HEMODIALYSIS COMPLICATIONS

GERALD SCHULMAN, MD, FASN
VANDERBILT UNIVERSITY SCHOOL OF MEDICINE
ACUTE PHYSICAL COMPLICATIONS

- HYPOTENSION 25-55%
- CRAMPS 5-20%
- NAUSEA 5-15%
- HEADACHES 5%
- CHEST PAIN 2-5%
- BACK PAIN 2-5%
-ITCHING 5%
- FEVER/CHILLS 1%
HEMOLYSIS

• SYMPTOMS
  – A port wine appearance of the blood in the venous line
  – Complaints of chest pain, shortness of breath, and/or back pain
  – A falling hematocrit
  – A pink color of the plasma in centrifuged specimens.

• CAUSES
  – Overheating
  – Hypotonicity due to an insufficient concentrate-to-water ratio
  – Contamination with formaldehyde, bleach, chloramine, or nitrates from the water supply, and copper from copper tubing or piping
OTHER COMPLICATIONS

• ARRHYTHMIAS
  – POTASSIUM AND CLACIUM

• AIR EMBOLISM
  – INEXCUSABLE
  – CORRECTED BY LEFT LATERAL DECUBITUS + LEG ELEVATION, 100% O₂, AND CPR

• ACCESS ISSUES

• HYPOTENSION
HYPOTENSION
COMPLICATIONS OF HEMODIALYSIS

- None: 46.0%
- Hypotension: 24.0%
- Cramps: 16.0%
- Light-headed: 14.0%
FACTORS INFLUENCING HYPOTENSION

• PATIENT RELATED
  – COMORBID CONDITIONS
  – COMPLIANCE
  – MEDICATION

• PROCEDURE RELATED
  – DIALYSATE PROPERTIES
  – MEMBRANE

• PROCESS RELATED
  – MONITORS, EPO, EATING
  – ASSESSMENT OF DRY WEIGHT
CONSEQUENCES OF HYPOTENSION

- MYOCARDIAL INFARCTION
- CVA
- SYNCOPE / TRAFFIC ACCIDENTS
- REDUCED DELIVERY OF DIALYTIC THERAPY
- INABILITY TO ACHIEVE DRY WEIGHT
DETERMINANTS OF BLOOD PRESSURE

\[
\text{BLOOD PRESSURE} = \text{CARDIAC OUTPUT} \times \underbrace{\text{SVR}}_{\text{STROKE VOLUME} \times \text{HEART RATE}}
\]

\[
\text{CONTRACTILITY} \sim \text{VENOUS RETURN}
\]

\[
\text{BLOOD VOLUME} \sim \text{VENOUS CAPACITANCE}
\]
CAUSES OF HYPOTENSION

• DECREASES IN BLOOD VOLUME
  – ABSOLUTE AND RELATIVE
  – HEMORRHAGE, SHIFTS, EXCESSIVE UF, EATING

• CARDIAC CONTRACTILITY
  – MYOCARDIAL DYSFUNCTION, MI, PERICARDITIS, ARRHYTHMIAS,

• LOSS OF VASOCONSTRICTION
  – AUTONOMIC NEUROPATHY, MEDICATION, DIFFUSIVE CLEARANCE, THERMAL ENERGY

• PROCEDURE RELATED
  – DIALYSATE, AIR EMBOLISM, HEMOLYSIS
BLOOD VOLUME

- EXCESSIVE WEIGHT GAIN REQUIRING A HIGH UFR: >1KG/HOUR IN AVERAGE SIZE PATIENT
- HEMORRHAGE
- EMBOLISM
- PERICARDITIS
- INACCURATE DRY WEIGHT
- EATING ON DIALYSIS
- DIALYSIS TIME

Ultrafiltration rate (ml/min/kg)

Graph showing the relationship between ultrafiltration rate (ml/min/kg) and percentage of dry weight achieved.
RESPONSE TO HYPOVOLEMIA

• INCREASE HEART RATE
• INCREASE MYOCARDIAL CONTRACTILITY SUPPORTING STROKE VOLUME
• INCREASE RESISTANCE
  – REDISTRIBUTE FLOW
  – EMPTY VENOUS CAPACITANCE BEDS
  – ACTIVATION OF HUMORAL RESPONSES: SYMPATHETIC NERVOUS SYSTEM AND RENIN ANGIOTENSIN SYSTEM
THE EFFECT OF HEMODIALYSIS ON CARDIAC CONTRACTILITY


