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

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Objectives

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

Resuscitation Fluids

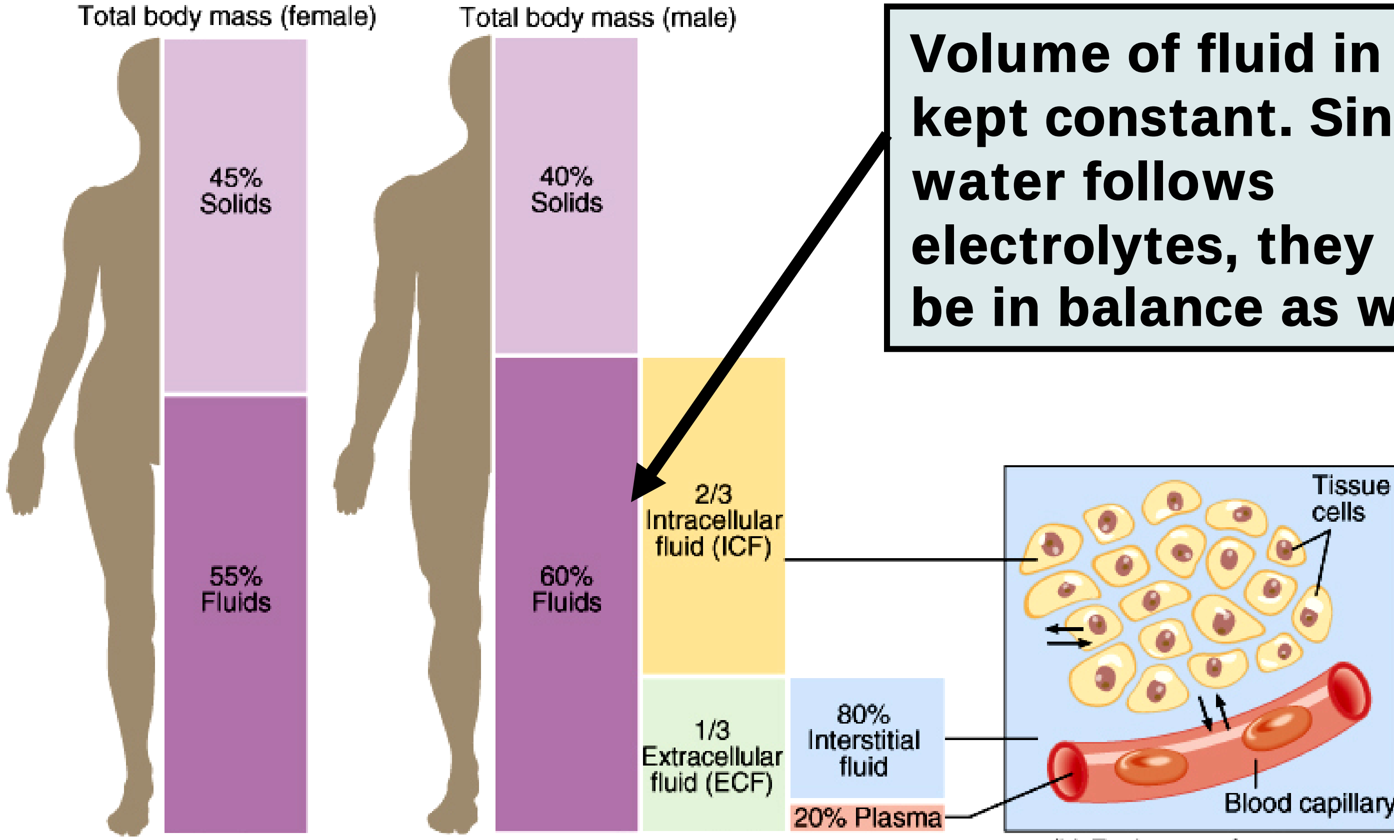
- Goal
  - Restore effective circulating volume for appropriate end-organ perfusion, DO2/VO2
- Types of FDA approved fluids
  - Crystalloids
  - Colloids
  - Whole blood
  - Component blood products

