Pediatric CRRT
The Basics

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Scott Sutherland
Jordan Symons
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San Diego 2012
Epidemiology Of and Indications For Pediatric CRRT
Hospitalized patient deteriorates  
Cardiac or other surgery  
ER patient resuscitated

ACUTE KIDNEY INJURY

HOW COMMON?
WHO DOES IT HAPPEN TO?

WHO GETS IT?
WHAT DO THEY GET?
WHO SHOULD GET IT?
## Pediatric AKI: Definition

### Pediatric RIFLE (pRIFLE)

**Ackan-Arikan et al, Kidney International, 2007**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Estimated CCl</th>
<th>Urine output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk</td>
<td>eCCl decrease by 25%</td>
<td>&lt;0.5 ml/kg/h for 8 h</td>
</tr>
<tr>
<td>Injury</td>
<td>eCCl decrease by 50%</td>
<td>&lt;0.5 ml/kg/h for 16 h</td>
</tr>
<tr>
<td>Failure</td>
<td>eCCl decrease by 75%</td>
<td>&lt;0.3 ml/kg/h for 24 h or</td>
</tr>
<tr>
<td></td>
<td>eCCl &lt; 35 ml/min/1.73 m²</td>
<td>anuric for 12 h</td>
</tr>
<tr>
<td>Loss</td>
<td>Persistent failure &gt; 4 weeks</td>
<td></td>
</tr>
<tr>
<td>End stage</td>
<td>End-stage renal disease (persistent failure &gt; 3 months)</td>
<td></td>
</tr>
</tbody>
</table>

eCCl, estimated creatinine clearance; pRIFLE, pediatric risk, injury, failure, loss and end-stage renal disease.

### Acute Kidney Injury Network

**Mehta et al, Crit Care Med, 2007**

<table>
<thead>
<tr>
<th>AKI stage</th>
<th>Creatinine criteria</th>
<th>Urine output criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>AKI stage I</td>
<td>Increase of serum creatinine by ≥ 0.3 mg/dl (≥ 26.4 μmol/L) or increase to ≥ 150% – 200% from baseline</td>
<td>Urine output &lt; 0.5 ml/kg/hour for &gt; 6 hours</td>
</tr>
<tr>
<td>AKI stage II</td>
<td>Increase of serum creatinine to &gt; 200% – 300% from baseline</td>
<td>Urine output &lt; 0.5 ml/kg/hour for &gt; 12 hours</td>
</tr>
<tr>
<td>AKI stage III</td>
<td>Increase of serum creatinine to &gt; 300% from baseline or serum creatinine ≥ 4.0 mg/dl (≥ 354 μmol/L) after a rise of at least 44 μmol/L or treatment with renal replacement therapy</td>
<td>Urine output &lt; 0.3 ml/kg/hour for &gt; 24 hours or anuria for 12 hours</td>
</tr>
</tbody>
</table>

Diagnostic criteria for AKI includes an abrupt (within 48 hours) reduction in kidney function defined as an absolute increase in serum creatinine of either 0.3 mg/dl or more (≥ 26.4 μmol/L) or a percentage increase of 50% or more (1.5 fold from baseline) or a reduction in urine output.

*a* according to Mehta and colleagues [8]
Pediatric AKI: Incidence in PICU
Population & Definition-dependent

- Cardiac Surgery

\[ N = 395 \]

\[ \text{AKI: 34\%} \]


\[ N=395 \]

\[ \text{AKI: 21\%} \]

Anesth Analg 2009;109:45–52 (Aprotinin study)

Renal replacement therapy: 1 to 10\% - CRRT not very common
Pediatric AKI: Incidence in PICU Population & Definition-dependent

- General PICU

Vasopressors+Ventilated + Catheter


82% AKI

N=150

All PICU stay>12hr

- Al-Kandari/Eddington, Crit Care, 2011

20% AKI

N=2148

All PICU admissions

- Schneider, Crit Care Med, 2010

10% AKI

N=3396

Renal replacement therapy: 1 to 9% -- some receive CRRT
CRRT Diagnoses
Mostly secondary renal disease

