Renal Section
Fluids, Electrolytes, AKI / ARF, Renal Support

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Section of Trauma, Surgical Critical Care and Surgical Emergencies
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Objectives

- Fluids
  - Resuscitation
    - Crystalloids vs colloids
    - Blood
  - Maintenance
- Common electrolyte management issues
- AKI and ARF
- Renal support methods
Resuscitation Fluids

- **Goal**
  - Restore effective circulating volume for appropriate end-organ perfusion, DO2/VO2

- **Types of FDA approved fluids**
  - Crystalloids
  - Colloids
  - Whole blood
  - Component blood products
Resuscitation Fluids

- Crystalloid vs Colloid
  - Often a matter of religion
  - Emerging science (esp. with crystalloid excess)
    - Abdominal compartment syndrome, edema

- Crystalloids
  - Normotonic fluids, NO DEXTROSE
    - Avoid inducing an osmotic diuresis!
  - Compartment physiology
    - ECF, plasma space, intracellular
Balance Between Fluid Compartments

- Only 2 places for exchange between compartments:
  - cell membranes (intracellular vs interstitial)
  - Only capillary walls permit exchange (plasma → interstitial)

Volume of fluid in each is kept constant. Since water follows electrolytes, they must be in balance as well.
Body Water Gain and Loss

- 45-75% body weight
  - declines with age
  - fat has ~ no water

Gains
- Intake (po)
- Metabolic H₂O (aerobic respiration)
- dehydration synthesis reactions
- Total = 2500 mL/day

Body Water Content

Normally gain = loss
Comparison Between Fluid Compartments

- Plasma proteins >> interstitial
- Plasma proteins
- Interstitial fluid
- Intracellular fluid

- colloid osmotic pressure

Key:
- Extracellular fluids
- Plasma
- Interstitial fluid
- Intracellular fluid

- Plasma proteins >> interstitial
Starling Forces

Key to pressure values:
- $HP_c$ at arterial end = 35 mm Hg
- $HP_c$ at venous end = 17 mm Hg
- $HP_f = 0$ mm Hg
- $OP_f = 1$ mm Hg
- $OP_c = 26$ mm Hg

Net HP (35-0) - Net OP (26-1)

Net HP (17-0) - Net OP (26-1)

Net pressure out

Net pressure in
Crystalloids for Resuscitation

- 0.9% NSS
- Lactated Ringer’s solution
- Other fluids
  - Plasmalyte
  - Normosol
# Electrolyte Composition

<table>
<thead>
<tr>
<th>Type</th>
<th>Na</th>
<th>Cl</th>
<th>K</th>
<th>Mg</th>
<th>Ca</th>
<th>LA</th>
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<tr>
<td>NSS</td>
<td>154</td>
<td>154</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>LR</td>
<td>130</td>
<td>110</td>
<td>3.3</td>
<td>2.8</td>
<td>4.5</td>
<td>28</td>
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<tr>
<td>Plasma</td>
<td>140</td>
<td>100</td>
<td>4</td>
<td>2</td>
<td>4.5</td>
<td>2</td>
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</table>
Resuscitation Fluid Volume

- General rule (may not apply with sepsis)
  - Whole blood loss replaced with 3 times as much crystalloid
  - 1 L EBL = 3 L crystalloid

- Intravascular retention
  - Health: 25% of infused crystalloid
  - 2000 cc infused = 500 cc retained
    - 10% plasma volume expansion (ATLS)
## Classes of Hemorrhagic Shock

<table>
<thead>
<tr>
<th>Class</th>
<th>HR</th>
<th>SBP</th>
<th>PP</th>
<th>EBV</th>
<th>Rx</th>
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<td><img src="#" alt="icon" /></td>
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<td><img src="#" alt="icon" /></td>
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<td><img src="#" alt="icon" /></td>
<td>15-30%</td>
<td>± Colloid</td>
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<tr>
<td>III</td>
<td><img src="#" alt="icon" /></td>
<td><img src="#" alt="icon" /></td>
<td><img src="#" alt="icon" /></td>
<td>30-40%</td>
<td>PRBC</td>
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<tr>
<td>IV</td>
<td><img src="#" alt="icon" /></td>
<td><img src="#" alt="icon" /></td>
<td><img src="#" alt="icon" /></td>
<td>&gt;40%</td>
<td>PRBC</td>
</tr>
</tbody>
</table>
Efficacy of Resuscitation Fluids