• n = 5 HD PATIENTS UNDERGOING ALL STUDIES
• CUPROPHANE, ACETATE-BUFFERED DIALYSATE WITH 132 mEq/L SODIUM
• 3 MANEUVERS
  – UF ONLY
  – REGULAR HD
  – ISOVOLEMIC HD
• PRE/POST HD ECHOCARDIOGRAMS UNDER BASELINE, LOW AND HIGH FILLING PRESSURES (NEGATIVE PRESSURE, TILT)
LV VOLUME: REGULAR DIALYSIS WITH ULTRAFILTRATION

PRE
42
0.61

POST
52 EF(%) 1.04 VCF

STROKE V

EDV

ESV
LV VOLUME: ULTRAFILTRATION ONLY

<table>
<thead>
<tr>
<th></th>
<th>PRE</th>
<th>POST</th>
</tr>
</thead>
<tbody>
<tr>
<td>STROKE V</td>
<td>44</td>
<td>31</td>
</tr>
<tr>
<td>ESV</td>
<td>0.65</td>
<td>0.43</td>
</tr>
</tbody>
</table>

EF(%) 0.65  VCF
LV VOLUME: ISOVOLEMIC HEMODIALYSIS

PRE
44
0.64

POST
59
1.26

STROKE V
0.64
1.26

EDV

EF(%)
LEFT VENTRICULAR FUNCTION CURVES

STROKE VOLUME

- PRE
- POST

LEFT VENTRICULAR END DIASTOLIC VOLUME

REGULAR

UF ONLY

ISOVOL HD

+CHANGE IN CONTRACTILITY +STARLING EFFECT

NO CHANGE IN CONTRACTILITY - STARLING EFFECT

+CHANGE IN CONTRACTILITY - STARLING EFFECT
SUMMARY: THE EFFECT OF HEMODIALYSIS ON LV FUNCTION

<table>
<thead>
<tr>
<th></th>
<th>SV</th>
<th>ESV</th>
<th>EDV</th>
<th>EF</th>
<th>VCF</th>
<th>S-F</th>
</tr>
</thead>
<tbody>
<tr>
<td>REG</td>
<td>←</td>
<td>↓</td>
<td>↓</td>
<td>↑</td>
<td>↑</td>
<td>YES</td>
</tr>
<tr>
<td>UF</td>
<td>↓</td>
<td>←</td>
<td>↓</td>
<td>↓</td>
<td>←</td>
<td>YES</td>
</tr>
<tr>
<td>IVHD</td>
<td>↑</td>
<td>↓</td>
<td>←</td>
<td>↑</td>
<td>↑</td>
<td>NO</td>
</tr>
</tbody>
</table>
CARDIAC FACTORS ASSOCIATED WITH HYPOTENSION

• SYSTOLIC DYSFUNCTION
• DIASTOLIC DYSFUNCTION
• INABILITY TO INCREASE HEART RATE
• ARRHYTHMIAS
• PERICARDITIS
• INFARCTION
LACK OF VASOCONSTRICITION

- ? DIFUSSION vs CONVECTION
- AUTONOMIC NEUROPATHY
- IMPAIRED HORMONAL RESPONSE
- DIALYSATE TEMPERATURE
- MEDICATION
- ANEMIA
- EATING DURING DIALYSIS
# HEMODYNAMIC CHANGES DURING EXTRACORPORAL THERAPIES

<table>
<thead>
<tr>
<th>HEMODYNAMIC PARAMETERS</th>
<th>UF</th>
<th>HD</th>
<th>HF</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARTERIAL PRESSURE</td>
<td>←</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>CARDIAC OUTPUT</td>
<td>↓</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>STROKE VOLUME</td>
<td>↓</td>
<td>↓</td>
<td>←</td>
</tr>
<tr>
<td>HEART RATE</td>
<td>←</td>
<td>↑</td>
<td>←</td>
</tr>
<tr>
<td>SYSTEMIC RESISTANCE</td>
<td>↑</td>
<td>←</td>
<td>↑</td>
</tr>
</tbody>
</table>
AUTONOMIC NEUROPATHY IN HEMODIALYSIS