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

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

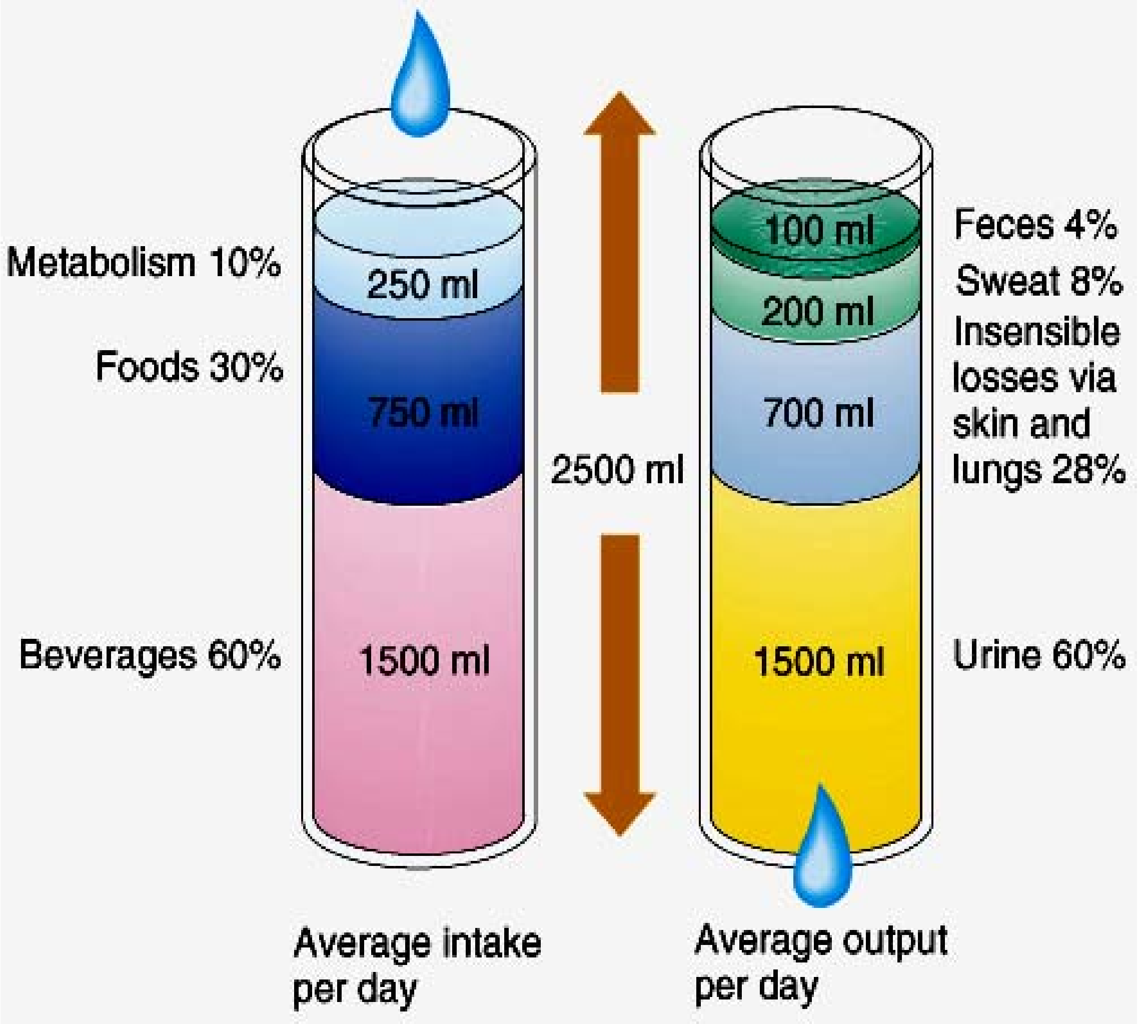


(a) Distribution of body water in an average lean, adult female and male

(b) Exchange of water among body fluid compartments

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

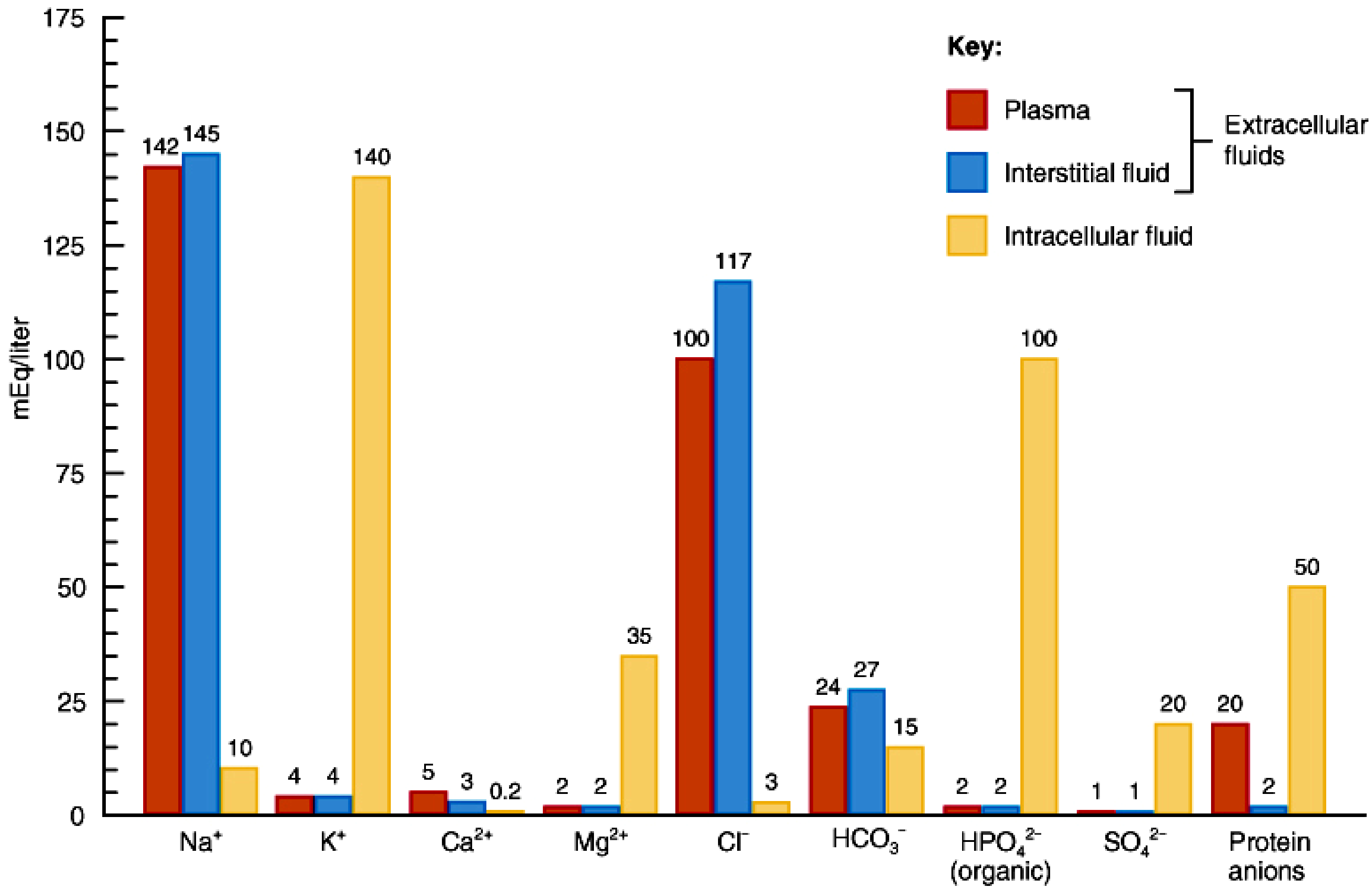
Body Water Gain and Loss



Body Water Content

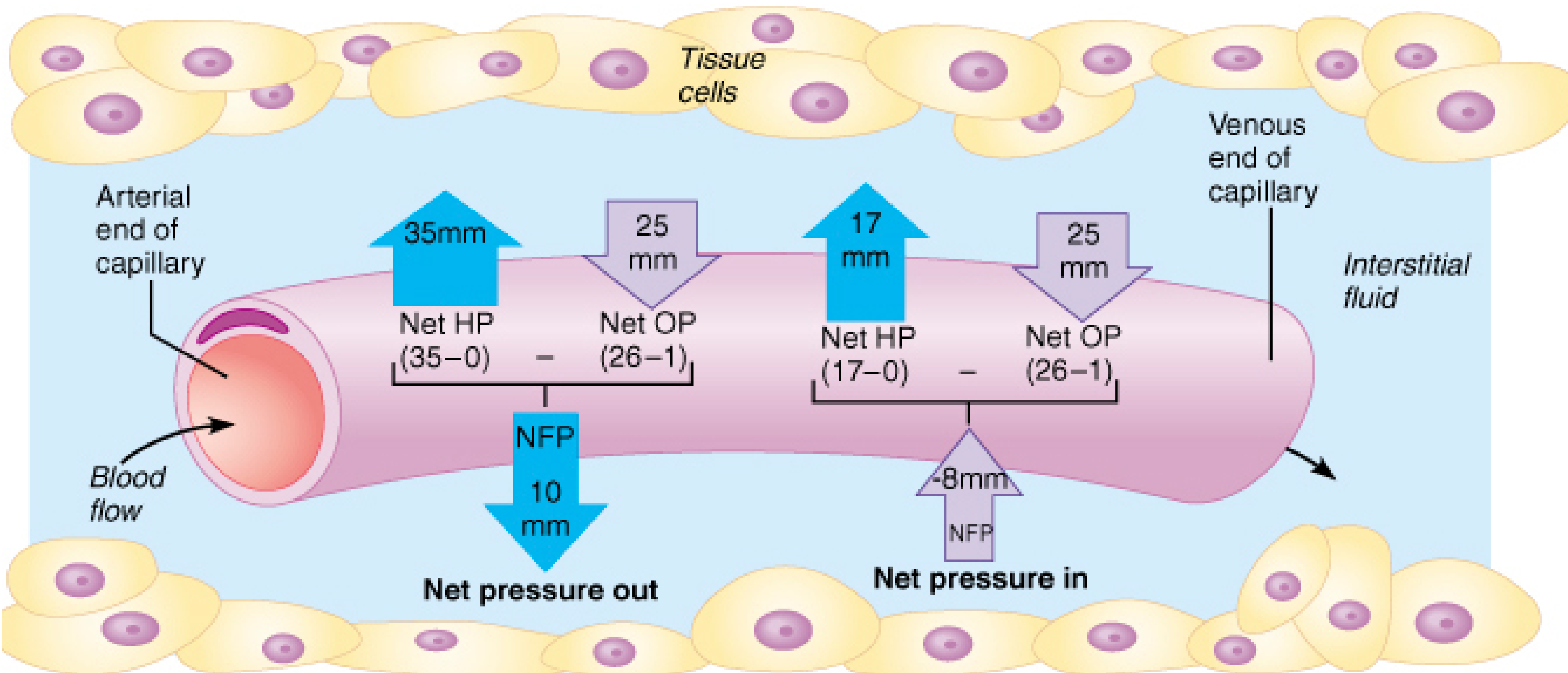
- 45-75% body weight
  - declines with age
  - fat has ~ no water
- Gains
  - Intake (po)
  - Metabolic H_2O (aerobic respiration)
  - dehydration synthesis reactions
  - Total = 2500 mL/day
- Normally gain = loss

Comparison Between Fluid Compartments



- Plasma proteins >> interstitial
  - colloid osmotic pressure

Starling Forces



Key to pressure values:

HP_c at arterial end = 35 mm Hg HP_{if} = 0 mm Hg OP_{if} = 1 mm Hg

HP_c at venous end = 17 mm Hg OP_c = 26 mm Hg

Crystalloids for Resuscitation

- 0.9% NSS
- Lactated Ringer's solution
- Other fluids
  - Plasmalyte
  - Normosol

Electrolyte Composition

Type	Na	Cl	K	Mg	Ca	LA
NSS	154	154	0	0	0	0
LR	130	110	3.3	2.8	4.5	28
Plasma	140	100	4	2	4.5	2

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

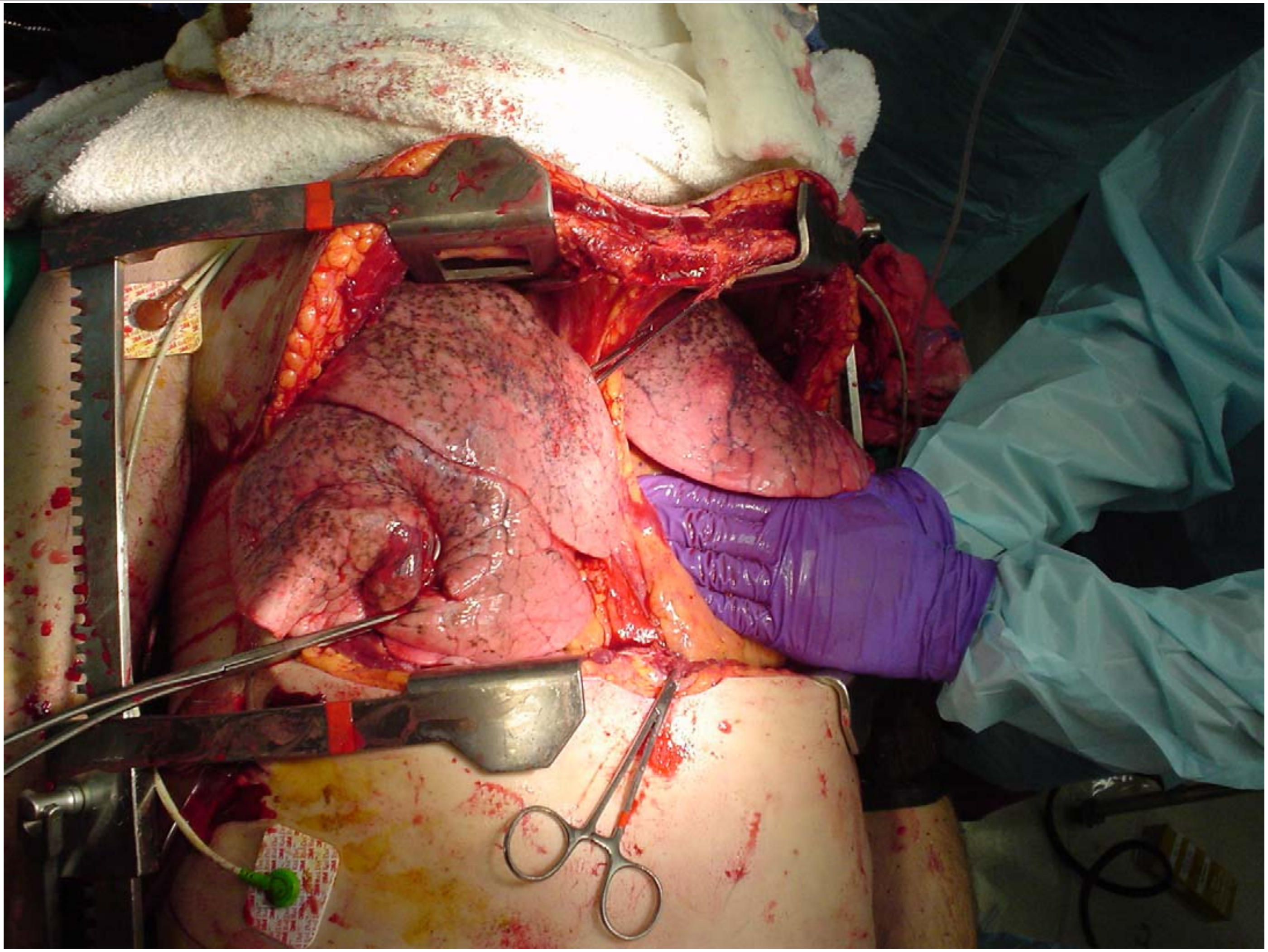
Class	HR	SBP	PP	EBV	Rx
I	↔	↔	↔	< 15%	Crystalloid
II	↑	↓	↓	15-30%	± Colloid
III	↑	↓ < 90	↓	30-40%	PRBC
IV	↑	↓	↓	> 40%	PRBC

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
Kaplan LJ, et al. *Curr Op Crit Care*; 2010; 16(4):323-31