- **ATLS**
  - 2000 cc crystalloid
    - 25% vascular retention = 500 cc bolus
    - 10% circulating volume expansion
  - Excessive crystalloids may lead to:
    - Tissue edema, HCMA
    - Coagulopathy, ALI/ARDS
    - Abdominal Compartment Syndrome

*Ditillo M, et al. Core Topics: Intra-abdominal Hypertension 2010*
Account for Cavity Losses
Account for Ongoing Losses
Evaporation and 3rd Space

25% maintenance  3rd space

25% maintenance  3rd space

1000 cc evaporative loss/hour

25% maintenance  3rd space

25% maintenance  3rd space
Capillary Leak

Colloid Resuscitation

- Ultimate colloid is whole blood
  - Military “buddy” transfusion
- Damage control resuscitation
  - Blood product ratio 1:1:1
  - Poorly followed in existing MTP
- Standard outside of the US
  - 1:1::infusion:retention ratio
Starches

- Molecular weight (MW)
  - Larger molecular size
    - Vascular retention; increases $t^{1/2}$
    - 7.0nm pore size admits 108kDa molecule
    - Albumin: 60kDa $\rightarrow \sim 5.3$nm pore size
      - Fournier RL. *Basic transport phenomena in biologic engineering*. Taylor & Francis, Phila, PA 1999; 23-60

- Degree of substitution (DS)
  - # hydroxyethyl gps/100 glucose groups
  - Large DS increases $t^{1/2}$
Glucose, Sucrose, Starch

- Glucose
- Sucrose
- Starch

Potato Maize
Starch Terminology

- Heta-starch
  - DS = 0.7
- Penta-starch
  - DS = 0.5
- Tetra-starch
  - DS = 0.4

Persistence increased with higher DS
- Originally was desirable
- Now is a design defect
Colloid Resuscitation

- FDA Approved Products
  - 6% hydroxyethyl starch (HES)
    - 0.9% NSS diluent (Hespan)
    - Balanced salt diluent (Hextend)
  - 6% HES 130/0.4
    - 0.9% NSS diluent (Voluven)
- Presumed effectiveness ratio 1:3
  - Actual ratio 1:1.4
    - Multiple studies (SAFE, VI SEP, 6S)
US Colloids

- 5% or 25% human albumin
  - 0.9% NSS diluent only
- Dextran 40% or 70%
  - Hyperoncotic and allergic reactions
- Fresh Frozen Plasma (FFP)
  - Ideal resuscitant
    - Specific criteria for Tx lacking
  - Associated with TRALI, TACO
Synthetic Colloids
Not For Sepsis Resuscitation

- Strongly implicated in AKI/ARF in sepsis
  - Causality not clear
  - Incorrect comparators (Schortgen, Brunkhorst)

- 6S Study
  - Modern starch in RA vs RA
    - Correct comparator
  - Higher incidence of AKI/ARF and mortality
Study Design (n=822)

Oncotic Pressure and Renal Injury

- SHOCK
  - Crystalloid 127
  - Hypooncotic 189
    - Gelatin
    - 4% Albumin
  - Hyperoncotic 401
    - 6% HES 130/0.4
    - 10% HES 200/0.5
  - Hyperoncotic 105
    - 20% Albumin

Renal events

Schortgen F. *Int Care Med* 2008; 34(12):2157-68
Oncoticity and Renal Injury

- Overall mortality: 27.1%
  - Hyperonc albumin: OR 2.79 (1.42-5.47)
- Renal event: 17%
  - Hyperonc colloids: OR 2.48 (1.24-4.57)
  - Hyperonc albumin: OR 5.49 (2.75-13.08)
- Improper usage?
  - Colloids provide little free water
- Dehydration and renal artery vasoconstriction?