• COMMON IN DIABETES
• AFFERENT LIMB IMPAIRED
• INCREASED TONIC SYMPATHETIC OUTPUT

BUT

EFFERENT LIMB IMPAIRMENT AS WELL
PARADOXICAL LOSS OF REFLEX VASOCONSTRICTION AS CAUSE OF HD-INDUCED HYPOTENSION

Hypotension-Prone Patient

- Muscle Sympathetic Nerve Activity
- Blood Pressure (mmHg)
- Heart Rate (beats/min)
- Calf Blood Flow (ml/min/100ml)
- Calf Vascular Resistance (units)

Baseline | 5 Minutes Prior to Hypotensive Episode | Hypotensive Episode | Hemodialysis
RESPONSE OF HEMODIALYSIS PATIENTS TO GRADED AII INFUSION

![Graph showing the response of hemodialysis patients to graded AII infusion. The graph plots the change in MAP (mm Hg) against the AII dose (ng/kg/min). Two lines represent different groups: HYPO and NORMO. The data points show a positive correlation between AII dose and change in MAP.]
SPECIFIC BINDING OF ANGiotensin II TO PLATELETS IN HD PATIENTS

% specific A II binding

<table>
<thead>
<tr>
<th></th>
<th>Hypotensive</th>
<th>Normotensive</th>
</tr>
</thead>
<tbody>
<tr>
<td>A II Binding</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>
THE EFFECT OF ANEMIA AND ITS CORRECTION IN HD

ANEMIA
- INCREASED CARDIAC OUTPUT
- DECREASED BLOOD VISCOSITY
- REDUCED PERIPHERAL VASCULAR RESISTANCE

TRANSFUSION AND ERYTHROPOIETIN
- DECREASED CARDIAC OUTPUT
- INCREASED PERIPHERAL VASCULAR RESISTANCE AND BP
- INCREASED INTERDIALYTIC BP
**VASCULAR CHANGES IN HD PATIENTS WITH EPO**

**PARAMETERS**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control</th>
<th>EPO</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAD (cm)</td>
<td>3.43 +/- 0.33</td>
<td>3.22 +/- 0.3</td>
</tr>
<tr>
<td>HR</td>
<td>76.1 +/- 8</td>
<td>70 +/- 10</td>
</tr>
<tr>
<td>LVMI (g/m²)</td>
<td>133 +/- 30.8</td>
<td>109.8 +/- 30.6</td>
</tr>
<tr>
<td>CI (L/min/m²)</td>
<td>4175 +/- 700</td>
<td>3635 +/- 444</td>
</tr>
<tr>
<td>TPR</td>
<td>1480 +/- 162</td>
<td>1943 +/- 250</td>
</tr>
</tbody>
</table>
POSTPRANDIAL HYPOTENSION: IMPAIRED VASOCONSTRICTION

- FOOD INGESTION
  - DECREASE IN PERIPHERAL VASCULAR RESISTANCE
  - WORSENUED BY AUTONOMIC DYSFUNCTION
  &
  - INCREASE IN SPLANCHNIC BLOOD FLOW
    ‡ DECREASED VENOUS RETURN
DIALYSATE CONSIDERATIONS

- BUFFER
- OSMOLARITY/SODIUM
- CALCIUM AND MAGNESIUM CONCENTRATION
- TEMPERATURE
DIALYSATE CONSIDERATIONS

- BUFFER
- OSMOLARITY/SODIUM
- CALCIUM AND MAGNESIUM CONCENTRATION
- TEMPERATURE
BUFFER

• ACETATE vs BICARBONATE
  – OF HISTORICAL NOTE ONLY ➔ UNIVERSAL USE OF BICARBONATE-BASED DIALYSATE

• ACETATE
  – VASODILATOR
  – MYOCARDIAL DEPRESSANT
  – 200 mM/hr MAXIMUM RATE OF METABOLISM
  – MUSCLE MASS DEPENDENT
DIALYSATE CONSIDERATIONS

- BUFFER
- OSMOLARITY/SODIUM
- CALCIUM AND MAGNESIUM CONCENTRATION
- TEMPERATURE
EFFECT OF DIALYSIS SODIUM ON SERUM OSMOLALITY