Other – Spain: Much more in cardiac patients. Santiago et al, Int Care Med, 2010

Severe AKI tends to occur EARLY in PICU admission
RRT Options

- Hemodialysis, Peritoneal Dialysis, CRRT
  - Patient Characteristics
    - Disease/Symptoms
    - Hemodynamic stability
  - Goals of therapy
    - Fluid removal
    - Electrolyte correction
    - Both
  - Availability, expertise and cost

Strazdins et al, Pediatr Nephrol, 2004*
## RRT Options

<table>
<thead>
<tr>
<th>Modality</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute Hemodialysis</td>
<td>Short treatment</td>
<td>Vascular access necessary</td>
</tr>
<tr>
<td></td>
<td>Accurate UF</td>
<td>Hemodynamic instability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heparin</td>
</tr>
<tr>
<td>Peritoneal Dialysis</td>
<td>No vascular access</td>
<td>Less efficient</td>
</tr>
<tr>
<td></td>
<td>Minimal equipment</td>
<td>Variable UF</td>
</tr>
<tr>
<td></td>
<td>Minimal training</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Feasible small infants</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Continuous</td>
<td></td>
</tr>
<tr>
<td>Continuous renal replacement therapy</td>
<td>Accurate UF, continuous alterations</td>
<td>Vascular access</td>
</tr>
<tr>
<td></td>
<td>Smaller circuit volumes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Citrate anticoagulation</td>
<td></td>
</tr>
</tbody>
</table>
Trends in Pediatric RRT

- CRRT use may be increasing in North America (Warady & Bunchman, Pediatr Nephrol, 2000)

- European guidelines (Strazdins et al, Pediatr Nephrol, 2004)

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**Singapore**

1980-95: 100%

Post-1995: 50%

*Gong et al, Ped Neph, 2001*

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**USA**

1979-88:

1989-1998:

*Williams et al, Arch Ped Adol Med, 2002*
Why CRRT?

- Deals well with hemodynamic instability
  - Precise Volume control/immediately adaptable
  - Effective control of uremia, hypophosphatemia, hyperkalemia, acid base balance

Management of sepsis/plasma cytokine filter

Allows for improved provision of nutritional support
Indications for Pediatric RRT

- Electrolyte (metabolic) imbalance
- Uremia with bleeding and or encephalopathy
- Acuity/Degree of Kidney Injury
  - reduction in GFR/elevated creatinine
  - reduction in urine output
- Nutritional support
- Intoxications, Inborn errors of Metabolism (IEM)
- Fluid Overload

Table 4. Indications for CRRT and survival

<table>
<thead>
<tr>
<th>Indication</th>
<th>n</th>
<th>Survivors</th>
<th>% Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid overload and electrolyte imbalance</td>
<td>157</td>
<td>80</td>
<td>51</td>
</tr>
<tr>
<td>Fluid overload only</td>
<td>100</td>
<td>61</td>
<td>61</td>
</tr>
<tr>
<td>Electrolyte imbalance only</td>
<td>44</td>
<td>30</td>
<td>68</td>
</tr>
<tr>
<td>Prevent fluid overload to allow intake</td>
<td>11</td>
<td>7</td>
<td>64</td>
</tr>
<tr>
<td>Other</td>
<td>32</td>
<td>23</td>
<td>72</td>
</tr>
</tbody>
</table>

Fluid Overload

(Total fluid in – Total out)/ weight X 100 = FO %: Goldstein et al, Pediatrics, 2001

Change in weight: Selewski et al, Intens Care Med, 2011

Outcome in Children Receiving Continuous Venovenous Hemofiltration

Stuart L. Goldstein, MD*; Helen Currier, RN, CNN‡; Jeanine M. Graf, MD§; Carmen C. Cosio, MD§; Eileen D. Brewer, MD*; and Ramesh Sachdeva, MD§

Pediatrics 2001:107:1309-1312

Foland et al, Crit Care Med, 2009

Hayes et al, J Crit Care, 2009

Selewski et al, Int Care Med, 2011

MV analysis: FO – mortality association independent of illness severity
How much is too much?