Schortgen F. *Int Care Med* 2008; 34(12):2157-68
Honore PM. *Int Care Med* 2008; 34(12):2127-9
VI SEP Study

- German: 18 ICUs
  - 4/03 - 6/05; two phases
  - Dual assessment of glycemic control and resuscitation fluid (presumed independent)
  - Tight glucose control
  - RL versus 10% pentastarch (200/0.5) for resuscitation
    - Maintenance fluid?

- Outcomes

  Brunkhorst F. *NEJM* 2008; 358: 125-39
VISEP Study

- RRT indications
  - ARF
    - Baseline serum creatinine x 2
    - Need for RRT
      - NO STANDARD CRITERIA FOR RRT
  - Volume overload
  - Hyperkalemia

- Dialysis dose, timing, and method not specified
VI SEP Study

- Study aborted due to safety concerns from Data Safety Monitoring Board
  - Arrested in phase 1
  - Hypoglycemia (glucose < 40 mg%)  
- Secondary analysis
  - Trend towards higher mortality with HES
  - Higher rate of RRT/ARF with HES
  - Increased rate of transfusion with HES

- Are these results valid and generalizable?
## VI SEP: Operations (p=0.04)

<table>
<thead>
<tr>
<th>Category</th>
<th>Ringers Lactate</th>
<th>Pentastarch</th>
</tr>
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<tbody>
<tr>
<td>Elective</td>
<td>18.2%</td>
<td>13.7%</td>
</tr>
<tr>
<td>Emergent</td>
<td>32%</td>
<td>42%</td>
</tr>
<tr>
<td>No OR</td>
<td>49.8%</td>
<td>43.9%</td>
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</table>

Greater emergent OR, less non-op management

High-risk population for ATN and ARF
VI SEP: Fluid Volumes

Indexed to Pentastarch volume
Median dose = 70.4 ml/kg bw
VISEP: CVP and PRBC

Unequal resuscitation and hemodilution

RL: 4U PRBC  HES: 6U PRBC
VISEP: Probability of Survival

Days

Prob Survival

n=275

n=262

p=0.14

RL

HES
Pentastarch Dose:
Low (<22 ml/kg) v High (>22 ml/kg)

Low cumulative dose: 48 ml/kg bw
High cumulative dose: 136 ml/kg bw

P<0.001

n=165
n=100
Hyperchloremia

- Independently decreases renal function
  - GFR, urine flow, creatinine clearance

- Hyperchloremic metabolic acidosis
  - Low pH out of proportion to AG or lactate

- Reduced rate of urine generation (human data)
Maintenance Fluid

- **Most** need maintenance fluid
- Hypotonic, dextrose + additives
- Derived from understanding minimum daily requirements (MDR) for electrolytes and muscle sparing effect of dextrose during starvation
  - LBM sparing debated
Catabolism and Lean Body Mass

- Starvation
- Hepatic glycogen stores
  - Depleted within 12 - 18 hours
  - Gluconeogenesis requires fuel source
- Skeletal muscle destruction
  - Cori cycle
    - Amino acid shuttling into TCA cycle
  - $\beta$-oxidation of fatty acids
    - Glycerol backbones
Dextrose

- Commonly provided as 5% dextrose in water (D$_5$W)
- D$_5$W = 50 gm dextrose per liter
- 100 gm dextrose/D
  - Muscle catabolism reduced by 50-85%
- Hence, 2000 cc D$_5$ something per day
  - NOT NORMOTONIC EXCEPT
    - Labor and Delivery (D$_5$ LR)
    - Mom and baby
MDR for Na and K

- Assume normal renal physiology
  - Adjust for excretion reductions
    - CHF, CRI, AKI/ARF

- Sodium
  - 1-2 meq/kg/D
  - 70 kg = 70 - 140 meq/D

- Potassium
  - 0.5 meq/kg/D
  - 70 kg = 35 meq/D
Maintenance Fluid Rate

- Multiple rules
- Weight (kg) + 40 cc = cc/hr.
- Weight based
  - 100 cc/hr -- 1st 10 kg
  - 50 cc/hr -- 2nd 10 kg
  - 20 cc/hr -- the rest of the weight
- 4-2-1 rule
- Nihilist: 125 cc/hr for everyone
Sample Calculation

