Alternative Therapies: Frequent, Long Dialysis, Hemodiafiltration

Balazs Szamosfalvi, MD
Monday, 08/31/2009 9:00-09:45
Adequacy 2000 – into the future

Reduced Inflammation: Better Biocompatibility and Ultrapure dialysate

Middle Molecule Removal: Hemo-diafiltration and Internal Filtration

Blood volume monitoring for safer ultrafiltration

Daily and or long (nocturnal) dialysis for BP and Ca x P control

Increasing Focus on Cost-control

Adequacy of Dialysis

Computer-Aided HD design and monitoring (Online Clearance)

OUTCOME: Quality of life Rehabilitation Morbidity & Mortality

OUTCOME:

Quality of life Rehabilitation

Morbidity & Mortality
1. Online Clearance (Kecn) versus urea kinetic modeling
2. Focus on removal of solutes other than urea
   - Hemo-diafiltration for β2-microglobulin
   - Dialyzer designs with improved geometry and pores
   - Computer modeling of solute fluxes other than urea (equivalent renal clearance, EKR=G/Average C; stdKt/V, etc.)

2. Alternate dialysis regimens to remove solutes
   - Importance of intra-patient solute kinetics
   - Emphasize frequency (daily HD)
   - Observation: longer duration of HD session - better survival
   - Focus on cost and acceptance by patient and provider (technology)

3. Biocompatibility
   - Improved membranes and ultrapure dialysate
   - Regional citrate anticoagulation

Online clearance measurement 2

1. Clinical uses
   • Continuous HD quality (adequacy) monitoring tool
   • Document small solute clearance every treatment
   • Detect partial clotting through decline of Kecn
   • Measure access flow; detect recirculating fistulas
   • Detect reverse cannulation of loop grafts
   • Adjust therapy to achieve targeted URR
   • Adjust therapy to achieve targeted serum sodium when correcting acute hyponatremia (personal observation)

Troubleshooting a low $K_{ecn}$ or Kt/V

- **Kecn and/or Kt/V below goal**
  - Kt/V low
  - Kecn good

- **Check QB, QD and Filter selection ($K_0A$)**
  - Kecn low

- **Confirm “V” value is appropriate**

- **Increase duration and/or frequency of HD sessions**

---

**Low Kt/V**

- Low QB or t (40% of cases)
- Access recirculation (25% of cases)
- Other (large V, blood tubing, low QD etc)

---

Converting Kt/V into URR

Biff F. Palmer; www.kidneyatlas.org
Online Hemodiafiltration (olHDF)

1. Combines dialysis with (usually) post-dilution hemofiltration
   • Better middle molecule clearance
   • Replacement fluid generated online (not available in US)
   • More complex equipment with higher costs

2. DOPPS observational study (2006)
   • “After adjustment, high-efficiency HDF patients had a significant 35% lower mortality risk than those receiving low-flux HD (relative risk=0.65, P=0.01). These observational results suggest that HDF may improve patient survival independently of its higher dialysis dose.

3. Dutch Convective Transport Study (Contrast)
   • Randomized, controlled olHDF trial in progress

Internal Filtration: Filter Design

- Large uniform pore size with very high Kuf and minimal resistance to the transfer of $\beta 2M^{1,2,3}$
- New dialysate flow pathway design reduces stagnant dialysate layers and shunting $^{1,2}$
- New blood header improves flow distribution in the fiber bundle $^1$
- New fibers with reduced internal diameter, wall thickness and wavy structure $^{1,2}$
- QD can be reduced 30% without a reduction in $K_D$ ($QD \leq 500$ ml/min)

A: from Depner T and Garred L: Solute transport mechanisms in dialysis; in Replacement of Renal Function by Dialysis, 5th edition; p85
1. Effective ionic dialysance (Kecn) for HDF
   • The technology is reliable and accurate as surrogate measurement of effective urea clearance even in highly convective therapies\(^1,2\)