**Table 3** Predictors of survival in all patients

<table>
<thead>
<tr>
<th>Variable</th>
<th>Survivors, n = 42</th>
<th>Nonsurvivors, n = 34</th>
<th>Odds ratio</th>
<th>95% CI</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;20% FO</td>
<td>8 (19.1%)</td>
<td>20 (58.8%)</td>
<td>6.1</td>
<td>(2.2-17.0)</td>
<td>.0006</td>
</tr>
<tr>
<td>Sepsis</td>
<td>13 (31%)</td>
<td>29 (85.3%)</td>
<td>12.9</td>
<td>(4.1-41.0)</td>
<td>.0001</td>
</tr>
<tr>
<td>MODS</td>
<td>29 (69%)</td>
<td>34 (100%)</td>
<td>a</td>
<td>a</td>
<td>.0003</td>
</tr>
</tbody>
</table>

*Unable to calculate odds ratio because 100% of nonsurvivors had MODS.*

*Gillespie et al, Pediatr Nephrol, 2004*

*Hayes et al, J Crit Care, 2009*
Figure 1. Mortality rates of pediatric intensive care unit patients receiving continuous renal replacement therapy subdivided by degree of fluid overload. Error bars represent 95% confidence intervals for the mortality rate in each fluid overload group. There was a statistically significant difference in mortality among the 3 groups. Patients with ≥ 20% fluid overload had significantly higher mortality than patients with < 10% fluid overload and those with 10%-20% fluid overload. Patients with 10%-20% fluid overload had a trend toward increased mortality compared with patients with < 10% fluid overload; however, this trend did not reach statistical significance (P = 0.07).

Sutherland et al, AJKD, 2010
CRRT for FO

Pediatric Stem Cell Transplant with Acute Lung Injury

Within 24-48 hours of CRRT initiation:

- Better oxygenation (PaO2/FiO2)
- More negative fluid balance

Elbahlawan et al, Pediatr Blood Cancer, 2010

Hoover et al, Intens Care Med, 2008
Timing of Pediatric RRT

Will depend on the patient, the individual physician and the place.

**Considerations**

Emerging importance of fluid overload prevention.

Children develop MODS and severe AKI *early* in ICU course

Children die with MODS very early in ICU course

Feasible in children
Summary: Pediatric CRRT
Epidemiology and Indications

- Pediatric AKI may be more common than previously described
- Primary renal disease giving way to MODS
- CRRT for children continues to expand
  - Advantageous in critically ill child
  - Effective
  - Useful in setting of volume overload
- Best time to start remains uncertain
CRRT Terminology and Modalities
Diffusion vs. Convection

Diffusion is solute transport across a semi-permeable membrane - molecules move from an area of higher to an area of lower concentration.

Convection is a process where solutes pass across the semi-permeable membrane along with the solvent in response to a positive transmembrane pressure.

Small molecules diffuse more readily than large molecules.

Small and large molecules convect equally well; limit is membrane cut-off.
Current Nomenclature for CRRT

SCUF: Slow Continuous Ultrafiltration
CVVH: Continuous Veno-Venous Hemofiltration
CVVHD: Continuous Veno-Venous Hemodialysis
CVVHDF: Continuous Veno-Venous Hemodiafiltration
CRRT Schematic

- SCUF
- CVVH
- CVVHD
- CVVHDF
CRRT Machines
Prescribing Pediatric CRRT
Prescribing Pediatric CRRT

- Vascular access
- Hemofilter
- Prime
- Blood pump speed ($Q_B$)
- Anticoagulation
- Ultrafiltration rate
- Infused fluids
  - CVVH: Pre- and/or post-dilutional replacement
  - CVVVHD: Counter-current dialysate
  - CVVHDF: Dialysate and replacement fluid
Hemofilter for CRRT

• Hemofilter size
  – Volume, porosity

• Membrane material
  – Polysulfone, AN-69, PAES, etc.