Baseline Na+7%
Baseline Na
Baseline Na-7%

DIALYSIS TIME (hours)
DIALYSATE SODIUM AND FLUID COMPARTMENTS

• DIALYSATE SODIUM ~ SERUM SODIUM:
  SOURCE OF ULTRAFILTRATE IS FROM THE ECF COMPARTMENT

• DIALYSATE SODIUM < SERUM SODIUM:
  SOURCE OF ULTRAFILTRATE IS FROM THE ECF COMPARTMENT AND ECF ALSO MOVES INTO THE ICF COMPARTMENT (INTERNAL PHLEBOTOMY)

• DIALYSATE SODIUM > SERUM SODIUM:
  SOURCE OF ULTRAFILTRATE IS FROM ECF AND ICF COMPARTMENTS
DIALYSATE SODIUM CONCENTRATION AND COMPARTMENTAL FLUID LOSS

% fluid removed

LOW SODIUM MOD SODIUM HIGH SODIUM

-24% 4% 44% 56%

ECF ICF
CHRONIC EFFICACY OF HIGH SODIUM DYALYSATE
AJKD 2:349-353, 1982

• n = 10
• Double blind, crossover
• [Na]: 144 mEq/L vs 132 mEq/L

OUTCOME

• DECREASED HYPOTENSION
• INCREASED INTERDIALYTIC WEIGHT GAINS
• INCREASED VOLUME REMOVED DURING DIALYSIS
HIGH SODIUM DIALYSATE OR BUFFER: WHICH IS MORE IMPORTANT?

• HIGH SODIUM DIALYSATE BUFFERED WITH ACETATE RESULTS IN INCREASED INTERDIALYTIC WEIGHT GAINS, BUT ALLOWS GREATER UFR WITHOUT HYPOTENSION

• AT THE SAME SODIUM CONCENTRATION, BICARBONATE RESULTS IN LESS HYPOTENSION

• SODIUM IS OF GREATER IMPORTANCE
CONCERNS INVOLVING HIGH DIALYSATE SODIUM CONCENTRATIONS

• TRADE-OFF HYPOTHESIS: A CHANGE INTRODUCED TO CORRECT ONE ABNORMALITY MAY RESULT IN OTHER PATHOPHYSIOLOGIC CONSEQUENCES: MAINTAINING $[\text{Ca}^+]$ LEADS TO ROD

• TRADE-OFFS IN ARTIFICIAL PHYSIOLOGY
  • ALUMINUM AND CALCIUM P-BINDERS
  • DIALYSATE SODIUM
  • ? DIALYSATE CALCIUM
CONSEQUENCES OF THE DONNAN EQUILIBRIUM: \((Na \times CL)_{\text{blood}} = (Na \times Cl)_{\text{dialysate}}\)

BLOOD SIDE [CATION] > DIALYSATE SIDE [CATION]
DIALYSATE SODIUM: ISSUES

• [DIALYSATE SODIUM] TO [SERUM SODIUM] GRADIENT AT WHICH SODIUM TRANSFER EXCHANGE IS PREVENTED: -3 mEq/L

• HIGH SODIUM AND ISONATREMIC DIALYSATE HAVE THE POTENTIAL TO INCREASE EXCHANGEABLE SODIUM POOL

• POTENTIAL CONSEQUENCES OF INCREASED EXCHANGEABLE SODIUM
  - THIRST
  - INCREASED INTERDIALYTIC WEIGHT GAIN
  - HYPERTENSION
DIALYSATE CONSIDERATIONS

- BUFFER
- OSMOLARITY/SODIUM
- CALCIUM AND MAGNESIUM CONCENTRATION
- TEMPERATURE
EFFECTS OF CALCIUM ON CARDIAC CONTRACTILITY

End systolic wall stress (g/cm²)