Account for Cavity Losses



Account for Ongoing Losses

Evaporation and 3rd Space

25% maintenance
3rd space

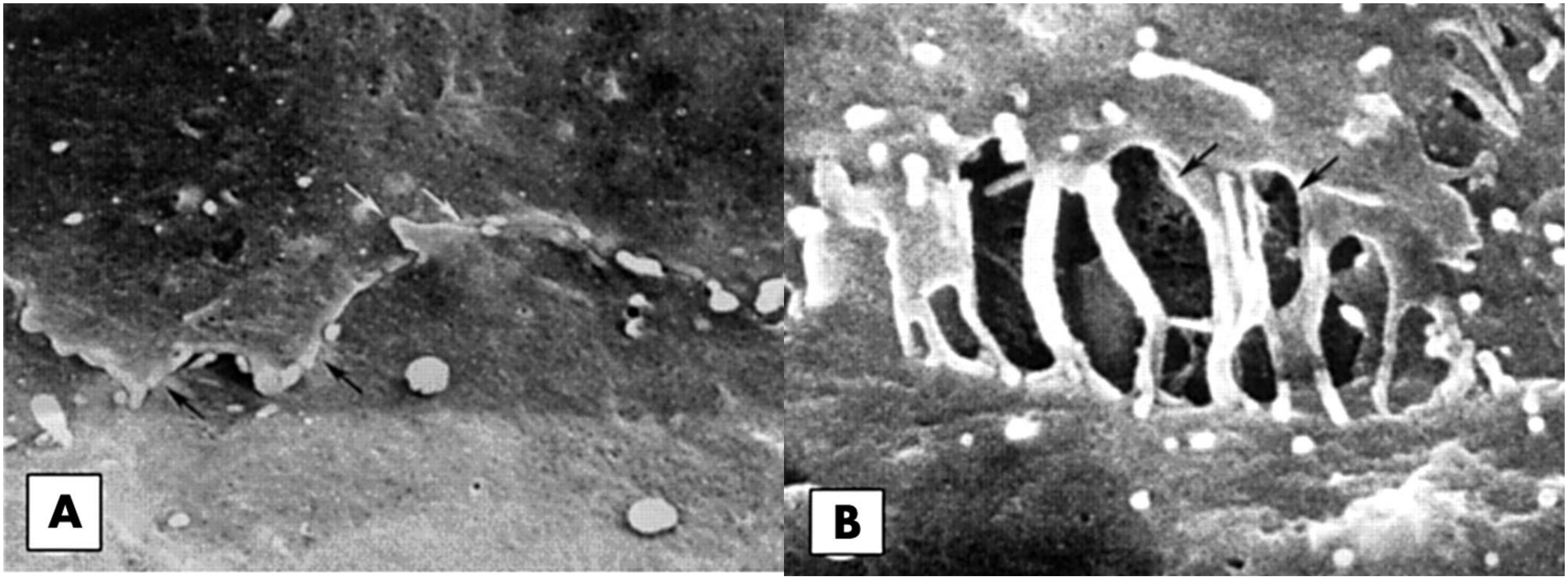
25% maintenance
3rd space

1000 cc evaporative loss/hour

25% maintenance
3rd space

25% maintenance
3rd space

Capillary Leak



Gosling P. *Emerg Med J* 2003; 20:306-15

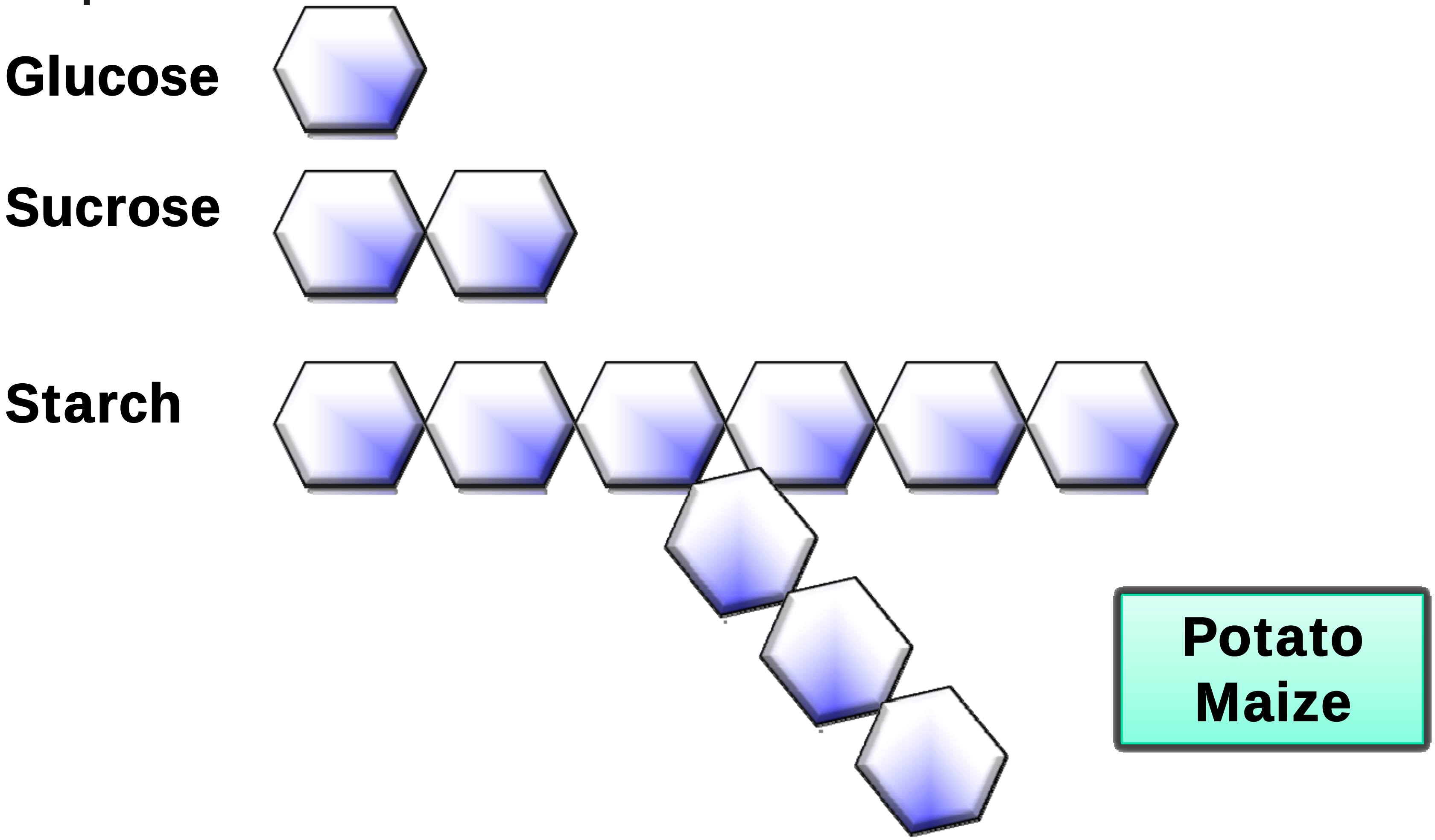
Colloid Resuscitation

- Ultimate colloid is whole blood
  - Military "buddy" transfusion
- Damage control resuscitation
  - **Barbeau JM, et al. *J Trauma* 2010; 69(1):46-52**
  - Blood product ratio 1:1:1
  - Poorly followed in existing MTP
    - **Schuster KM, et al. *Transfusion* 2010; 50:1545-51**
- 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 --> ~ 5.3nm 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



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, VISEP, 6S)

US Colloids

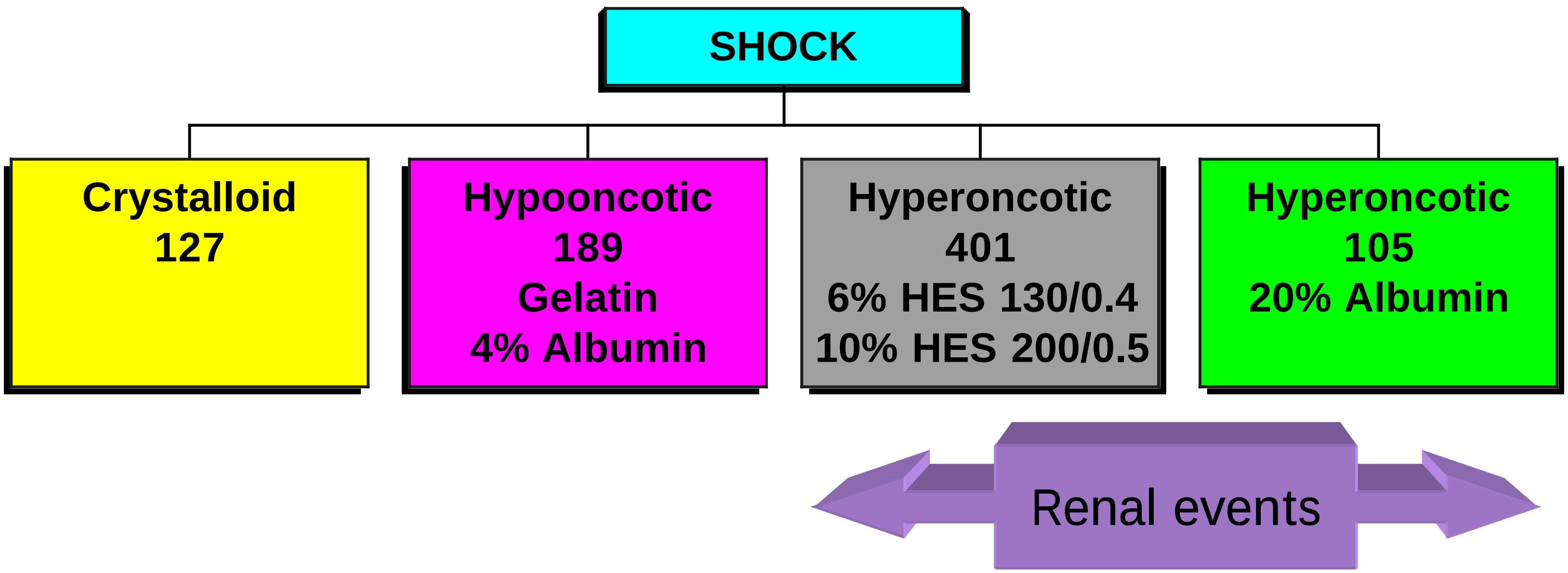
- 5% or 25% human albumin
  - 0.9% NSS diluent only
- Dextran 40% or 70%
  - Hyperoncotic and allergic reactions
- Fresh Frozen Plasma (FFP)
  - Ideal resuscitant
    - Specific criteria for Tx lacking
  - Associated with TRALI, TACO

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
    - Perner A, et al. 2012

Study Design (n=822)

Oncotic Pressure and Renal Injury



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

VISEP 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

VISEP Study

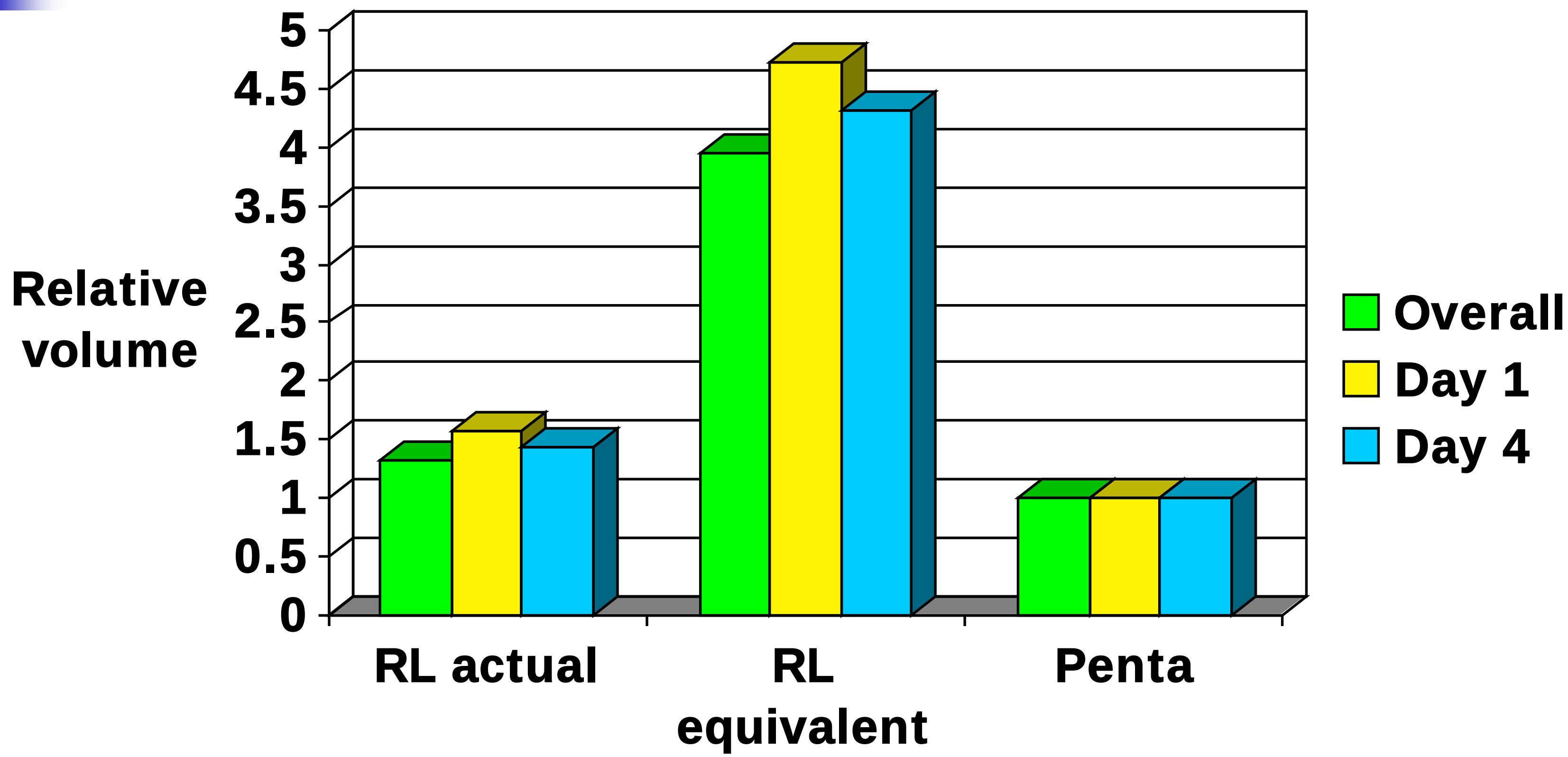
- Study aborted due to safety concerns from Data Safety Monitoring Board
  - Arrested in phase 1
  - Hypoglycemia (glucose < 40 mg%)
  - Secondary analysis
    - Trend towards higher mortality with HES
    - Higher rate of RRT/ARF with HES
    - Increased rate of transfusion with HES
- Are these results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