• Tubing set – integrated or separate?

• “Open” vs. “closed” systems – do you have a choice?
Priming the Circuit for Pediatric CRRT

• Blood
  – Small patient, large extracorporeal volume
• Albumin
  – Hemodynamic instability
• Saline
  – Common default approach
• Self
  – Volume loaded renal failure patient
Choosing $Q_B$ for Pediatric CRRT

- Equation for blood flow rate ($Q_B$):
  - 3-5ml/kg/min
- Choose from a table:
  - 0-10 kg: 25-50ml/min
  - 11-20kg: 80-100ml/min
  - 21-50kg: 100-150ml/min
  - >50kg: 150-180ml/min
- CRRT device may affect choices for $Q_B$

The real determinant – the vascular access
Ultrafiltration in Pediatric CRRT

• Choose UF rate to
  – balance input
  – remove excess fluid over time
  – “make room” for IV fluids and nutrition
  – provide solute clearance by convection

• SCUF, CVVHD, post-dilution CVVH: UF rate may be limited by blood flow (filtration fraction)

• Pre-dilution CVVH: High flow of pre-dilution fluid lessens hemoconcentration

• Remember to consider UF limits of the filter, especially in higher-volume hemofiltration
Ultrafiltration Rates

• No study has identified effective, safe UF rates in children

• For HEMODIALYSIS—NET UF rate of 0.2ml/kg/min is tolerated
  – This extrapolates to 1 ml/kg/ hr (NET UF) over 48 hr of continuous hemofiltration

Donckerwolke –Ped Neph 8:103-106,1994
Infused Fluids for Pediatric CRRT

- SCUF: No infused fluids
- CVVHD: Counter-current dialysate
- CVVH: Pre- and/or post-dilution replacement fluid
- CVVHDF: Dialysate and replacement fluids
Rate for Infused Fluid

• Higher rates increase clearance
• Lower rates may simplify electrolyte balance and limit protein loss
• Equations to help choose rate for fluid:
  – 20-60 ml/kg/hr
  – 2000-3000 ml/hr/1.73m²
• May need higher rates to balance citrate delivery
Characteristics of the Ideal CRRT Solution

- Physiological
- Reliable
- Inexpensive
- Easy to prepare

- Simple to store
- Quick to the bedside
- Widely available
- Fully compatible
Purpose of CRRT solutions

• Provide safe and consistent metabolic control
• To be adaptive to the choice of therapy-CVVH, CVVHD, CVVHDF
Options for CRRT Solutions

- Peritoneal dialysate: **NO**
- Pre-made IV solutions: **MAYBE**
  - Saline, Lactated Ringers
- Custom-made solutions: **RARELY**
  - Local pharmacy; outsource
- Commercially available CRRT solutions
Prevalence and Consequences of Errors in Solution Preparation

• 16/31 programs reported errors:
  – 7 errors in replacement solutions
  – 9 errors in dialysate solutions

• Consequences of improper solutions
  – 2 deaths
  – 1 non lethal cardiac arrest
  – 6 seizures (hypo/hypernatremia)
  – 7 without complications

What’s the Difference Between Dialysate and Replacement Fluid?

Dialysate is a Device
Replacement Fluid is a Drug
## CRRT Solutions – Many Choices

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>R / D</th>
<th>Bag Size*</th>
<th>Flavors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normocarb HF</td>
<td>DSI</td>
<td>R</td>
<td>3.24 L</td>
<td>2</td>
</tr>
<tr>
<td>Prismasate</td>
<td>Gambro</td>
<td>D</td>
<td>5 L</td>
<td>6</td>
</tr>
<tr>
<td>Accusol</td>
<td>Baxter</td>
<td>D</td>
<td>2.5 L</td>
<td>5</td>
</tr>
<tr>
<td>Prismsasol</td>
<td>Gambro</td>
<td>R</td>
<td>5 L</td>
<td>7</td>
</tr>
<tr>
<td>Duosol</td>
<td>B Braun</td>
<td>D</td>
<td>5 L</td>
<td>6</td>
</tr>
<tr>
<td>PureFlow</td>
<td>NxStage</td>
<td>D</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