2. Expanding use of \(K_{ecn}\) based Kt adequacy
   • Targeting online Kt as non-linear function of body surface area (BSA) was proposed from the Fresenius North America patient registry\(^3\)
   • This new method for targeting online Kt based on BSA was subsequently validated on a separate data set from the same registry\(^4\)

In search of better measures of patient toxin removal

1. Observation
   - 3x/week intermittent HD with weekly spKt/V 1.2x3=3.6 has similar survival to continuous CAPD with weekly Kt/V=2.0

2. Different models to adjust Kt/V for frequency and time
   - Equivalent renal urea clearance \( (EKR_{\text{urea}})^2 = G/TAC \text{ urea} \)
   - Standard stdKt/V_{urea} by Gotch
   - Other adjustments for frequency and duration (nKt/V)
   - Normalizing Kt to body surface area Kt/S_{dub}

References:
4. Depner et al: Seminars in Dialysis—Vol 17, No 2 (March–April) 2004 pp. 79–84
Two-compartment variable volume solute kinetic model

\[
\begin{align*}
\frac{d(C_1V_1)}{dt} &= G - C_1(K_D + K_R) + K_C(C_2 - C_1) \\
\frac{d(C_2V_2)}{dt} &= -K_C(C_2 - C_1)
\end{align*}
\]

Adapted from Depner T and Garred L: Solute transport mechanisms in dialysis; in Replacement of Renal Function by Dialysis, 5th edition; p85
Multi-compartment solute kinetics

1. Computer modeling
   - Indispensable to visualize effects of $K_0A$, frequency (f), duration (t), compartments sizes ($V_{12}$), $K_C$, generation rate (G)
   - Only as accurate as the parameters; results need validation

2. Specific solutes of interest
   - Phosphate: multi-compartmental complex kinetics
   - B2-microglobulin: improved $K_D$ (olHDF), low $K_C$
   - Guanidino compounds: kinetic effects of HD f and t
   - Cytokine mobilization with convection and adsorption
   - Creatinine and other non-protein bound plasma solutes

Coplon Dialysis Simulator: Urea w High $K_F$ and High $K_C$

Conventional HD
3 x 3.5 hours
$K_F = 283 \text{ ml/min}$

Daily Short HD
6 x 2.5 hours
$K_F = 283 \text{ ml/min}$

Daily Nocturnal HD
6 x 7 hours
$K_F = 203 \text{ ml/min}$

$G = 9000 \text{ mg/day}$
$K_C = 800 \text{ ml/min}$
$V1/V2 = 14/28 \text{ L}$

Coplon Dialysis Simulator: Solute w High $K_F$ and Low $K_C$

Conventional HD
3 x 3.5 hours
$K_F = 179$ ml/min

Daily Short HD
6 x 2.5 hours
$K_F = 179$ ml/min

Daily Nocturnal HD
6 x 7 hours
$K_F = 137$ ml/min

$G = 900$ mg/day
$K_C = 100$ ml/min
$V_1/V_2 = 14/28$ L


Conventional HD
3 x 3.5 hours
$K_F = 57 \text{ ml/min}$

Daily Short HD
6 x 2.5 hours
$K_F = 57 \text{ ml/min}$

Daily Nocturnal HD
6 x 7 hours
$K_F = 49 \text{ ml/min}$

$G = 140 \text{ mg/day}$

$K_C = 70 \text{ ml/min}$

$V_1/V_2 = 3.5/10.5 \text{ L}$
1. Observation
   - Cost of 3x/week in-center HD has shown explosive growth
   - No government wants to spend more per patient

2. In-center HD cost-effectiveness study and editorial\(^1,2\)
   - “In conclusion, given the extraordinarily high costs of the ESRD program, the viability of more frequent hemodialysis strategies depends on significant improvements in the economic model underlying the delivery of hemodialysis.”\(^1\)
   - A subsequent editorial raised the issue of even funding clinical studies for >3x/week in center HD considering the projected 75,000-125,000 USD cost/per quality life-year gained\(^2\)

Short Daily Hemodialysis (SDHD)

1. Benefits
   - Relatively easy to do with current equipment
   - Can be done while patient is awake in 2-4 hours (safety)
   - Improved volume and solute control
   - Improved sense of well-being