Velocity of fiber shortening

2mg/dl  7mg/dl  10mg/dl

high Ca  mid Ca  low Ca
# DIALYSATE MAGNESIUM AND HYPOTENSION

<table>
<thead>
<tr>
<th>MAGNESIUM CONCENTRATION</th>
<th>CHANGE IN MAP (mm Hg)</th>
<th>HYPOTENSIVE EPISODES (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW Mg (0.38 mM)</td>
<td>-16 +/- 4</td>
<td>28.5</td>
</tr>
<tr>
<td>HIGH Mg (0.75 mM)</td>
<td>-28 +/- 4</td>
<td>61.9</td>
</tr>
</tbody>
</table>
CONCERNS WITH CALCIUM AND MAGNESIUM

• WIDESPREAD USE OF CALCIUM SALTS TO CONTROL PHOSPHORUS
  – HYPERCALCEMIA ~30%
  – CALCIPHYLAXIS
  – ADYNAMIC BONE DISEASE

• HYPOMAGNESEMIA
  – CRAMPS
DIALYSATE CONSIDERATIONS

- BUFFER
- OSMOLARITY/SODIUM
- CALCIUM AND MAGNESIUM CONCENTRATION
- TEMPERATURE
DIALYSATE TEMPERATURE AND CARDIAC CONTRATILITY

VELOCITY OF FIBER SHORTENING @ CONSTANT ESWS

REGULAR HD

COOL HD

KI 42 1999
<table>
<thead>
<tr>
<th>DIALYTIC MODALITY</th>
<th>CORE TEMPERATURE</th>
<th>VASCULAR ACTIVITY</th>
<th>VENOUS TONE</th>
</tr>
</thead>
<tbody>
<tr>
<td>UF</td>
<td>DECREASE</td>
<td>INCREASE</td>
<td>INCREASE</td>
</tr>
<tr>
<td>HD&lt;sub&gt;37&lt;/sub&gt;</td>
<td>INCREASE</td>
<td>NO CHANGE</td>
<td>DECREASE</td>
</tr>
<tr>
<td>HD&lt;sub&gt;35&lt;/sub&gt;</td>
<td>DECREASE</td>
<td>INCREASE</td>
<td>INCREASE</td>
</tr>
<tr>
<td>HD&lt;sub&gt;UF ET&lt;/sub&gt;</td>
<td>NO CHANGE</td>
<td>INCREASE</td>
<td>INCREASE</td>
</tr>
</tbody>
</table>
DIALYSATE TEMPERATURE AND CYTOKINE GENERATION

![Graph showing TNF pg/ml at 35°C and 37°C for PRE and POST conditions.](image)
# TEMPERATURE AND BP DURING HD

*n = 8 HYPOTENSION PRONE HD PATIENTS*

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>37°C</th>
<th>35°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYSTOLIC BP (mmHg)</td>
<td>145</td>
<td>138</td>
</tr>
<tr>
<td>WEIGHT LOSS (KG)</td>
<td>1.5</td>
<td>1.9</td>
</tr>
<tr>
<td>HYPOTENSIVE EPISODES (%)</td>
<td>45</td>
<td>30</td>
</tr>
</tbody>
</table>
THE EFFECTS OF HEMODIALYSIS AND CHANGES IN THERMAL ENERGY

• ISOTHERMIC HD: 6% of INTRADRÄLALYTIC ENERGY EXPENDITURE IS LOST FOR EACH 1% WEIGHT ULTRAFILTERED AJKD 2000

• COOL DIALYSATE: LESS HYPOTENSION
  – THE MAIN REASON FOR SUPERIOR HEMODYNAMIC STABILITY OF ISOLATED ULTRAFILTRATION
    • INCREASE IN MYOCARDIAL CONTRACTILITY
    • INCREASED VASCULAR TONE

• MIXED ACCEPTANCE BY PATIENTS
DETERMINANTS OF BLOOD PRESSURE AND THE EFFECTS OF DIALYSIS

**BLOOD PRESSURE** = CARDIAC OUTPUT \( \times \) SVR

STROKE VOL \( \times \) HEART RATE

DIALYSATE

CONTRACTILITY

DIALYSATE

UF RATE/FLUID SHIFTS

BLOOD VOLUME \( \sim \) VENOUS CAPACITANCE
INTERVENTIONS

• EVALUATE DRY WEIGHT
• TREAT REVERSIBLE CAUSES
• BELLS, WHISTLES AND GIZMOS
• MEDICATIONS
INTERVENTIONS

• **EVALUATE DRY WEIGHT**
  – LIMIT WEIGHT GAINS

• **TREAT REVERSIBLE CAUSES**
  – HYPOTENSIVE MEDICATION
  – CONSIDER INCREASING DIALYSIS TIME
    • TASSIN/NOCTURNAL HD EXPERIENCE