*after mixing
Summary: Prescribing Pediatric CRRT

• All modalities (SCUF, CVVH, CVVHD, CVVHDF) are available for treating critically ill children
• Newer solutions make CRRT safer for children as they do for adults
• Devices and equipment are adapted for kids
• Special consideration for flow rates, based on
  – Vascular access
Vascular Access and Anticoagulation for Pediatric CRRT
Why

- Access function is crucial for therapy
- Flows obtained will affect adequacy of blood flow for dose delivered and can affect filter-circuit life
- Downtime from clotted circuits-access is time off therapy
Access Considerations

• Low resistance
  – Resistance \( \sim 8\eta/2r^4 \)
  – So, the biggest and shortest catheter should be best

• Vessel size
  – French \( \sim 3 \times \) diameter of vessel
  – Beside ultrasound nearly universal
  – SVC is bigger than femoral vein
Access Considerations

• Internal Jugular
  – Very accessible
  – Large caliber (SVC)
  – Great flows
  – Low recirculation rate
  – Risk for Pneumothorax
  – Cardiac monitoring may take precedence.

• Femoral
  – Usually accessible
  – Smaller than SVC
  – Flows may be diminished by:
    • Abdominal Pressures
    • Patient movement
  – Risk for retroperitoneal hemorrhage
  – Higher recirculation rate

• Subclavian: Many feel current double lumen vas cath are too stiff to make the turn into the SVC and I don’t personally use them. Although they are used in some centers.
  • Better for bigger kids likely.
1. Provide optimal access for acute dialysis/CRRT/Pheresis to maximize blood flow while minimizing vessel trauma

2. Site – Internal jugular vein preferred, femoral vein second option

<table>
<thead>
<tr>
<th>Patient size</th>
<th>Catheter size</th>
<th>Special</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neonates</td>
<td>7 French</td>
<td>Triple lumen is available for CaCl₂ if providing citrate regional anticoagulation</td>
</tr>
<tr>
<td>3-6 kg</td>
<td>7 French</td>
<td>Triple lumen is available for CaCl₂ if providing citrate regional anticoagulation</td>
</tr>
<tr>
<td>6-12 kg</td>
<td>8 French</td>
<td></td>
</tr>
<tr>
<td>12-20 kg</td>
<td>9 French</td>
<td></td>
</tr>
<tr>
<td>20-30 kg</td>
<td>10 French</td>
<td></td>
</tr>
<tr>
<td>30+ kg</td>
<td>10 French or 11 French</td>
<td>Triple lumen 11.5 Fr should always be used for CaCl₂ if providing citrate regional anticoagulation</td>
</tr>
</tbody>
</table>
The effect of vascular access location and size on circuit survival in pediatric continuous renal replacement therapy: A report from the PPCRRT registry

376 Patients
1574 circuits

Femoral 69%
IJ 16%
Sub-Clavian 8%
Not Specified 7%
Circuit Survival Curves by French Size of Catheter

Hackbarth R et al: IJA/O December 2007
Summary: Vascular Access for Pediatric CRRT

• Put in the largest and shortest catheter when possible
  – Caveat: short femoral catheters have been shown to have high rate of recirc in adult patients. (Little et al. AJKD 2000;36:1135-9)

• The IJ site is preferable (over femoral) when clinical situation allows

• Avoid 5Fr Catheters
Anticoagulation

• Another crucial step in delivering the prescribed dose (reducing downtime)
• Critically ill patients are at risk for both increased and decreased clot formation simultaneously
Calcium is necessary for each event in the cascade.