2. Barriers to use
   - Requires a motivated patient (5-10% of HD population)
   - Care provider inexperience may limit utilization
   - High cost of therapy compared to clearance gained
   - The patient must sacrifice a lot of active time for HD
   - Reimbursement must support use of the modality
Nocturnal Daily Hemodialysis (NDHD)

1. Benefits
   - Provides the best solute removal of all modalities
   - The patient can sleep through the therapy overnight
   - Excellent BP control, BP medications reduced
   - Excellent phosphate control, P-binders often stopped
   - Survival may be comparable to cadaveric renal Tx

2. Barriers to use
   - Requires a very motivated patient (5% of HD population)
   - Significant safety concerns limit utilization
   - Access connection monitoring and effective, safe anticoagulation is needed
   - A dedicated, good home nocturnal HD machine should have been developed at least 10 years ago!

Improving Biocompatibility

1. Technology improvements
   - Novel membranes with hydrophilic inner skin
   - Ultrapure dialysate generation

2. Regional citrate anticoagulation (RCA)
   - Has the potential to eliminate blood clotting 100%
   - Maintains filter performance in long HD
   - Blocks WBC, PLT and complement activation in the extracorporeal circuit\(^1\)
   - Avoids systemic bleeding tendency or true toxicity

Heparin versus Citrate: Scanning Electron Micrograph of Polysulfone Dialyzer Membrane

Overview of 10-h SLED w/ RCA

1. Case and novel RCA protocol features
   • Mathematical proof of safety in shock liver patients
   • Safe, ex vivo modeled protocol development
   • Lower QB of 200 ml/min for fewer access alarms
   • High hourly clearance measured online
   • Online blood volume and $O_2$ saturation monitoring
   • Reduced blood circuit leukocyte and complement activation with citrate anticoagulation: biocompatibility

2. Bedside implementation of SLED with RCA
   • Computerized prescription generation
   • Fixed citrate infusion rate and very simple Ca-dosing
Case of RCA with Shock Liver

- 61 y.o. male with HTN, DM, CKD in SICU after leg fracture complicated by SIRS and MODS
- BW 186 Kg, febrile, on-off vasopressors, ventilator-dependent, lactate 4; total bilirubin >20
- Treatment: SLED with citrate anticoagulation
- Filter clotting completely prevented; delivered ionic dialysance 80-90 liters / 8-10 hour sessions
- Citrate anticoagulation safe despite shock liver; systemic ionized calcium in range 1-1.3 while circuit ionized calcium <0.3 mM
- Disposables cost negligible compared to CRRT
Uniform SLED prescription

1. SLED Prescription
   - QB = 200 ml/min
   - QD = 400 ml/min
   - QCit = 400 ml/h
   - QCa = 240 ml/h (from table)
   - QNetUF = 0-500 ml/h
   - 8-10-hour duration

2. Other Features
   - Continuous display of the hematocrit (BVM)
   - Online measured delivered dose of dialysis
SLED [or HD] with RCA

