #1

CRRT AND ECMO
Case #1 – Clinical Scenario

• 14 years old, previously healthy with h/o URI for 4-5 days, sore throat and cough.
• Transferred from outside hospital to PICU with hypoxic respiratory failure, sepsis, necrotizing pneumonia
• Cannulated for VA-ECMO
• VA-ECMO with flows currently at 3.5 Liters/Min
  – Pressures Pre-membrane 300
  – Post-membrane 310
• Weight (actual) 61.2kg
• Intubated – Vent settings R-18, 30/10, 30% O2
Case #1 – Clinical Scenario (Continued)

• Urine output noted to go down
• Serum creatinine rising
  – 0.7mg/dL → 1.3mg/dL
• Worsening edema on exam
• PICU team contacts you regarding AKI and possible need for RRT
Case #1 – Discussion

• How do you address the need for RRT when a patient is on ECMO?
• What technical challenges must you anticipate?
• How do you coordinate care between teams?
CRRT and ECMO: Blood Pathway

- Blood Flow
  - ECMO Venous – Pull line, Drain line
  - ECMO Arterial – Return line, Re-infuse line
  - CRRT Arterial (Access) – Pull line
  - CRRT Venous (Return) – Re-infuse line
Oxygenator
Pump
Motor
Deoxygenated Blood
Venous
Oxygenated Blood
Arterial
Bridge
Negative Pressure
SVO₂ probe
Cannula
Pigtails
CRRT and ECMO: Issues with the ECMO Circuit

• Negative Pressure
  – CRRT circuit standard pressure mode
  – Lower pressures, likely less pressure alarms
  – Danger of AIR if disconnected
Oxygenator

Pump

Motor

Deoxygenated Blood Venous

Oxygenated Blood Arterial

Bridge

Cannula

SVO₂ probe

Positive Pressure

Pigtails
CRRT and ECMO: Issues with the ECMO Circuit

• Positive Pressure
  – CRRT circuit positive pressure mode
  – High ECMO pressures will influence CRRT pressures, likely more pressure alarms
  – Danger of **Exsanguination** if disconnected
CRRT and ECMO: Ideal Connection

1. Least risk for introducing air
2. Minimize pressure alarms on CRRT
   – Connection location will determine Arterial pressure
     • Stopcocks and/or restrictors
   – Venous
     • NO restrictors
ECMO Circuit Access Centrifugal Pump

Color-coded according to color of labels

- Patient
- Venous Sampling
- Arterial CDI
- Arterial CDI Return
- Post-Membrane Transducer
- Hemofilter Access
- CRRT Return
- Plasmapheresis Return
- CRRT Access
- Plasmapheresis Access
- Hemofilter Return
- Centrifugal Pump
- Bladder
- Bladder Air Port
- Bladder Transducer
- Heparin
- Continuous Infusions
- Intermittent Fluids
- Lab Sampling
- Blood Products

Positive Pressure:
- Light Blue Line

Negative Pressure:
- Dark Blue Line
Case #1 – Additional Discussion

• Do you perform ECMO and CRRT at your center?
• What challenges and issues have you needed to address when considering RRT for patients receiving ECMO?
Case #1 – Summary

• ECMO circuit determines CRRT pressures
• Ideal location – post pump/pre oxygenator
• Connections secure, frequent checks
• Standardized the process
  – Options for high pressures
Case #2

WEIRD LAB RESULTS
Case #2 – Clinical Scenario

• 16 year old girl with relapsed ALL s/p BMT
• Develops sepsis with MODS
• AKI, oliguria, 12% volume overload
• Placed on CRRT for fluid and metabolic control
  – Has been on CRRT for 5 days
  – Overall stable but still unable to remove fluid due to hypotension
Case #2 – CRRT Prescription

- CVVHDF
- Polysulfone filter – 1.1m²
- Qb 200 ml/min via right IJ catheter (12Fr)
- Prismasol BGK 4/2.5
  - Qd 1300 ml/hr; Qr 1300 ml/hr (ttl ~3L/hr/1.73m²)
- Heparin anticoagulation
  - aPTT has been stable on infusion
- UF plan – net zero loss per hour (hypotension)
Reviewing labs this morning, you notice the following:
## Case #2 – Laboratory Results