Heparin acts in conjunction with ATIII on thrombin and F IX, FX, FXII
What the filter looks like

Hofbauer R et al. Kid Int 1999;56:1578-83

Electron microscopy of polysulfone hemodiafilter with two varieties of anticoagulation during IHD. Granted, no monitoring of degree of anticoagulation was performed to assess adequacy of response.
Anticoagulation

- **Systemic Heparin**
  - Goal ACT 180-240 sec
  - Patient anticoagulated
    - Risk of bleeding
  - Risk for HIT

- **Regional Citrate**
  - Goal Circuit iCal 0.3-0.4 mmol/L
  - Goal Patient iCal 1.1-1.4 mmol/L
  - Risk for
    - Hypocalcemia
    - Alkalosis
    - Hyponatremia
Multi-centre evaluation of anticoagulation in patients receiving continuous renal replacement therapy (CRRT)

Patrick D. Brophy1, Michael J. G. Somers2, Michelle A. Baum2, Jordan M. Symons3, Nancy McAfee3, James D. Fortenberry4, Kristine Rogers4, Joni Barnett5, Douglas Blowey6, Cheryl Baker7, Timothy E. Bunchman8 and Stuart L. Goldstein7

- 138 Patients in multicenter registry study
- 442 Circuits
- Circuit survival time evaluated for three anticoagulation strategies
  - Heparin (52% of circuits)
  - Regional Citrate (36% of circuits)
  - No anticoagulation (12% of circuits)
• Mean circuit survival (42 and 44 hr) were not different for Hep vs Citrate, but both longer than no anticoagulation (27 hr)

• At 60 hr, 69% of Hep and Citrate circuits were functional, but only 28% of the no-anticoagulation circuits

• In this analysis circuit survival was not affected by the access size

• Citrate group had no bleeding complications, 9 Heparin patients with bleeding
Citrate Specific Issues

• Alkalosis
  – 1 mmol Citrate to 3 mmol HCO3
  – Normocarb protocols may exacerbate (35 mEq/L)

• Hypernatremia
  – Tri-Sodium Citrate infusion

• Hypocalcemic Citrate Toxicity
  – Incomplete clearance of citrate, usually due to liver dysfunction
  – Rising total calcium, decreasing iCal
Summary: Anticoagulation for Pediatric CRRT

• Heparin or Citrate is better than no anticoagulation (even in liver failure, DIC, etc)
• Citrate has fewer bleeding complications
• Circuit survival means less downtime hence more delivered therapy
• Pick institutional strategy and learn to use it well
• Consider citrate as the method of choice
Demographics and Outcomes
Demographics

• Provision of CRRT to children requires care of a disparate population

• Prospective Pediatric CRRT Registry (ppCRRT)
  – 344 children from 13 US centers
  – Age range from newborn to 25 years of age
  – Weight range from 1.3kg to 160kg
  – Numerous underlying diseases states
  – Multiple organ systems affected

Demographics

Which children receive CRRT?

• Mostly critically ill children with AKI and fluid overload

• ppCRRT data
  – 2/3 of kids were receiving vasopressor support
  – 1/2 of patients were receiving diuretics

• Outcome highly dependent on underlying disease and severity of illness
Demographics
Underlying Disease

<table>
<thead>
<tr>
<th>Primary Diagnosis</th>
<th>Patients</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sepsis</td>
<td>81</td>
<td>23.5%</td>
</tr>
<tr>
<td>Stem Cell Transplant</td>
<td>55</td>
<td>16.0%</td>
</tr>
<tr>
<td>Cardiac Disease/Transplant</td>
<td>41</td>
<td>11.9%</td>
</tr>
<tr>
<td>Renal Disease</td>
<td>32</td>
<td>9.3%</td>
</tr>
<tr>
<td>Liver Disease/Transplant</td>
<td>29</td>
<td>8.4%</td>
</tr>
<tr>
<td>Malignancy (w/o tumor lysis)</td>
<td>29</td>
<td>8.4%</td>
</tr>
<tr>
<td>Ischemia/shock</td>
<td>19</td>
<td>5.5%</td>
</tr>
<tr>
<td>Inborn Error of Metabolism</td>
<td>15</td>
<td>4.4%</td>
</tr>
<tr>
<td>Drug Intoxication</td>
<td>13</td>
<td>3.8%</td>
</tr>
<tr>
<td>Tumor Lysis Syndrome</td>
<td>12</td>
<td>3.5%</td>
</tr>
<tr>
<td>Pulmonary Disease/Transplant</td>
<td>11</td>
<td>3.2%</td>
</tr>
<tr>
<td>Other</td>
<td>7</td>
<td>2.0%</td>
</tr>
</tbody>
</table>