- 70 kg patient
- Add 40 rule: 110 cc/hr
- Weight based:
  - 1000 + 500 + 1000
  - 2500 cc/day / 24 hours = ~ 110 cc/hr
- Assuming 110 cc/hr, and the need for Na and K ....
Fluid Prescription

- $D_5$ provides just over 100 gm dextrose
- $\frac{1}{2}$NSS gives 77 meq Na/L
  - 2 liters = 154 meq (close to 140)
- Add 20 meq K/L
  - Provides just over 40 meq/D (close to 35)
- $D_5\frac{1}{2}$NSS + 20 meq KCl/L @ 110 cc/hr
Na\textsuperscript{+} Abnormalities

- Hyponatremia
  - Post-op pt.
  - Total body fluid and salt excess
    - Dilutional, not true deficit
  - Medical pt
    - May have true total body salt deficit
    - Loop diuretics + salt restriction

Excessive blood loss, sweating, vomiting, or diarrhea coupled with intake of plain water

Decreased Na\textsuperscript{+} concentration of interstitial fluid and plasma (hyponatremia)

Decreased osmolarity of interstitial fluid and plasma

Osmosis of water from interstitial fluid into intracellular fluid

Water intoxication (cells swell)

Convulsions, coma, and possible death
Na⁺ Abnormalities
Dilutional vs True Na Deficiency

- **Dilutional**
  - Low Na but normal (near normal) Cl
    - Na 128, Cl 98
      - High UNa

- **True total body deficit**
  - Low Na and low Cl
    - Na 128, Cl 88
      - Low UNa
Na\textsuperscript{+} Abnormalities: Therapy

- Dilutional
  - Free H\textsubscript{2}O restriction
    - May be coupled with diuresis
    - Aquaporins (V2 receptor antagonists)
      - Pure aquarestriction

- True salt deficit
  - Provision of salt
    - PO or IV
  - Rate of correction ~ rate of acquisition
Na Abnormalities

- Correct [Na] when low
  - Not > 0.5 mEq/L per hour
  - Not > 10 mEq per 24 hours
    - Central pontine myelinolysis

- Correct [Na] when high
  - As above
    - Acute cellular edema
    - Intracranial HTN
K⁺ Abnormalities

- Hypokalemia
  - [Nonlinear] when < 3.0 mEq/L
  - K < 3.0 ➔ usually need 100-200 mEq
    - Central access + monitored bed
  - Associated with hypoMg
    - Correct both due to contransportation
    - Associated with resuscitation, diuresis, GI losses
      - Not gastric
K⁺ Abnormalities

- Hyperkalemia
- Therapy depends on [K] and presence of dysrhythmia
  - Peaked T-waves (ECG)
- Three goals
  - Support of myocardial conduction
  - Displacement of K
  - Removal of K
Hyperkalemia ECG
Post-Therapy
Hyperkalemia

- Support of conduction
  - Calcium chloride (not gluconate)
    - Strong ions → immediately available
      - Central access
  - Magnesium SO₄
    - Membrane stabilizer
  - NaHCO₃
- Restores normal pH as most are acidotic
  - Supports Na-K ATPase fnc and ATP hydrolysis
Hyperkalemia

- Displacement
  - Also preserves myocardial conduction

- Insulin (growth hormone)
  - Drives $K^+$ intracellularly
  - Also happens to drive glucose intracellularly
    - Exogenous glucose ($D_{50}$) to avoid hypoglycemia
Hyperkalemia

- Removal
- Primary clearance renal excretion
  - Plasma volume expansion (0.9% NSS)
    - Acidyfying
  - Coupled with forced diuresis (furosemide)
    - Alkalinizing
- What to do if the patient has ARF or is anuric or cannot tolerate PVE?
Hyperkalemia

- Cation exchange resin (Kayexelate)
  - Exchanges a Na\(^+\) (resin) for a K\(^+\) (pt)
    - Mixed in sorbitol to induce osmotic catharsis
      - PO or PR (generally 45-60 gm)
      - Goal is diarrhea
  - Acute dialysis (ultrafiltration)
    - Rapid restoration of normokalemia
      - Life-threatening dysrhythmias
Hypomagnesemia