• BELLS, WHISTLES AND GIZMOS

• MEDICATIONS
INTERVENTIONS

• EVALUATE DRY WEIGHT
• TREAT REVERSIBLE CAUSES
• **BELLS, WHISTLES AND GIZMOS**
• MEDICATIONS
AIDS TO PREVENT HYPOTENSION DURING HD

- VOLUMETRIC MACHINES
- VARIABLE DIALYSATE TEMPERATURE
- SODIUM MODELING
- VARIABLE ULTRAFILTRATION
- ON-LINE HEMOGLOBIN MEASUREMENT
- HEMODYNAMIC MONITORING/IVC ECHO
- PRESSORS, ALBUMIN
- INCREASED DIALYSIS TIME
HEMODYNAMIC EFFECTS OF DIALYSATE TEMPERATURE CONTROL

Fixed dialysis fluid temperature

Controlled dialysis fluid temperature

T body (°C)

MAP (mmHg)

HR (beats/min)

△ MAP (pre/post) = 50 mmHg

△ MAP (pre/post) = 17 mmHg

Time (min)
SODIUM MODELING AND ULTRAFILTRATION PATTERNS

[DIALYSIS TIME]

[STEP]

[EXPONENT]

[STANDARD]

[SODIUM OR UFR]
### SYMPTOMS DURING STEADY vs RAMP SODIUM PATTERN

<table>
<thead>
<tr>
<th></th>
<th>HYPOTENSION</th>
<th>LOWEST BP</th>
<th>CRAMPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT</td>
<td>1.3</td>
<td>114/66</td>
<td>0.9</td>
</tr>
<tr>
<td>BOTH RAMP PATTERNS</td>
<td>0.7</td>
<td>123/69</td>
<td>0.5</td>
</tr>
</tbody>
</table>
SYMPTOMS DURING STEADY vs RAMP SODIUM PATTERN

• 22% (5 PATIENTS) REPORTED MARKED IMPROVEMENT

• SIGNIFICANTLY MORE THIRST AND FATIGUE DURING RAMPING

• INTERDIALYTIC WEIGHT GAIN 5.1% (RAMPING) vs 4.4% (STEADY); p<0.0001

• PREDIALYSIS BP: 152/81 (RAMPING) vs 143/79 (STEADY); p<0.001
VARIABLE ULTRAFILTRATION

- n = 53 Patients in 188 treatments
- Constant UF vs Ramp UF vs Intermittent

High UF

AJKD 36:115-123, 2000
HEMATOCRIT MONITORS

MEASUREMENT OF BLOOD VOLUME: ASSESSMENT OF EDW AND PREVENTION OF HYPOTENSION
CritLine Monitor

Hematocrit at arterial line
Changes in Hct & RELATIVE Blood Volume during Hemodialysis

TECHNOLOGY: HCT and Blood Volume

\[ \text{Hct} = \frac{\text{RCV}}{\text{BV}} \times 100 \]

Caveats: Unstable RBC mass; fistula recirculation
BLOOD VOLUME MONITORS

How to use Volume Monitor to assess Dry Weight?
Stable Plasma Volume

Plasma Refilling Rate (PRR) = Ultrafiltration Rate (UFR)

**Common Interpretation:**

1. Total body fluid overload and high interstitial pressure (PRR)
2. Dry weight is too high

**Caveat:** Low UFR (small fluid gain or long dialysis)

Useful if high UFR and still has stable PV
Rapid decrease in Plasma Volume

Plasma Refilling Rate < Ultrafiltration Rate

Common Interpretation:
(1) Volume depleted and low interstitial pressure (PRR)
(2) Dry weight is too low

Caveat:
High UFR (intravascular volume depletion despite edema)
BLOOD VOLUME MONITOR

• How to use Volume Monitor to predict and prevent Intradialytic Hypovolemic Symptoms?
CONCEPT OF CRITICAL BLOOD VOLUME

Hematocrit

Time (hours)