Isolated Renal Disease Uncommon
Majority have systemic disease
Most common diagnoses
- Sepsis (23.5%)
- Oncologic (27.9%)
### Outcomes

#### General Survival Rates

<table>
<thead>
<tr>
<th>Study</th>
<th>Age</th>
<th>Pt. #</th>
<th>Survival</th>
<th>Associated with Increased Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunchman et. al. (2001)</td>
<td>6.2y</td>
<td>106</td>
<td>40%</td>
<td>Vasopressor use, non-renal diagnosis</td>
</tr>
<tr>
<td>Goldstein, et. al. (2001)</td>
<td>8.8y</td>
<td>22</td>
<td>43%</td>
<td>Greater FO</td>
</tr>
<tr>
<td>Gillespie (2004)</td>
<td>5.1y</td>
<td>77</td>
<td>50%</td>
<td>Greater FO</td>
</tr>
<tr>
<td>Foland et. al. (2004)</td>
<td>9.6y</td>
<td>113</td>
<td>61%</td>
<td>MODS, Greater FO</td>
</tr>
<tr>
<td>ppCRRT</td>
<td>8.5y</td>
<td>344</td>
<td>58%</td>
<td>Oncologic disease, MODS, Greater FO,</td>
</tr>
<tr>
<td>-Symons et. al. (2007)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Sutherland et. al. (2010)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hayes, et. al. (2009)</td>
<td>5.8y</td>
<td>76</td>
<td>55%</td>
<td>Sepsis, MODS, Greater FO</td>
</tr>
</tbody>
</table>

Survival rate has improved over time from **40-45%** to **55-60%**

Underlying disease, comorbidities, risk factors determine mortality
Outcomes

Question 1

• Does underlying or primary disease matter?
  – Yes
  – No

• What diseases are associated with worse outcomes?
# Outcomes

## Risk Factors

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds Ratio (Mortality)</th>
<th>95% Confidence Interval</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid Overload Group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\geq 20%$ FO vs. $&lt;10%$ FO</td>
<td>21.1</td>
<td>5.2 – 85.7</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>$\geq 20%$ FO vs. 10%-20% FO</td>
<td>11.2</td>
<td>1.8 – 68.4</td>
<td>$0.009$</td>
</tr>
<tr>
<td>10%-20% FO vs. $&lt;10%$ FO</td>
<td>1.9</td>
<td>0.33 – 10.8</td>
<td>$0.48$</td>
</tr>
<tr>
<td>Oncologic Diagnosis</td>
<td>5.8</td>
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<td>$&lt;0.001$</td>
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<td>1.4 – 9.9</td>
<td>$0.008$</td>
</tr>
<tr>
<td>Sepsis Diagnosis</td>
<td>3.6</td>
<td>1.3 – 9.8</td>
<td>$0.01$</td>
</tr>
<tr>
<td>Convective CRRT Modality</td>
<td>0.49</td>
<td>0.28 – 0.86</td>
<td>$0.01$</td>
</tr>
<tr>
<td>PRISM II PICU Admission</td>
<td>1.04</td>
<td>1.0 – 1.1</td>
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</tr>
<tr>
<td>IEM/Intoxication Diagnosis</td>
<td>3.4</td>
<td>0.75 – 15.2</td>
<td>$0.11$</td>
</tr>
<tr>
<td>Inotrope Number</td>
<td>1.2</td>
<td>0.9 – 1.6</td>
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</tr>
<tr>
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<td>1.01</td>
<td>0.97 – 1.05</td>
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</tr>
<tr>
<td>Sex</td>
<td>0.96</td>
<td>0.55 – 1.7</td>
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</table>