- Associated with PVE or diuresis
- Generally under-treated
  - $\text{Mg}^{2+} \geq 2.0$
  - Generally safely repleted without monitors
    - $1.6 = 4 \text{ mg}$
    - $1.4 = 6 \text{ gm}$
    - $1.2 = 8 \text{ gm}$
    - $1.0 = 10 \text{ gm}$
- Associated with hypokalemia
Hypermagnesemia

- Quite rare outside of Labor and Delivery
- Generally associated with tocolysis
- HyperMg therapy
  - Generally expectant observation
  - Plasma volume expansion
  - Forced diuresis
  - Airway control if severe
    - Hyporeflexia and muscle weakness
Calcium Abnormalities

- Hypocalcemia
  - Repletion depends on acuteness of abnormalities and symptomaticity
    - \( \text{CaCl}_2 \) versus Cagluconate

- Hypercalcemia
  - Treat underlying cause
  - Therapy is similar to hyperkalemia
    - Forced diuresis + PVE
    - \( \text{Mg}^{2+} \)
Corrected Calcium

- Calcium is protein bound
  - Principally to albumin
    - Correct the measured calcium for hypoAlb
      - \[ \left( \text{Normal}_{\text{Alb}} - \text{measured}_{\text{Alb}} \right) \times 0.8 \] + Ca
  - Alternatively, obtain an ionized Ca
    - Denoted as Ca\(^{2+}\)
Hypophosphatemia

- Primary clearance is renal
- Hypophosphatemia associated with
  - Resuscitation
  - Diuresis
  - Refeeding syndrome
    - Phosphatidylcholine in membranes
      - GI mucosal turnover q 72 hours
Hyperphosphatemia

- Major association is renal failure
  - Iatrogenesis less frequently
- Low PO$_4$ intake
- PO$_4$ binders
- Watch Ca-PO$_4$ product
  - Ca x PO$_4$ and if > 55
  - Concern for soft tissue deposition
Renal Functions

- **Excretory**
  - Nitrogenous wastes, others

- **Regulatory**
  - Body water and circulating blood volume
  - Plasma sodium and potassium levels
  - Blood pH

- **Neuro-Endocrine**
  - Erythropoietin
  - Renin-Angiotensin system – blood pressure

- **Detoxification**
  - Major pathway for therapeutic agents and toxins
# AKIN: AKI Stages

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<thead>
<tr>
<th>Stage</th>
<th>Uop</th>
<th>Scr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt; 0.5 cc for &gt; 6 hr</td>
<td>Inc. 0.3 or 150% baseline Scr</td>
</tr>
<tr>
<td>2</td>
<td>&lt; 0.5 for &gt; 12 hr</td>
<td>200-300% baseline Scr</td>
</tr>
<tr>
<td>3</td>
<td>&lt; 0.3 for &gt; 24 hr</td>
<td>300% baseline Scr</td>
</tr>
<tr>
<td></td>
<td>Anuria for &gt; 12 hr</td>
<td>Scr &gt; 4 and inc. &gt; 0.5</td>
</tr>
</tbody>
</table>

CRRT = Stage 3

www.AKIN.org
RI FLE Criteria for Acute Kidney Injury

**GFR Criteria**
- Increased Scr x 1.5 or GFR decrease > 25%
- Increased Scr x 2 or GFR decrease > 50%
- Increase Scr x 3 or GFR dec > 75% or Scr ≥ 4mg/dl (Acute rise of ≥0.5 mg/dl)

**Urine Output Criteria**
- Uop < 0.5ml/kg/h x 6 hr
- Uop < 0.5ml/kg/h x 12 hr
- Uop < 0.3ml/kg/h x 24 hr or Anuria x 12 hrs