VISEP: Operations (p=0.04)

Category	Ringers Lactate	Pentastarch
Elective	18.2%	13.7%
Emergent	32%	42%
No OR	49.8%	43.9%

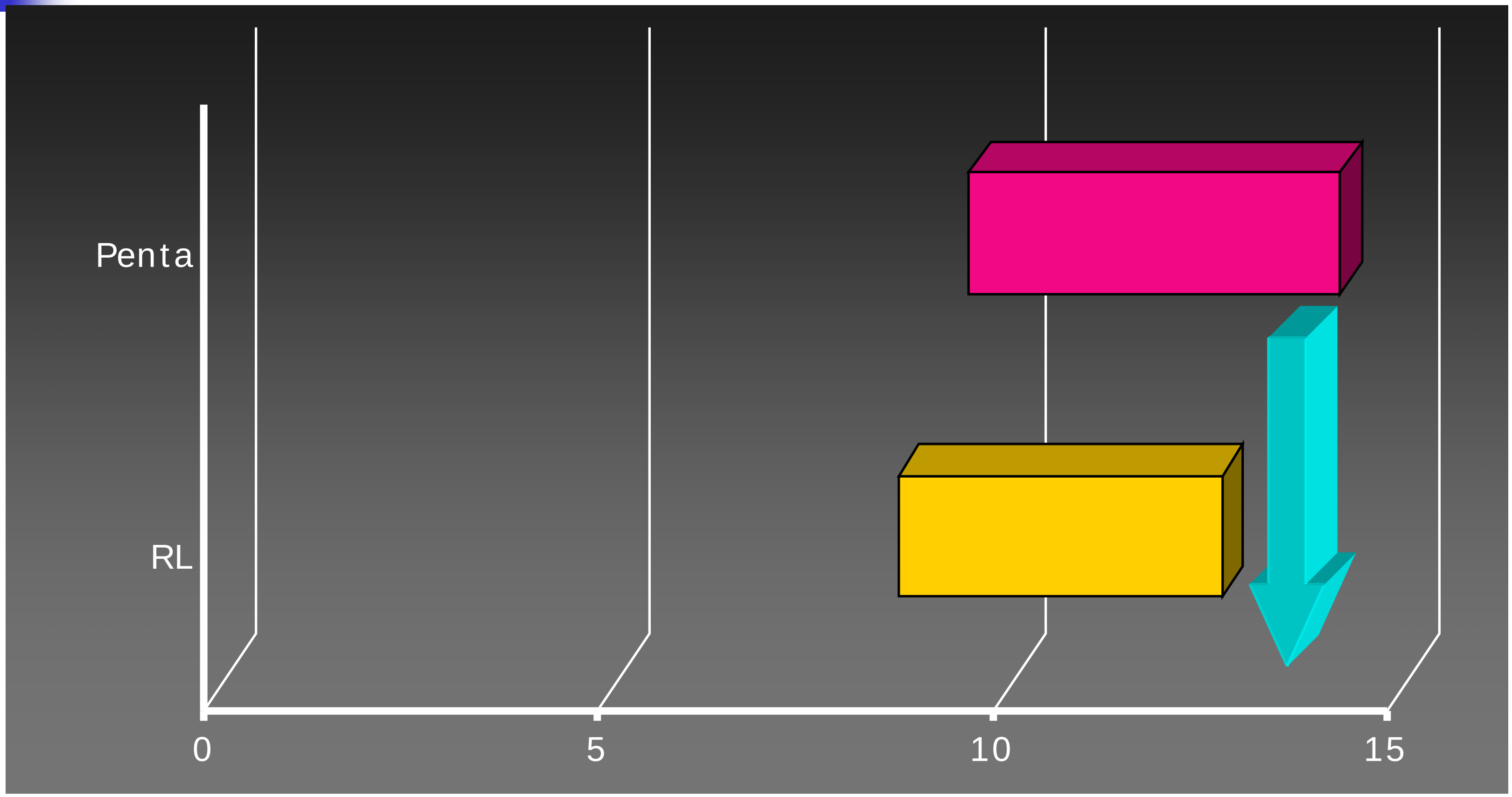
Greater emergent OR, less non-op management
High-risk population for ATN and ARF

VISEP: Fluid Volumes



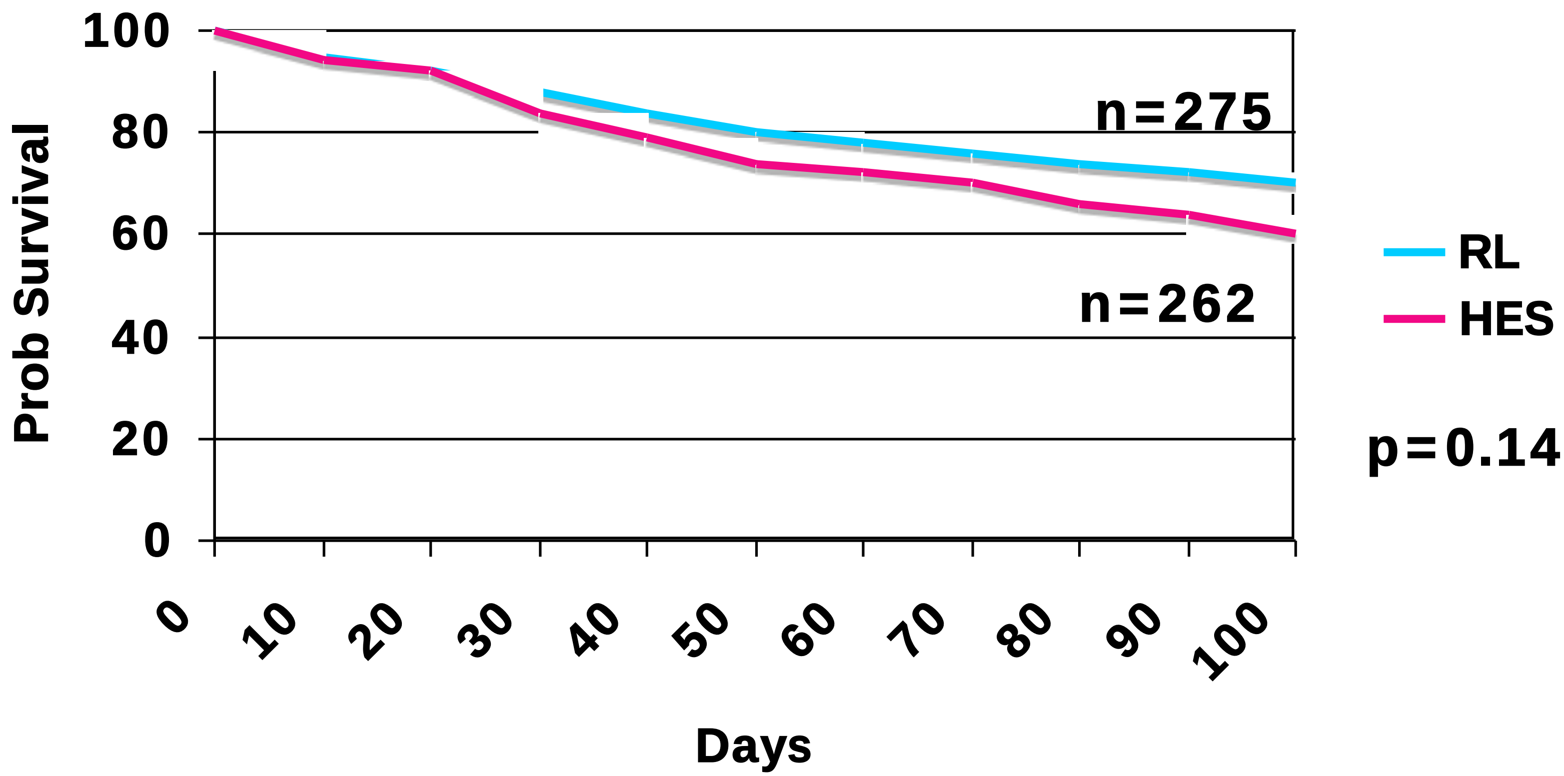
Indexed to Pentastarch volume
Median dose = 70.4 ml/kg bw