Outcomes
Risk Factors: Oncologic Illness

• 51 patients in ppCRRT w/ stem cell transplant
• 45% survival

• Improved survival w/ convective modality (univariate analysis)


76% also had MODS
Mean FO was over 12%
Outcomes
Risk Factors: MODS

• Critically ill kids w/ multi-organ dysfunction syndrome from ppCRRT Registry

• n = 116

• Survival 51.7%

• Causes of AKI necessitating CRRT
  – Sepsis (39.2%)
  – Cardiogenic shock (20%)

• Fluid overload higher in non-survivors (again)

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<th>Primary Diagnosis</th>
<th>Survival</th>
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<td>Liver Disease/Transplant</td>
<td>31%</td>
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<td>45%</td>
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<tr>
<td>Stem Cell Transplant</td>
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<tr>
<td>Malignancy (w/o tumor lysis)</td>
<td>48%</td>
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<tr>
<td>Cardiac Disease/Transplant</td>
<td>51%</td>
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<tr>
<td>Sepsis</td>
<td>59%</td>
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<tr>
<td>Ischemia/shock</td>
<td>68%</td>
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<tr>
<td>Inborn Error of Metabolism</td>
<td>73%</td>
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<tr>
<td>Renal Disease</td>
<td>84%</td>
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<tr>
<td>Tumor Lysis Syndrome</td>
<td>83%</td>
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<tr>
<td>Drug Intoxication</td>
<td>100%</td>
</tr>
<tr>
<td>Other</td>
<td>71%</td>
</tr>
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Outcomes
Question 2

• Does fluid overload matter?
  – Yes
  – No
Outcomes
Risk Factors

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Outcomes
Risk Factors: Fluid Overload


If treated as a continuous variable, odds ratio for FO is 1.03

For every 1% increase in FO, mortality increases by 3%, even after adjusting for severity of illness
Outcomes

Question 3

• Are long term outcomes good or bad?
  – Yes
  – No
  – Nobody Knows
Outcomes
ECMO and CRRT

• Retrospective, single center analysis of ECMO data base
  – 154/378 patients received ECMO and CRRT
  – 68/154 survived to hospital discharge
  – 65/68 (96%) RECOVERED RENAL FUNCTION AND DID NOT REQUIRE RRT AT DISCHARGE

• 3/68 who required RRT at discharge all had primary renal disease

Outcomes

Long term outcomes AKI #1

- Original study of 245 inpatients with AKI
- 174 kids survived to hospital discharge and had long term data available
  - Survival amongst these kids was ~ 80% (139/174)
  - Of these deaths, ~ 70% occurred in the first 12mo
- At 3-5 years post hospital discharge
  - Renal survival ~ 90%
  - WORSE in those with primary renal disease (69% vs. 96%)
  - 60% of patients (n=29) had either microalbuminuria, hyperfiltration, reduced GFR, or hypertension

Outcomes
Long term outcomes AKI #2

- 37 children with AKI (age 1mo to 10y)
- West Bengal and East India
  - AKI due to glomerulonephritis in 46%
  - AKI due to snakebite in 24%
  - AKI due to sepsis in 8%
- Survival 65%
- 1/3 of survivors with long term data had abnormal creatinine, hematuria, proteinuria, or hypertension

- Patients with AKI requiring CRRT are likely to be on the more severe end of the spectrum and likely have greater incidence of long term sequelae

Outcomes

Summary

• The majority of patients who receive CRRT are:
  – Critically ill
  – Have multisystem illness (rather than primary renal disease)
  – Have fluid overload

• Outcome hinges on:
  – Underlying disease and cause of AKI
  – Severity of illness
  – Severity of fluid overload
  – Seems to not hinge on CRRT dose
Outcomes

Summary

• Overall survival ranges from 45-60%
• Survivors can expect recovery of renal function and RRT independence
  – Unless cause of AKI is a primary renal disease
• Survivors are likely to have long-term sequelae and require long term follow up
  – Hypertension
  – Proteinuria
  – Chronic kidney disease