<table>
<thead>
<tr>
<th>Lab</th>
<th>3 days ago</th>
<th>2 days ago</th>
<th>Yesterday</th>
<th>Today</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium (mEq/L)</td>
<td>141</td>
<td>139</td>
<td>140</td>
<td>148</td>
</tr>
<tr>
<td>Potassium (mEq/L)</td>
<td>3.9</td>
<td>3.8</td>
<td>3.8</td>
<td>4.2</td>
</tr>
<tr>
<td>Chloride (mEq/L)</td>
<td>113</td>
<td>112</td>
<td>113</td>
<td>116</td>
</tr>
<tr>
<td>CO2-total (mEq/L)</td>
<td>27</td>
<td>26</td>
<td>28</td>
<td>32</td>
</tr>
<tr>
<td>BUN (mg/dL)</td>
<td>15</td>
<td>12</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Creatinine (mg/dL)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Calcium-ionized (mmol/L)</td>
<td>1.20</td>
<td>1.19</td>
<td>1.21</td>
<td>0.7</td>
</tr>
<tr>
<td>Magnesium (mg/dL)</td>
<td>1.8</td>
<td>1.7</td>
<td>1.8</td>
<td>0.6</td>
</tr>
<tr>
<td>Phosphorus (mg/dL)</td>
<td>4.7</td>
<td>4.2</td>
<td>3.9</td>
<td>3.6</td>
</tr>
</tbody>
</table>
Case #2 – Discussion

• What could be going on here?
• How do you determine the source of this problem?
• What actions do you take?
CRRT Schematic

- SCUF
- CVVH
- CVVHD
- CVVHDF

UF

D

R

Person
# CRRT Solutions – Many Choices

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>R / D</th>
<th>Bag Size*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normocarb HF</td>
<td>DSI</td>
<td>R</td>
<td>3.24 L</td>
</tr>
<tr>
<td>Prismasate</td>
<td>Gambro</td>
<td>D</td>
<td>5 L</td>
</tr>
<tr>
<td>Accusol</td>
<td>Baxter</td>
<td>D</td>
<td>2.5 L</td>
</tr>
<tr>
<td>Prismasol</td>
<td>Gambro</td>
<td>R</td>
<td>5 L</td>
</tr>
<tr>
<td>Duosol</td>
<td>B Braun</td>
<td>D</td>
<td>5 L</td>
</tr>
<tr>
<td>PureFlow</td>
<td>NxStage</td>
<td>D</td>
<td>5</td>
</tr>
</tbody>
</table>

*Dialysate mixed on-line for SLED*
Case #2 – Our CRRT Solution

<table>
<thead>
<tr>
<th>Component</th>
<th>Final Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca</td>
<td>2.5 mEq/L</td>
</tr>
<tr>
<td>Bicarb</td>
<td>32 mEq/L</td>
</tr>
<tr>
<td>K</td>
<td>4 mEq/L</td>
</tr>
<tr>
<td>Mg</td>
<td>1.5 mEq/L</td>
</tr>
<tr>
<td>Na</td>
<td>140 mEq/L</td>
</tr>
<tr>
<td>Cl</td>
<td>113 mEq/L</td>
</tr>
<tr>
<td>Lactate</td>
<td>3 mEq/L</td>
</tr>
<tr>
<td>Dextrose</td>
<td>100 mg/dL</td>
</tr>
</tbody>
</table>
CRRT Fluids: Biochemical Profile Has Strong Impact on the Patient

- Patient’s blood chemistry approaches that of infused fluids
- Errors in fluid content (mixing or inappropriate choice for situation) can lead to significant abnormalities
Prismasol Bag Technology

Small compartment A

Peel seal

Large compartment B

Injection connector (or spike connector)

Luer connector
Immediately before use, remove the overwrap from the bag and mix the solutions in the two different compartments. Hold the small compartment with both hands and squeeze it until an opening is created in the peel seal.