VISEP: CVP and PRBC

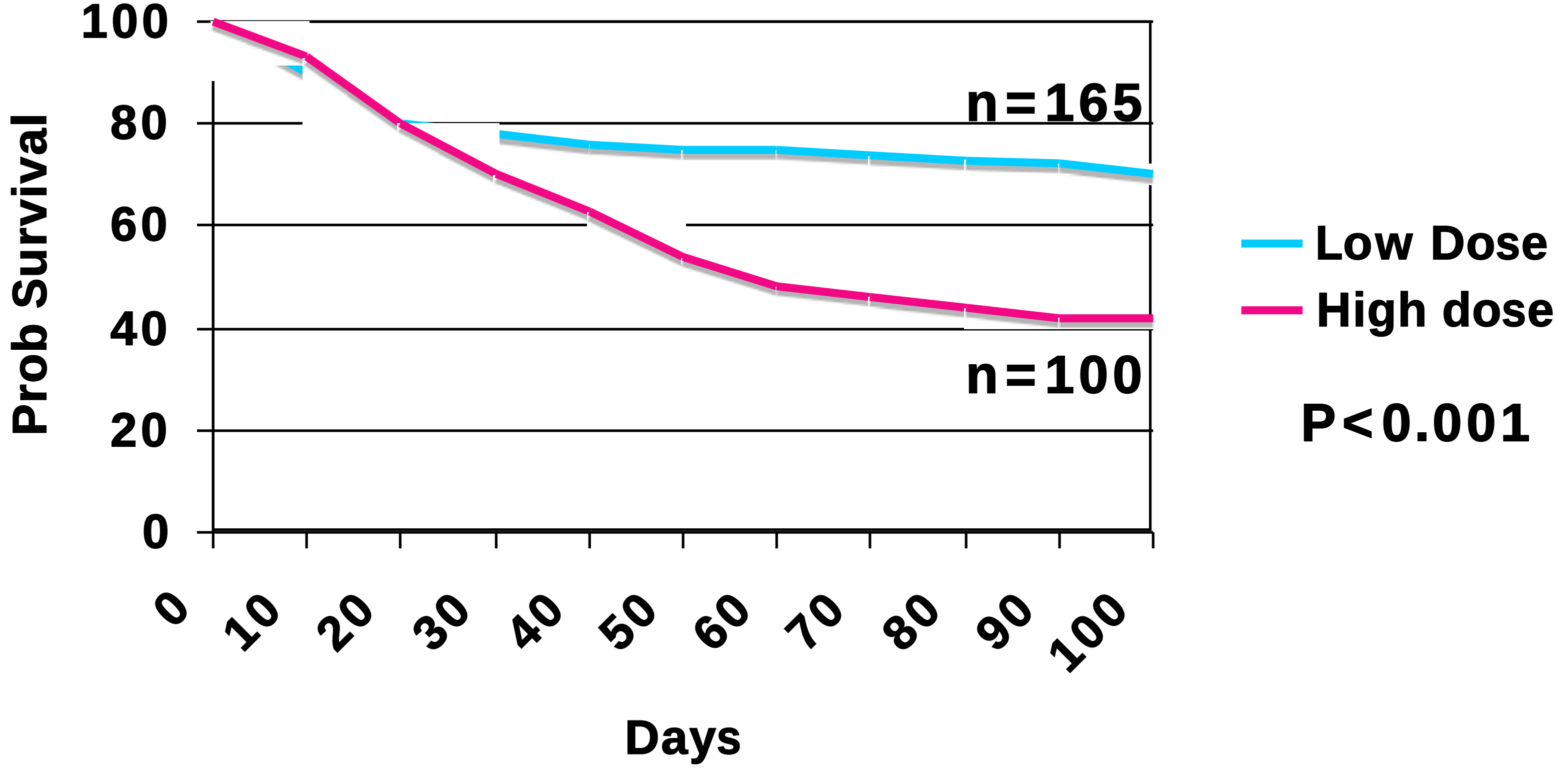


RL: 4U PRBC HES: 6U PRBC
Unequal resuscitation and hemodilution

VISEP: Probability of Survival



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

Hyperchloremia

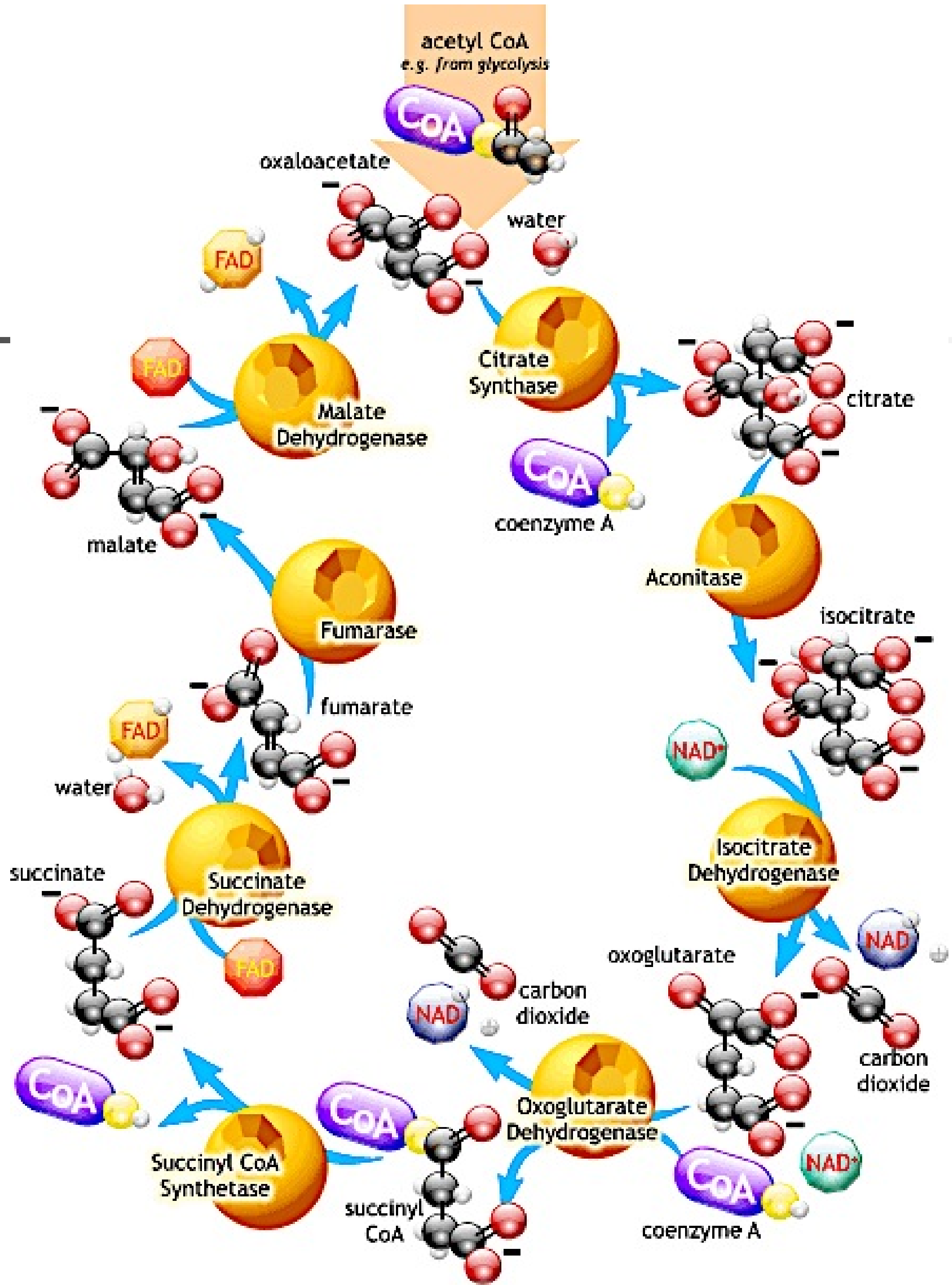
- Independently decreases renal function
  - GFR, urine flow, creatinine clearance
    - Wilcox CS. *J Clin Invest* 1983; 71: 726-35
- Hyperchloremic metabolic acidosis
  - Low pH out of proportion to AG or lactate
    - Waters JH, et al. *Crit Care Med* 1999; 27: 2298-9
    - Prough DS, et al. Anesth 1999; 90: 1247-9
    - Scheingraber S, et al. *Anesth* 1999; 90(5):1265-70
- Reduced rate of urine generation (human data)
  - Williams EL, et al. Anesth Analg 1999; 88: 999 - 1003