UFR = 1828 ml/hr

UF Off (shock)

UF Off (shock)

UF Off (shock)

THRESHOLD
<table>
<thead>
<tr>
<th>PATIENT</th>
<th># SESSIONS</th>
<th>THRESHOLD HEMATOCRIT</th>
<th>SESSIONS WITH SYMPTOMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14</td>
<td>51.0 +/- 1.2</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>11</td>
<td>40.9 +/- 1.3</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>35.8 +/- 1.1</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>36.7 +/- 1.2</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>41.4 +/- 0.4</td>
<td>6</td>
</tr>
</tbody>
</table>
BLOOD VOLUME MONITOR: PREDICTIVE ABILITY

- n = 13 HYPOTENSION-PRONE HD PATIENTS
- RELATIVE BLOOD VOLUME MEASUREMENT
- 8/13 HAVE RBV DEFINED BELOW WHICH > 92% HYPOTENSION EPISODES OCCUR

RBV PREDICTS EPISODES IN 62% OF HYPOTENSION-PRONE PATIENTS
Signals & Responses for Integrated Biofeedback System

Signals from Patient
- Plasma vol & BP
- Plasma Na⁺
- Plasma temp

Responses from machine
- UFR
- Dialysate Na⁺
- Dialysate temp
FRESENIUS BLOOD TEMPERATURE AND VOLUME MONITOR
# EXPERIENCE WITH AN INTEGRATED BIOFEEDBACK SYSTEM

**AJKD 32:738, 1998**

<table>
<thead>
<tr>
<th>n = 8 PATIENTS, 96 treatments</th>
<th>STANDARD HD</th>
<th>BIOFEEDBACK HD</th>
<th>STANDARD HD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SEVERE HYPOTENSION</strong></td>
<td>26</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td><strong>% DECLINE SBP</strong></td>
<td>20 +/- 8.1</td>
<td>12.4 +/- 3.5</td>
<td>17.5 +/- 4.5</td>
</tr>
<tr>
<td><strong>SALINE INFUSION/Rx (cc)</strong></td>
<td>160 +/- 50</td>
<td>60 +/- 35</td>
<td>95 +/- 30</td>
</tr>
<tr>
<td><strong>ULTRAFILTRATE</strong></td>
<td>3.1 +/- 0.6</td>
<td>3.5 +/- 0.5</td>
<td>3.2 +/- 0.7</td>
</tr>
</tbody>
</table>
INTERVENTIONS

- EVALUATE DRY WEIGHT
- TREAT REVERSIBLE CAUSES
- BELLS, WHISTLES AND GIZMOS
- MEDICATIONS
MEDICATIONS TO SUPPORT BLOOD PRESSURE

• SALINE: LIMITED EFFICACY, EDW NOT ACHIEVED
• MANNITOL, DEXTRAN: RETENTION
• ALBUMIN: $$!
• ? HYDROXYETHYLSTARCH (10%): PRELIMINARY STUDIES SUGGEST SIMILAR EFFICACY TO ALBUMIN; NO LONG TERM STUDIES
• ? LIMIT EATING DURING DIALYSIS: MALNUTRITION ?
• MIDODRINE: MODEST EFFECT
• FLUDROCORTISONE: AUTONOMIC DYSFUNCTION; 1 MG (10X USUAL DOSE)
DIALYSIS TIME

• DIALYSIS TIME IS ULTIMATELY GOVERNED BY ULTRAFILTRATION REQUIREMENTS

• MULTIPLE LINES OF EVIDENCE SUGGEST COMPLICATIONS OF DIALYSIS ARE REDUCED BY LENGTHENING $T_D$
  ≜ MORTALITY
  ≜ HYPERTENSION
  ≜ PHOSPHORUS CONTROL

• IT’S TIME TO CONSIDER A “DIALYSIS TIME HYPOTHESIS”
FUTURE DIRECTIONS

- More definitive outcome measures
  - What constitutes optimum dialysate?
  - What constitutes optimum dialysis time?
  - What are optimum dry weight & blood pressures?
  - What portion of the patients can benefit from given interventions?
  - How can these patients are identified?

- Development of advanced biofeedback systems

- Introduction of alternative modalities of hemodialysis
THANKS FOR YOUR ATTENTION!!