Squeeze with both hands on the large compartment until the peel seal between the two compartments is entirely open. Shake gently to mix. The solution is now ready for use and can be hung on the equipment.
Case #2 – Explanation

• Forgot to snap and mix the Prismasol bag – running patient on the B compartment only

• Gives following concentrations:
  – Na 148 mEq/L
  – K 4.2 mEq/L
  – HCO3 37 mEq/L
  – Cl 116 mEq/L
  – No magnesium, no calcium (all in A compartment)
Case #2 – Additional Discussion

• How do you assure that lab tests remain stable during CRRT?
• How do you address a situation when lab tests change?
• Who is responsible in your program to monitor and review biochemical balance?
Case #2 – Summary

- Errors in CRRT solution can lead to changes in patient biochemical profile
- Must have clear understanding of solution options in your program
- High index of suspicion with abnormalities
- Develop systems/methods for monitoring and review
- Patient safety first
Case #3

CRRT IN PEDIATRIC LIVER FAILURE
Case #3 – Clinical Scenario

• 2 year old girl (previously healthy) weighing 10kg
• Admitted to PICU with fulminant hepatic failure
  – INR = 9, NH3 = 814, lactate = 11, AST > 20,000, ALT > 3,500
  – Fever (106F), altered mental status, seizures, hypotension
• Resuscitated, intubated, massive blood product requirement
  – Developed 10% FO within first 24 hours of admission
  – BUN 30, Creatinine 1mg/dL (eGFR of 35mL/min/1.73m2)
Case #3 – Clinical Scenario (Continued)

• Patient has
  – AKI
  – Fluid overload,
  – Large volume requirements
  – Elevated ammonia levels
  – Increased bleeding risk
• Nephrology consulted; CRRT initiated
Case #3 – Discussion

• What prescription/clearance challenges are posed by this patient?
• What are the priming considerations?
• What are our options for anticoagulation?
Case #3 – Prescription and Clearance

• Can use fairly standard Rx
  – May want to run blood flow rate higher to reduce clotting

• Clearance
  – In a small patient with large volume needs, UF alone will lend a tremendous amount of clearance
  – Citrate 100mL/hr
  – Ca 50mL/hr
  – Average 2.6L/day 110mL/hr
  – Total 260mL/hr = 26mL/kg/hr
Clearance: Goals and Delivery

- UF alone brings you to the target CRRT clearance (20-25)

- Minimum Qd (50mL/hr) and Qr (50-100mL/hr) settings add another 10-15mL/kg/hr

- If you are not paying attention its easy to overclear
Case #3 – Prescription and Clearance

- What if you want a lot of clearance?
- Should we treated like a hyperammonemic neonate?
  - 8000mL/1.73m$^2$/hr
  - 0.51m$^2$
  - Target a Qd of 2400mL/hr
- Could consider this initially
  - Pt likely to have prolonged CRRT course
  - Overclearance likely to have negative impact on electrolytes, medication dosing, nutrition, calcium balance
Circuit Priming

• Prime options: saline, albumin, blood, “self”

• Patient is small enough and unstable enough to warrant a blood prime

• Blood prime options
  – Prime it and forget it
  – Manual normalization
  – Bypass
  – Recirculation
  – Single pass dialysis
  – Circuit to circuit crossprime
Bypass System

Recirculation System

Recirculation Plan:
Qb 200ml/min
Qd ~40ml/min
Time 7.5 min

Normalize pH

Normalize K⁺

Single Pass Dialysis

Waste

Qb = 30mL/min
Qd = 3.6L/hr
Time = 6 minutes

Qb = 50mL/min
Qd = 6L/hr
Time = 4 min

Dialysate

PRBC
Hct 35

Waste
Circuit-to-Circuit Cross-Prime NS
Anticoagulation

- Anticoagulation options

  - No anticoagulation: circuit loss (bad)
  - Citrate and heparin have equal circuit survival
  - More bleeding with heparin

Anticoagulation

• Anticoagulation options
• Adult studies seem to suggest citrate is associated with longer circuit survival and perhaps better outcomes
• Most centers use one or the other
  – May be challenging to manage both from a staffing/training issue
• We use citrate except if the pt is systemically heparinized (ECMO, VAD, LMWH for thrombus)
Case #3 – Anticoagulation