- Calcium Infusion in 0.9% NS
- Concentrated Citrate Infusion
- Treatment Data on Machine Display
- Integrated Infusion Pumps With Air Detector
- Novel Access Catheter
- Hematocrit Sensor
- Internal Balancing Chambers
- Conductivity Sensors
- Dialyzer
- Effluent
<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>ALB Albumin, Serum g/dL</th>
<th>BUN Bun mg/dL</th>
<th>CRET Creatinine mg/dL</th>
<th>ICAY Ca,ionized,whole Bld mmol/L</th>
<th>TBL Bilirubin, Total mg/dL</th>
</tr>
</thead>
<tbody>
<tr>
<td>03/18/2009</td>
<td>09:25</td>
<td>1.2 -Stat</td>
<td>41 -Stat</td>
<td>5.0 -Stat</td>
<td>17.3 -Stat</td>
<td></td>
</tr>
<tr>
<td>03/18/2009</td>
<td>09:00</td>
<td>55</td>
<td>55</td>
<td>5.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/15/2009</td>
<td>22:00</td>
<td>1.7 -Stat</td>
<td>51 -Stat</td>
<td>6.0 -Stat</td>
<td></td>
<td>20.6 -Stat</td>
</tr>
<tr>
<td>03/15/2009</td>
<td>17:57</td>
<td>1.7 -Stat</td>
<td>51 -Stat</td>
<td>4.5 -Stat</td>
<td></td>
<td>29.6 -Stat</td>
</tr>
<tr>
<td>03/12/2009</td>
<td>21:00</td>
<td>1.6 -Stat</td>
<td>26 -Stat</td>
<td>3.0 -Stat</td>
<td></td>
<td>24.4 -Stat</td>
</tr>
<tr>
<td>03/12/2009</td>
<td>19:45</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/12/2009</td>
<td>15:50</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/12/2009</td>
<td>12:47</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/12/2009</td>
<td>11:30</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/12/2009</td>
<td>05:00</td>
<td>36 -Stat</td>
<td>20 -Stat</td>
<td>3.1 -Stat</td>
<td>22.4 -Stat</td>
<td></td>
</tr>
<tr>
<td>03/11/2009</td>
<td>17:50</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/11/2009</td>
<td>14:50</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/11/2009</td>
<td>11:50</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/11/2009</td>
<td>09:40</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/11/2009</td>
<td>00:05</td>
<td>45 -Stat</td>
<td>32 -Stat</td>
<td>3.2 -Stat</td>
<td>21.1 -Stat</td>
<td>1.0</td>
</tr>
<tr>
<td>03/09/2009</td>
<td>17:40</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/09/2009</td>
<td>14:40</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/09/2009</td>
<td>19:00</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/09/2009</td>
<td>09:05</td>
<td>53 -Stat</td>
<td>32 -Stat</td>
<td>2.2 -Stat</td>
<td>19.4 -Stat</td>
<td></td>
</tr>
<tr>
<td>03/07/2009</td>
<td>18:20</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/07/2009</td>
<td>10:20</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/07/2009</td>
<td>13:20</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/07/2009</td>
<td>19:45</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/07/2009</td>
<td>10:37</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/07/2009</td>
<td>00:05</td>
<td>45 -Stat</td>
<td>2.2 -Stat</td>
<td>1.1 -Stat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/06/2009</td>
<td>19:30</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/06/2009</td>
<td>17:35</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/06/2009</td>
<td>17:30</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/06/2009</td>
<td>14:20</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/06/2009</td>
<td>11:11</td>
<td>Dialysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ionized Calcium
Dialyzer After Saline Rinse Back
Citric Acid / Citrate
Fundamental Properties

- Only citrate$^{3-}$ in plasma
- Molecular weight
  - Citrate$^{3-}$ 189 Da
  - Ca-Citrate$^{-}$ 229 Da
- No RBC entry
- Metabolized to $\text{HCO}_3^-$
- Blocks WBC, PLT and complement activation

Crismon et al, J Appl Physiol 1961; 16(6):1103-1108
Citrate Effects on Plasma

- 90–95% of Ca dialyzable
- $K_{Ca} = 0.95 \times K_{Citrate}$
- $K_{Ca} \approx K_{Mg}$
Parameters Used to Model The Systemic Citrate Concentration, $C(t)$

**QP:** Circuit arterial limb plasma flow (L/h)

**C_{inf}:** Citrate infused into 1 L of plasma in the arterial limb of the blood circuit (mmol/L)

**E_{cit}:** Extraction ratio of citrate in a single-pass on the artificial kidney
Citrate Fluxes In The Blood Circuit: Absent Metabolism

Systemic Citrate: $QP \times C_{\text{max}}$

Infusion of Citrate: $QP \times C_{\text{inf}}$

Cleared Infused Citrate: $QP \times C_{\text{inf}} \times E_{\text{cit}}$

Cleared Systemic Citrate = Removal: $QP \times C_{\text{max}} \times E_{\text{cit}}$

Remaining Infused Citrate = Load: $QP \times C_{\text{inf}} \times (1 - E_{\text{cit}})$
Calculation of the Highest Systemic Citrate Concentration (Cmax)