**Risk**
- Increased Scr x 1.5 or GFR decrease > 25%

**Injury**
- Increased Scr x 2 or GFR decrease > 50%

**Failure**
- Increase Scr x 3 or GFR dec > 75% or Scr ≥ 4mg/dl (Acute rise of ≥0.5 mg/dl)

**Loss**
- Persistent ARF** = complete loss of renal function > 4 weeks

**ESRD**
- End Stage Renal Disease

**High Sensitivity**

**High Specificity**

www.ADQI.net
RI FLE_{max} and Hospital Mortality

Cumulative Survival

Days after hospital admission

P<0.001 (Log Rank)

Incidence of ARF requiring RRT
“ICU period prevalence”

- ICU admissions: 29,269
- 54 centers in 28 countries
- Total: 1,758 (5.7%)  
  - ~2 million people/yr world-wide
- Financial, resource, staffing implications


Overall Outcomes

- ICU stay: 9 days (4-21)
- Hospital stay: 22 (11-44)
- ICU mortality: 51.7%
- Hospital mortality: 60.2%
- Hospital discharge with RRT: 13.8% (of survivors)

Timing of Initiation of Dialysis in Post-Traumatic ARF

Survival

BUN < 60 mg/dL: 39%
BUN > 60 mg/dL: 20%

Renal Support with CRRT

- **Solute Clearance**
  - Small molecule clearance
  - Larger (middle) molecule clearance

- **Fluid Management**
  - Much more fluid *can* be removed with CRRT
  - More rapid reduction in EVLW, cerebral edema

- **Drug Dosing**
  - A constant “GFR” with CRRT

- **Nutritional Support**
  - No need to limit volume with CRRT
Indications for Dialysis in the ICU Patient

- Volume overload
- Metabolic acidosis
- Hyperkalemia
- Uremic state
  - encephalopathy
  - pericarditis
- Azotemia without uremic manifestations
- Blood purification in sepsis
Diuretics, Mortality, and Nonrecovery of Renal Function in Acute Renal Failure
Ravindra L. Mehta, MD; Maria T. Pascual, RN, MPH; Sharon Soroko, MS; Glenn M. Chertow, MD, MPH; for the PICARD Study Group
*JAMA.* 2002;288:2547-2553.

- 4-Center, Retrospective analysis of nephrology consults (1989-1995; n=552)
- Multivariate analyses and propensity scores
- Adjustments in the covariates and propensity scores, diuretic use:
  - **Significantly increased risk of death or non-recovery of renal function** (odds ratio 1.77; 95% CI 1.14-2.76)
- Conclusion: “the use of diuretics in critically ill patients with acute renal failure should be discouraged”
General Mechanisms of Dialysis
Convection vs. Diffusion

Blood Flow

Convection

Diffusion

Ultrafiltrate

Dialysate

- small molecular wt substances (< 1 kD)
- large molecular wt substances (5 - 50 kD)
Diffusive Clearance

Concentration gradient based transfer. Small molecular weight substances (<500 Daltons) are transferred more rapidly.
Convective Clearance

Movement of water across the membrane carries solute across the membrane.

Middle molecules are removed more efficiently.
Convection vs. Diffusion

Clearance vs. Molecular Weight

- Diffusive Clearance
- Convective Clearance
Intermittent Hemodialysis

Intermittent Renal Replacement Therapy

- **Advantages**
  - high solute clearance
  - rapid volume removal

- **Disadvantages**
  - hemodynamic instability
  - intermittent treatment
  - dialysis associated hypoxia
  - vascular access
  - anticoagulation
  - requires special equipment and nursing staff
Intermittent RRT

- Special Considerations for the ICU Patient
  - adequacy of dialysis
  - risk of prolongation of ARF
    - hemodynamic factors
    - membrane bioincompatibility

- Vascular Access
  - Subclavian/IJV vs common femoral
  - Recirculation 4% vs 16%
    - Retards dialysis efficiency
IRRT and Prolongation of ARF

- Does transient hypotension during hemodialysis prolong ARF?
  - ARF results in impaired autoregulation of RBF
  - ARF kidneys have a blunted vasodilatory response to NO and amplified vasoconstriction to agonists
    - Midodrine, Dopamine, NorEpinephrine
Recovery from Dialysis Dependence