• We would use citrate
• However, in liver failure citrate accumulation is quite common – especially in little kids
Case #3 – Clinical Case (Continued)

• 24 hours later:
  – Total calcium 19.7mg/dL
  – Patient pH 7.09 (HCO3 12)
  – Pt iCal 1.15, circuit iCal 0.38
  – Qb 50mL/min
  – Citrate running at 100mL/hr
  – Calcium running at 40mL/hr

• Suspected citrate accumulation
  – Elevated total calcium = Ca-citrate
  – Although *alkalosis* is more common, unmetabolized citrate can cause *acidosis*
Citrate Accumulation: Management

• Techniques to mitigate citrate accumulation
  – Increase clearance (already > 100mL/kg/hr)
  – Reset citrate/calcium
  – Increase circuit iCal target (increase range to 0.45-0.55 or higher)
  – Reduce Qb (less citrate required)
  – Heparin (wholesale switch or low dose infusion into arterial lumen with higher circuit iCal range)
  – Look the other way and hope for transplant 😊
Case #3 – Additional Discussion

• How do you determine clearance goals (“dose”) for your patients?
• What circuit priming methods have you found to be most successful?
• What is your approach to anticoagulation?
Case #3 – Summary

• Clearance maintains metabolic balance but data on best goals for dose are lacking
• Pediatric patients more likely to require special circuit priming
• Anticoagulation is necessary, and sometimes it can be tricky
Case #4

CRRT IN THE OPERATING ROOM
Case #4 (or, continuation of #3) – Clinical Scenario

• 48 hours later – our patient receives offer for liver transplant

• Surgeons request CRRT support in OR
  – Fluid management
  – Hyperkalemia
Case #4 – Discussion

• What technical considerations are posed?
• How are prescription and dosing choices affected by OR location?
Intraoperative CRRT: Goals

• Maximize circuit life
• Address/mitigate surgeon concerns
  – Hyperkalemia
  – Fluid Overload
• Avoid complexity
  – Coordination with anesthesiologists
• Permit successful surgery and reasonable start to recovery
Case #4 – Technical Discussion

• Staffing
  – One dialysis nurse and one PICU nurse (may transition to single dialysis nurse)
  – One nephrology attending

• Preparation
  – IJ catheter is preferrable
    • Easier access if circuit is lost, troubleshooting
    • Not affected by intraabdominal clamping and procedure
    • Femoral catheter: prepare surgeons for need to access line
  – Second circuit primed and ready outside OR
  – Higher fluid alarm limit (infants 200mL, adults 400mL)
Case #4 – Prescription and Anticoagulation

• Prescription
  – Blood Prime if prime volume > 10% of pt blood volume
  – Qb 4-6mL/min (higher if possible to prevent clotting)
  – Clearance ~ 30-45mL/kg/hr unless needs higher for ammonia
  – QUF set to maintain even fluid balance if possible (requires constant communication with anesthesia)

• Anticoagulation
  – Citrate anticoagulation with std iCal targets (short run time so citrate toxicity is unlikely)
  – Could consider no anticoagulation with NS flushes (50-250mL q30min)
Case #4 – Solutions

• Dialysate Bags
  – Need to have both 0K and 2K bags from the start
  – Start with 0K
  – Maintain $K$ in the 2.5-3 range
  – Use 0K bags 15 min prior to unclamping and throughout hepatic reperfusion
Case #4 – Additional Discussion

• Does your program provide RRT in the OR? What approach do you use?
• What challenges have you encountered with intraoperative RRT?
Case #4 – Summary

• CRRT in the OR presents unique challenges
• Careful planning and coordination ahead of time is essential
Not Your Parent’s CRRT: Summary

• Pediatric CRRT can present many challenges:
  – Prescription
  – Coordination with other therapies/interventions
  – Complications

• We have touched upon some common problems and some unique issues

• CRRT is a team effort:
  – Between colleagues at the bedside
  – Among colleagues around the world
Any Other Comments or Questions?
Thanks for Your Participation!