Citrate Load: \( QP \times C_{inf} \times (1 - E_{cit}) \)

Citrate Removal: \( QP \times C_{max} \times E_{cit} \)

Steady State:
Citrate Load = Citrate Removal

\[
C_{max} = C_{inf} \times \frac{1 - E_{cit}}{E_{cit}}
\]
Cmax = \( f(\text{Ecit}) \)

Cmax at \( C_{\text{inf}} = 6 \text{ mM} \)
SLED *in vitro* Testing

**Calcium Infusion**

**Citrate Infusion**

**Venous Post Calcium**

**Venous Pre Calcium**

**Blood Container**

**Arterial Pre Citrate**

**Arterial Post Citrate**
SLED in vitro Testing

- Calcium Infusion
- Citrate Infusion

Blood Container

Anticoagulation Region
# Commercial Citrate Solutions

<table>
<thead>
<tr>
<th>ACD-A Solution</th>
<th>4%-TSC Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na⁺</td>
<td>225 mM</td>
</tr>
<tr>
<td>Citrate³⁻</td>
<td>75 mM</td>
</tr>
<tr>
<td>Citric acid</td>
<td>38 mM</td>
</tr>
<tr>
<td>Dextrose</td>
<td>124 mM</td>
</tr>
<tr>
<td>Na⁺</td>
<td>408 mM</td>
</tr>
<tr>
<td>Citrate³⁻</td>
<td>136 mM</td>
</tr>
<tr>
<td>Citric acid</td>
<td>0 mM</td>
</tr>
<tr>
<td>Dextrose</td>
<td>0 mM</td>
</tr>
</tbody>
</table>

**ACD-A — Acid**
- Used most often
- Provides acidic circuit pH
- Plasma $\Delta$Na⁺ $\approx +3$ mEq
- Plasma $\Delta$HCO₃⁻ $\approx -3$ mEq

**4%-TSC — Basic**
- Used rarely, briefly
- Acidemic patients (pH $< 7.1$ or $\text{HCO}_3^-$ $< 10$)
- Plasma $\Delta$Na⁺ $\approx +9$ mEq
- Plasma $\Delta$HCO₃⁻ $\approx 0$ mEq

$$Q_{\text{cit}} \text{ (ml/h)} = 2 \times Q_B \text{ (ml/min)} \text{ for ACD-A and 4%-TSC}$$

(Ex: $Q_B$ 100 ml/min $\rightarrow Q_{\text{cit}}$ 200 ml/h)
# Online-Generated Dialysate

<table>
<thead>
<tr>
<th>Ion</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na⁺</td>
<td>140 (130-150)</td>
<td>mM</td>
</tr>
<tr>
<td>K⁺</td>
<td>1, 2, 3 or 4</td>
<td>mM</td>
</tr>
<tr>
<td>HCO₃⁻</td>
<td>32 (20-40)</td>
<td>mM</td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>0.5</td>
<td>mM</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>102</td>
<td>mM</td>
</tr>
<tr>
<td>P</td>
<td>1.0</td>
<td>mM</td>
</tr>
<tr>
<td>Acetate</td>
<td>4</td>
<td>mM</td>
</tr>
<tr>
<td>Dextrose</td>
<td>5.5</td>
<td>mM</td>
</tr>
</tbody>
</table>

- High Mg²⁺; IV Mg²⁺ supplementation not required
- Contains P; IV phosphate supplementation not required
Calcium Solution

For ACD-A or 4%-TSC

<table>
<thead>
<tr>
<th>Ion</th>
<th>Concentration (mM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca^{2+}</td>
<td>68</td>
</tr>
<tr>
<td>Na^{+}</td>
<td>140</td>
</tr>
<tr>
<td>Cl^{-}</td>
<td>276</td>
</tr>
</tbody>
</table>

- Ca infusion restores Ca mass balance
- Na mass balance is restored by dialysate
- Dextrose mass balance set by dialysate dextrose
- At QB of 200 ml/min, QCa = 220–290 (255) ml/h
RCA Circuit Chemistry Data [n=6]