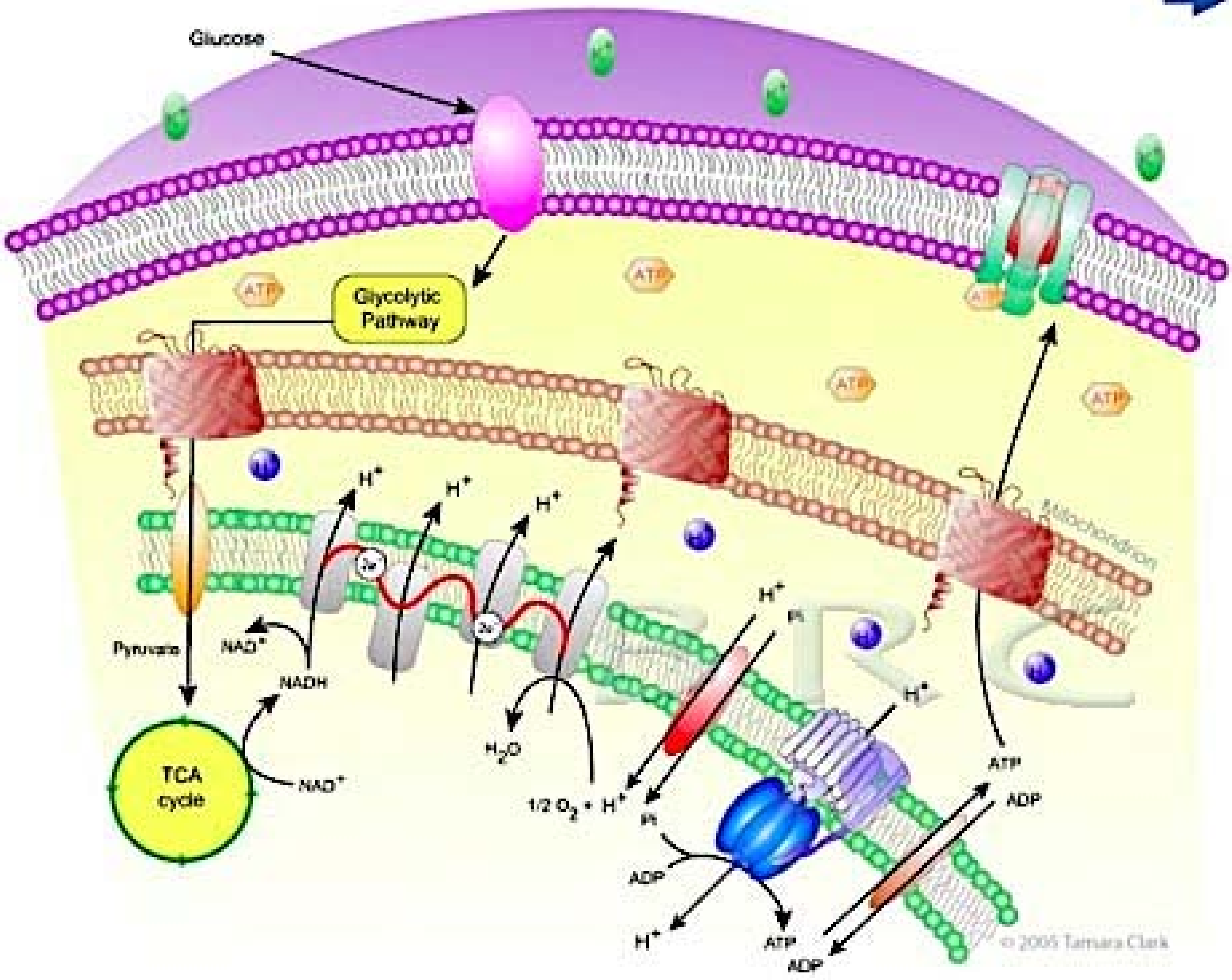
Maintenance Fluid

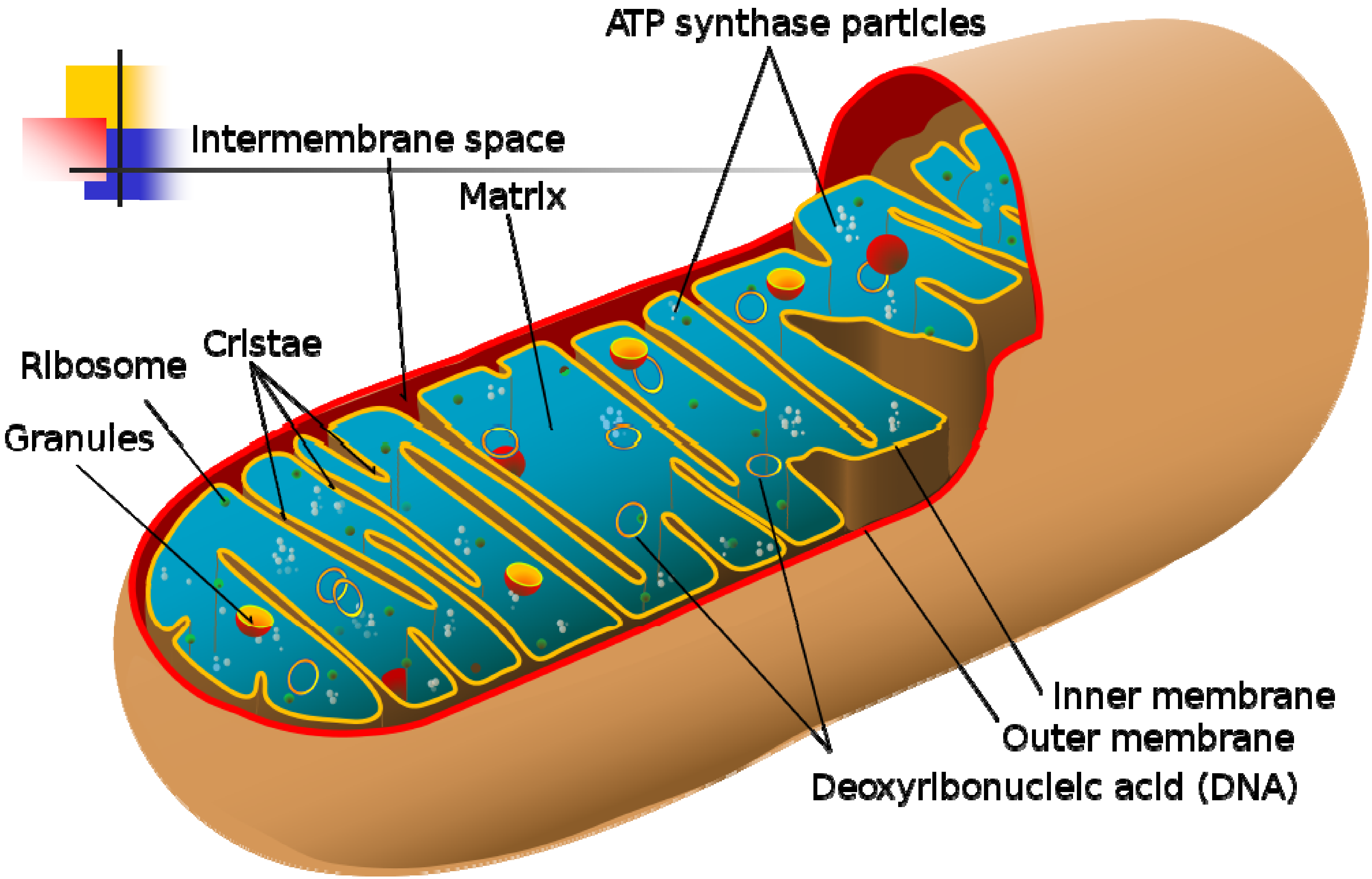
- **Most** need maintenance fluid
- Hypotonic, dextrose $\pm$ additives
- Derived from understanding minimum daily requirements (MDR) for electrolytes and muscle sparing effect of dextrose during starvation
  - LBM sparing debated

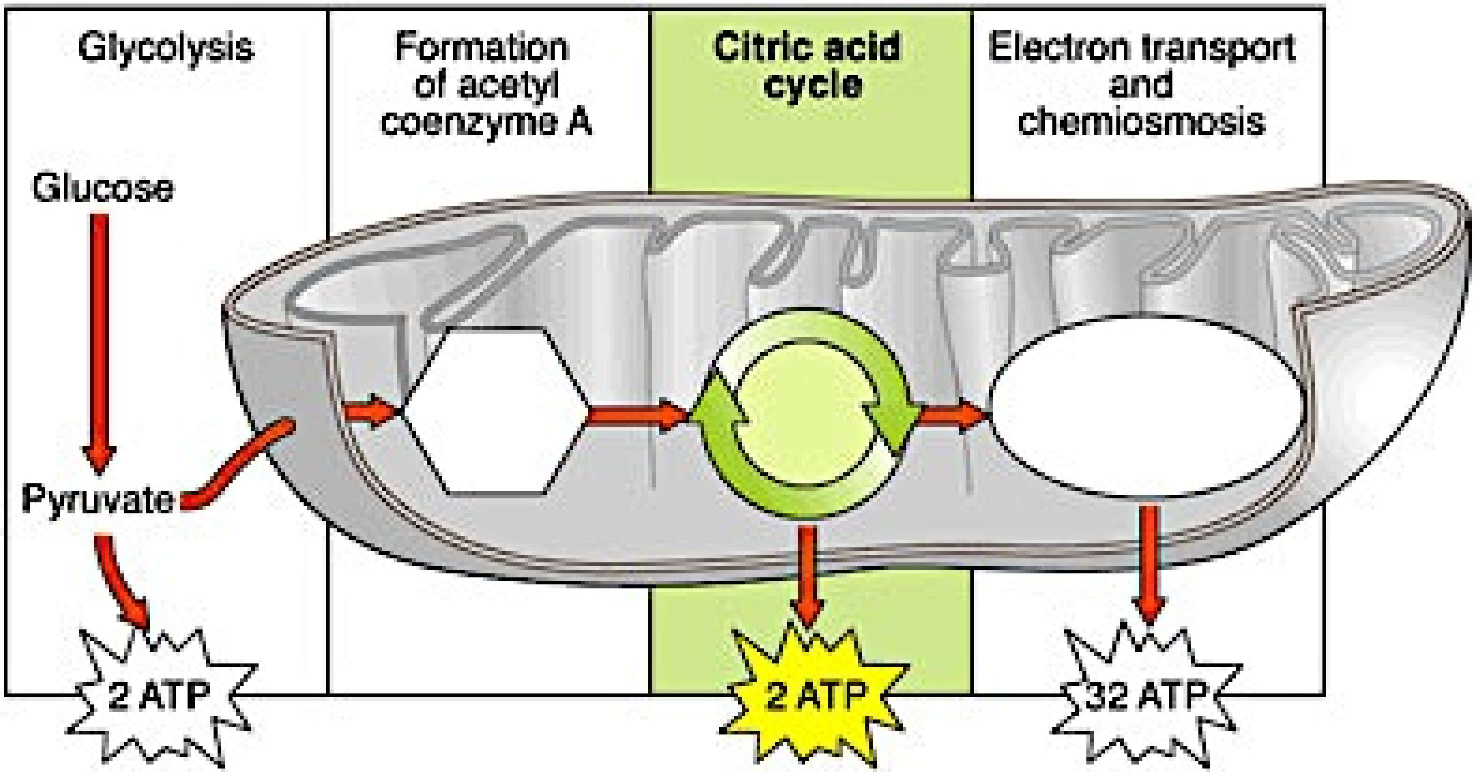
Catabolism and Lean Body Mass

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


acetyl CoA
e.g. from glycolysis
CoA
oxaloacetate
water
Citrate Synthase
citrate
CoA
coenzyme A
Aconitase
isocitrate
NAD+
Isocitrate Dehydrogenase
NAD
carbon dioxide
oxoglutarate
Oxoglutarate Dehydrogenase
NAD
carbon dioxide
NAD+
CoA
coenzyme A
CoA
succinyl CoA
Succinyl CoA Synthetase
CoA
succinate
Succinate Dehydrogenase
FAD
FAD
water
fumarate
Fumarase
malate
Malate Dehydrogenase
FAD
FAD


Glucose
Glycolytic Pathway
ATP
Pyruvate
NAD+
NADH
TCA cycle
H+
H2O
1/2 O2 + H+
Pi
ADP
ATP
Mitochondrion
© 2005 Tamara Clark


ATP synthase particles
Intermembrane space
Matrix
Cristae
Ribosome
Granules
Inner membrane
Outer membrane
Deoxyribonucleic acid (DNA)


Glycolysis
Formation of acetyl coenzyme A
Citric acid cycle
Electron transport and chemiosmosis
Glucose
Pyruvate
2 ATP
2 ATP
32 ATP

Dextrose

- Commonly provided as 5% dextrose in water (D_5W)
- D_5W = 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

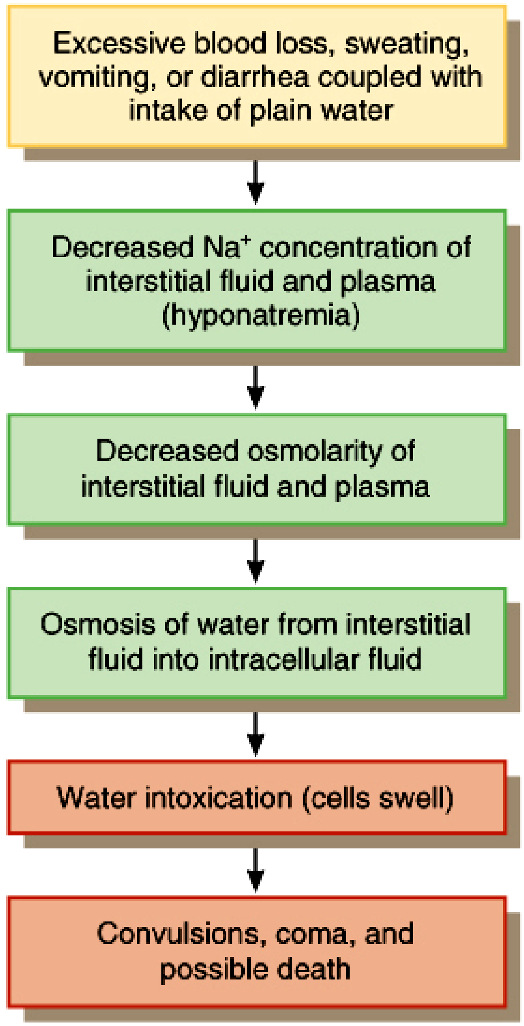
- 70 kg patient
- Add 40 rule: 110 cc/hr
- Weight based:
  - 1000 + 500 + 1000
  - 2500 cc/day / 24 hours = ~ 110 cc/hr
- Assuming 110 cc/hr, and the need for Na and K ....

Fluid Prescription

- D_5 provides just over 100 gm dextrose
- $^1/_2$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)
- $D_5{}^1/_2$NSS + 20 meq KCl/L @ 110 cc/hr

Na$^+$ 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



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^+ Abnormalities: Therapy

- Dilutional
  - Free H_2O restriction
    - May be coupled with diuresis
    - Aquaporins (V2 receptor antagonists)
      - Pure aquaresis
- 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