BEST Kidney *JAMA* 2005; 294:813-818
CRRT

- Advantages
  - Well tolerated hemodynamically
  - (More) Biocompatible membrane
  - Continuous therapy
  - High solute clearance and ultrafiltration rate
  - Cytokine clearance

- Disadvantages
  - Labor intensive
  - Training of ICU nurses
  - Vascular access
  - Anticoagulation
CRRT Techniques

- Slow Continuous Ultrafiltration (SCUF)
  - volume control; minimal solute clearance
  - Arterio-venous circuit
- Continuous Hemofiltration (CVWH)
  - convective solute removal
- Continuous Hemodialysis (CVWHD)
  - diffusive solute removal
- Continuous Hemodiafiltration (CVVHDF)
  - convective and diffusive solute removal
Continuous Hemofiltration
Pre-Dilution vs. Post-Dilution

Pre-Dilution

\[ Q_U F = C_B x \frac{Q_B}{Q_B + Q_R} \]
Continuous Hemofiltration
Pre-Dilution vs. Post-Dilution

Post-Dilution

- \( Q_R \)
- Higher filtration fraction
- Solute concentration within hemofilter unchanged from systemic concentration

\( Q_{UF} \)
Replacement Fluid/Dialysate

- Electrolyte composition
- Glucose concentration
- Buffer selection
  - acetate
  - lactate
  - citrate
  - bicarbonate
Replacement Fluid/Dialysate

- Optimal Electrolyte Composition
  - Sodium: 140-155 mmol/L
  - Potassium: 0-4 mmol/L
  - Chloride: 110-120 mmol/L
  - Calcium: 1.5-1.75 mmol/L
  - Magnesium: 0-0.75 mmol/L
Cumulative Proportional Survival


Survival Time (Days)

Group 1

Group 2 (p = 0.0007)

Group 3 (p = 0.0013)

High 45

Medium 35

Low 20
Dose of CVVH in ARF

28-day survival

LV-Late: 74.3
LV-Early: 68.8
HV-Early: 75

SOFA

CWH vs CWHDF

Saudan et al. *Kidney Int* 2006; 70:131

**Survival (%)**

- **CVVH**: 25 ml/kg/hr
- **CVVHDF**: 42 ml/kg/hr
Effect of CVVH-D vs CVVH on Plasma TNF levels

Kellum et al. Crit Care Med 1998;26: 1995-

P = 0.02
Kruskal Wallis

(166%)
### Influence of Dose Escalation

<table>
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<th>Study</th>
<th>n</th>
<th>Treatment groups</th>
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<tbody>
<tr>
<td>Ronco</td>
<td>425</td>
<td>CVVH 20/ h vs. 35-45 ml/ kg/ h*</td>
</tr>
<tr>
<td>Bouman</td>
<td>106</td>
<td>CVVH 20ml/ kg/ h* vs. 48 ml/ kg/ h</td>
</tr>
<tr>
<td>Schiffl</td>
<td>160</td>
<td>Alternate day vs. daily hemodialysis</td>
</tr>
<tr>
<td>Saudan</td>
<td>206</td>
<td>CVVH 25 vs. CVVHDF 42 ml/ kg/ h</td>
</tr>
</tbody>
</table>

Total (fixed effects)

Total (random effects)

**OR: 1.95 (1.48-2.58), p < 0.001**

Effects on HF Dose on Survival in Patients with and without Sepsis

IHD vs. CRRT

Intensity of Renal Support in Acute Kidney Injury

- Stable versus Unstable (n=1124)
  - IHD vs CRRT
  - More vs less dialysis dose
- Multicenter trial
- Anticipated an outcome benefit with CRRT
  - VA/NIH Cooperative Trial
- NO BENEFIT

ATN Investigators; *NEJM* 2008; 359; 7-20
Survival Not Impacted by Dose

OR crosses 1 for all subgroups
Conclusions

- Fluids and electrolytes
  - Easy to understand
  - Easy to misuse
  - Anticipate untoward effects

- Renal support
  - Stable pt: non-inferiority - mode and dose
  - Unstable pt: data for CRRT only
    - May impact renal recovery
      - Esp. with diuretic use