Anhepatic Sham Dialysis

Hct 30% (repeated at Hct = 21-45%)
# SLED Chemistry Data

<table>
<thead>
<tr>
<th></th>
<th>Alb (g/dL)</th>
<th>Total Ca (mM)</th>
<th>Ionized Ca (mM)</th>
<th>Citrate (mM)</th>
<th>Mg (mg/dL)</th>
<th>P (mg/dL)</th>
<th>Na (mM)</th>
<th>K (mM)</th>
<th>Cl (mM)</th>
<th>CO₂ (mM)</th>
<th>GLU (mg/dL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial Pre-Citrate Infusion</td>
<td>2.10</td>
<td>2.10</td>
<td>1.01</td>
<td>1.45</td>
<td>2.10</td>
<td>2.9</td>
<td>139</td>
<td>4.5</td>
<td>111</td>
<td>21</td>
<td>105</td>
</tr>
<tr>
<td>Arterial Post-Citrate Infusion</td>
<td>2.00</td>
<td>1.95</td>
<td>0.23</td>
<td>6.87</td>
<td>1.90</td>
<td>2.6</td>
<td>149</td>
<td>4.0</td>
<td>110</td>
<td>19</td>
<td>221</td>
</tr>
<tr>
<td>Venous Pre-Ca Infusion</td>
<td>2.2</td>
<td>0.48</td>
<td>0.21</td>
<td>1.44</td>
<td>0.32</td>
<td>2.9</td>
<td>141</td>
<td>4.5</td>
<td>109</td>
<td>22</td>
<td>51</td>
</tr>
<tr>
<td>Venous Post-Ca Infusion</td>
<td>2.1</td>
<td>2.20</td>
<td>1.08</td>
<td>1.35</td>
<td>2.10</td>
<td>2.8</td>
<td>139</td>
<td>4.4</td>
<td>110</td>
<td>22</td>
<td>106</td>
</tr>
<tr>
<td>Input Dialysate</td>
<td>NA</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>2.8</td>
<td>145</td>
<td>4.5</td>
<td>116</td>
<td>23</td>
<td>0</td>
</tr>
<tr>
<td>Output Dialysate</td>
<td>NA</td>
<td>0.68</td>
<td>0.20</td>
<td>4.42</td>
<td>0.59</td>
<td>2.6</td>
<td>151</td>
<td>4.3</td>
<td>118</td>
<td>24</td>
<td>87</td>
</tr>
</tbody>
</table>
Safe SLED-RCA Operation

1. Obtain Patient labs
2. Start RCA
3. Disease process: less impact with large Kt/V
   - SLED only normalizes labs
   - Citrate metabolism irrelevant
4. Check Ca²⁺, Na⁺, HCO₃⁻ (ABG)
5. Stable patient chemistry
   Modify treatment if needed
SLED with RCA at HFH

Nephrology orders SLED with RCA in CarePlus NG (EHR)

CRRT Team sets up system

ICU Team notified of SLED order and progress

Pharmacy notified of SLED order and progress

SLED is performed by ICU RN per protocol with CRRT Team support

Telemetry by CRRT Team

Automatic charting in MetaVision

Clinical Monitoring

Nephrology modifies SLED with RCA as needed
CONCLUSIONS: RCA

RCA — safe and amenable to automated delivery using a protocol with a single pass fractional extraction ratio for citrate >0.80

RCA protocols — can attain and maintain target plasma total Ca and iCa^{2+} levels as well as normal plasma Na^+, K^+, HCO_3^-, Mg^{2+}, HPO_4^{2-} & dextrose

Current dialysis equipment — good for safe, kinetic RCA protocols; integrated citrate- and calcium pumps may expand the use of dialysis with RCA
Acknowledgments

HFH “Citrate Group”

• Balazs Szamosfalvi, MD
• Stanley Frinak, MSEE
• Jerry Yee, MD
• Tom Lubkowski
• CRRT Technician Team
• Greenfield Health System
• ICU Teams