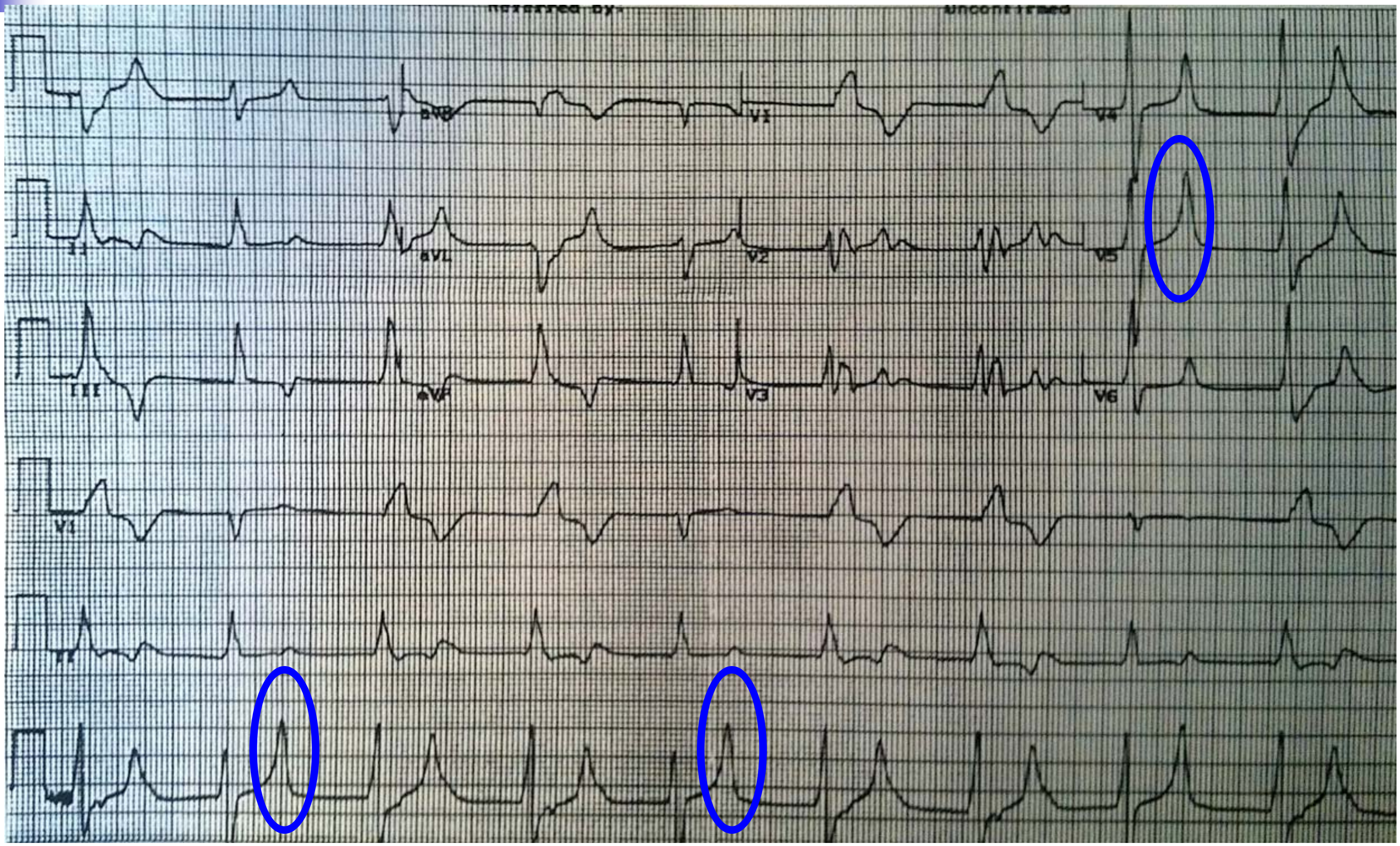
K^+ Abnormalities

- 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

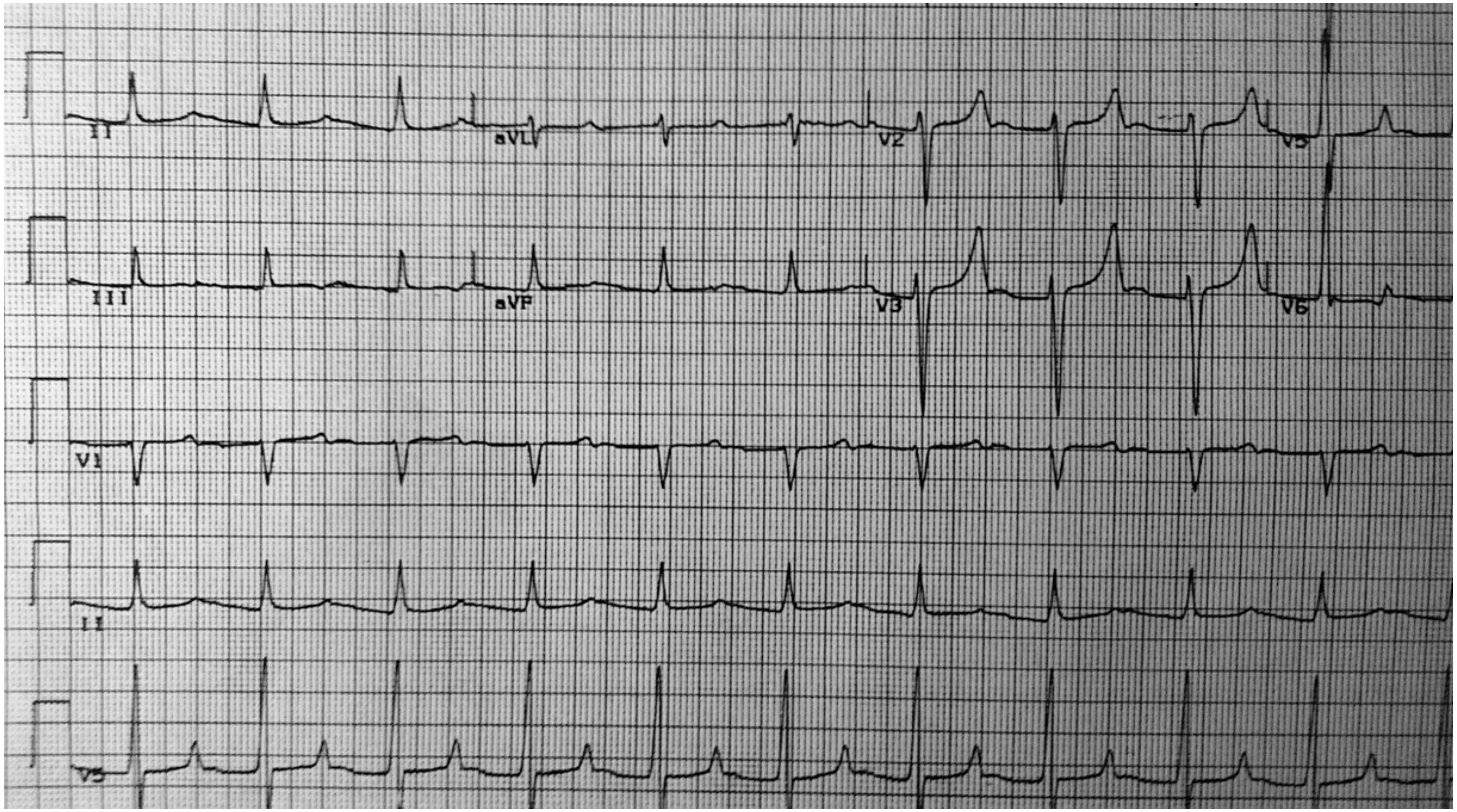
K^+ Abnormalities

- 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 SO_4
    - Membrane stabilizer
  - $NaHCO_3$
  - 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
  - Mg^{2+} 2.0 or >
  - Generally safely repleted without monitors
    - 1.6 = 4 mg
    - 1.4 = 6 gm
    - 1.2 = 8 gm
    - 1.0 = 10 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
    - $CaCl_2$ versus Cagluconate
- Hypercalcemia
  - Treat underlying cause
  - Therapy is similar to hyperkalemia
    - Forced diuresis + PVE
    - Mg^{2+}

Corrected Calcium

- Calcium is protein bound
  - Principally to albumin
    - Correct the measured calcium for hypoAlb
  - $[(\text{Normal}_{\text{Alb}} - \text{measured}_{\text{Alb}}) \times 0.8] + \text{Ca}$
- 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

Hyperphosphatmiea

- 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

Stage	Uop	Scr
1	< 0.5 cc for > 6 hr	Inc. 0.3 or 150% baseline Scr
2	< 0.5 for > 12 hr	200-300% baseline Scr
3	< 0.3 for > 24 hr Anuria for > 12 hr	300% baseline Scr Scr > 4 and inc. > 0.5

CRRT = Stage 3

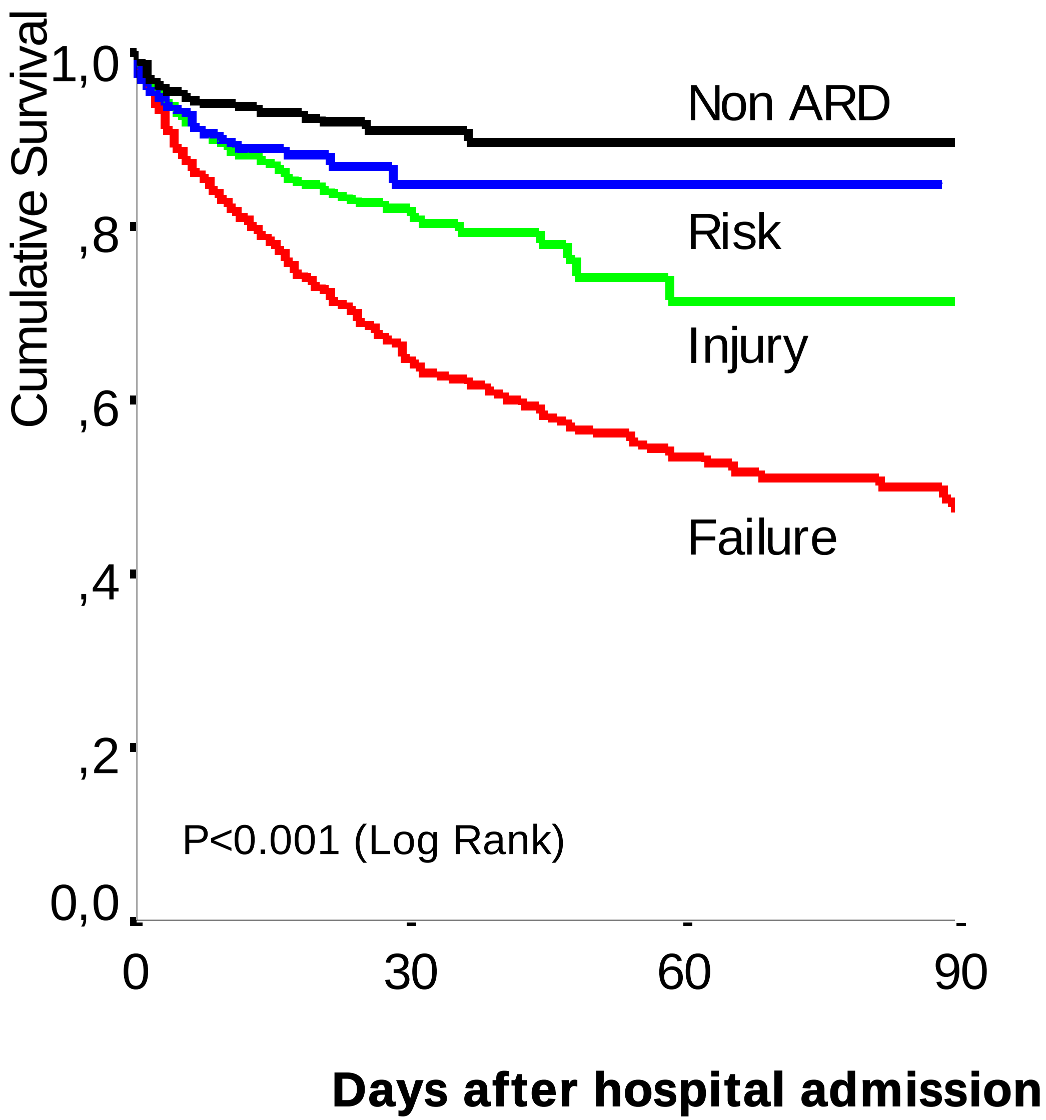
www.AKIN.org

RIFLE Criteria for Acute Kidney Injury

	GFR Criteria*	Urine Output Criteria	
Risk	Increased Scr x 1.5 or GFR decrease > 25%	Uop < 0.5ml/kg/h x 6 hr	High Sensitivity
Injury	Increased Scr x2 or GFR decrease > 50%	Uop < 0.5ml/kg/h x 12 hr	Oliguria
Failure	Increase Scr x3 or GFR dec > 75% or Scr ≥ 4mg/dl (Acute rise of ≥0.5 mg/dl)	Uop < 0.3ml/kg/h x 24 hr or Anuria x 12 hrs	High Specificity
Loss	Persistent ARF** = complete loss of renal function > 4 weeks		
ESRD	End Stage Renal Disease		

www.ADQI.net

RIFLE$_{max}$ and Hospital Mortality



Hoste E, et al. *Crit Care* 2005

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

JAMA. 2005; 294: 813-818.

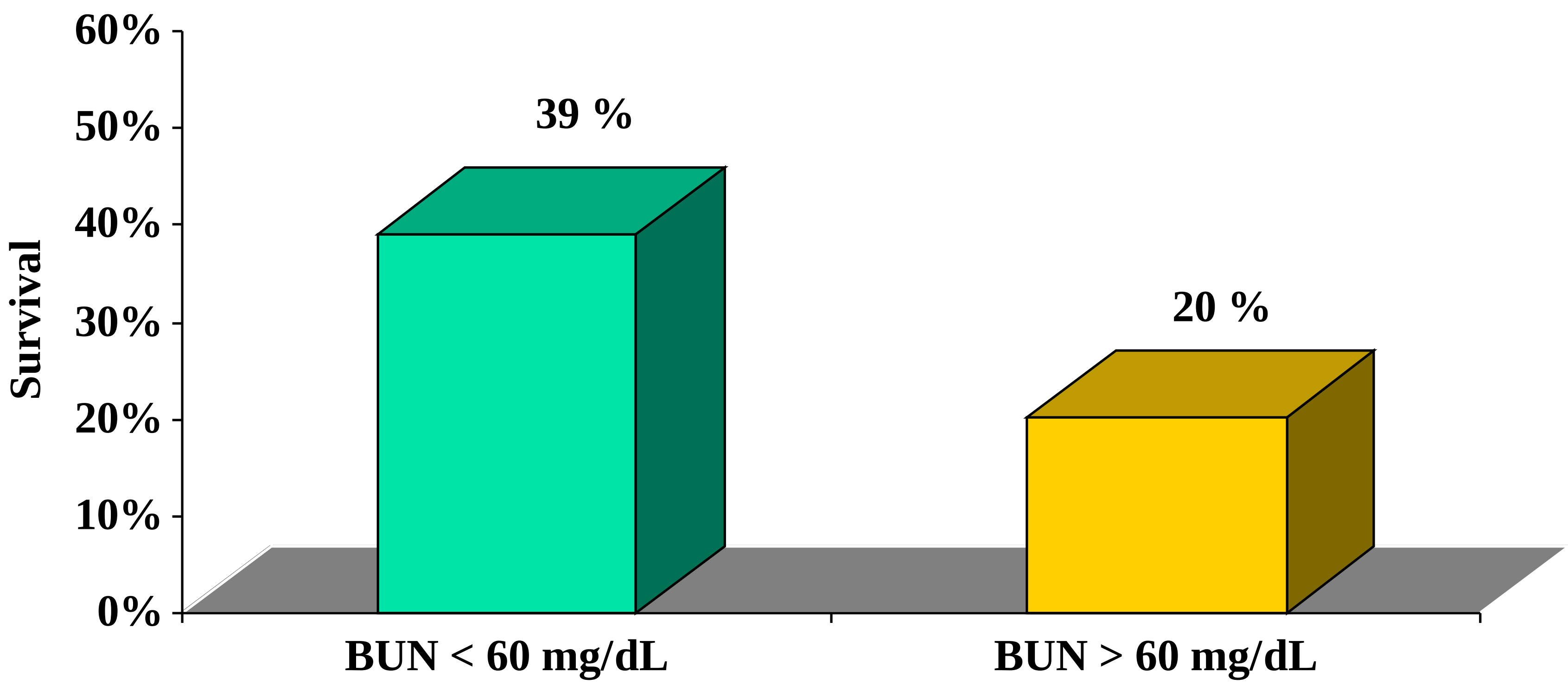
Cerda J. *Clin J Am Soc Nephrol* 3 200; 881-886

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)

JAMA. 2005; 294: 813-818.

Timing of Initiation of Dialysis in Post-Traumatic ARF



Gettings et al., *Intensive Care Med* 1999; 25:805-813

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

JAMA

Diuretics, Mortality, and Nonrecovery of Renal Function in Acute Renal Failure

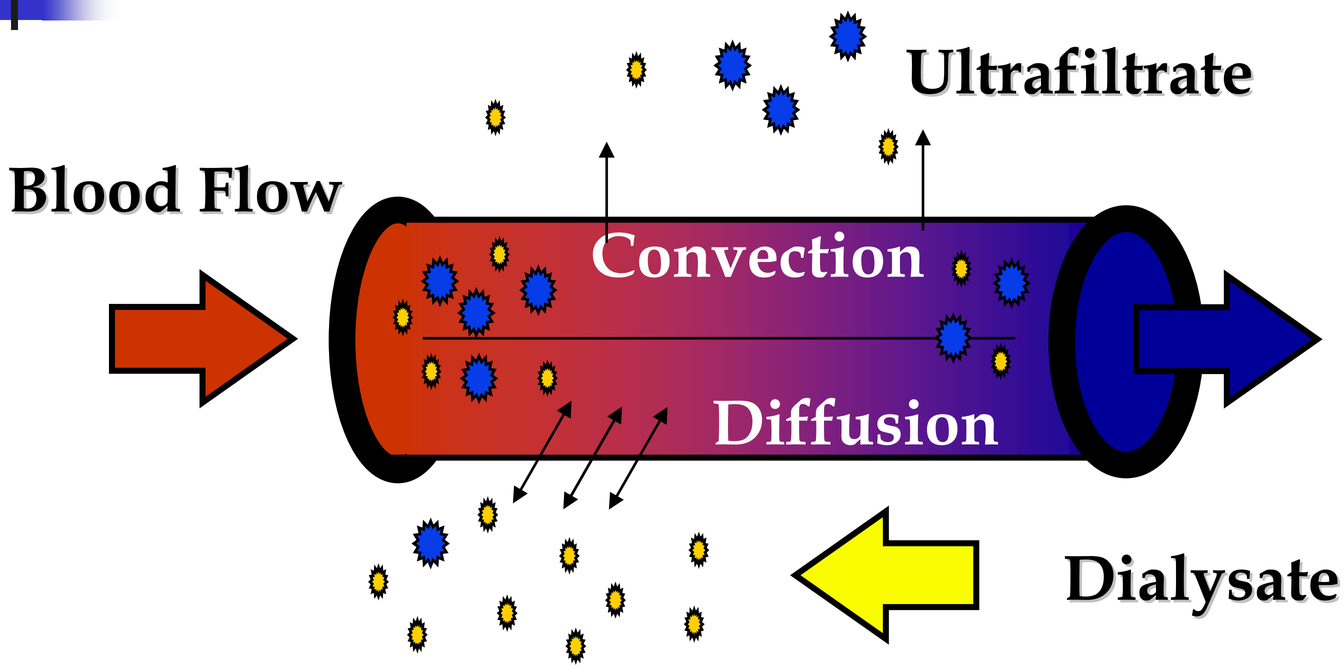
Ravindra L. Mehta, MD; Maria T. Pascual, RN, MPH; Sharon Soroko, MS; Glenn M. Chertow, MD, MPH; for the PICARD Study Group

***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”

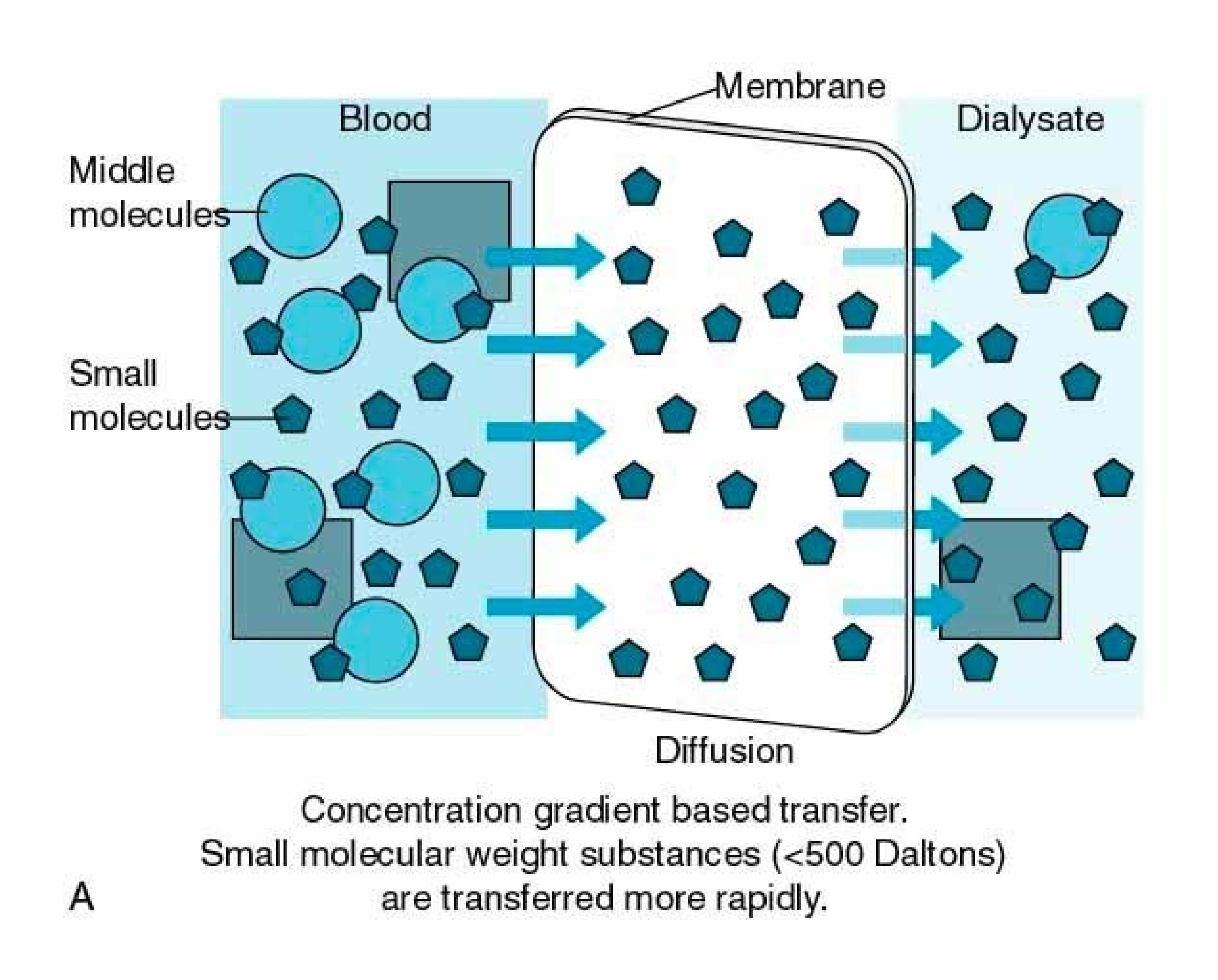
General Mechanisms of Dialysis

Convection vs. Diffusion

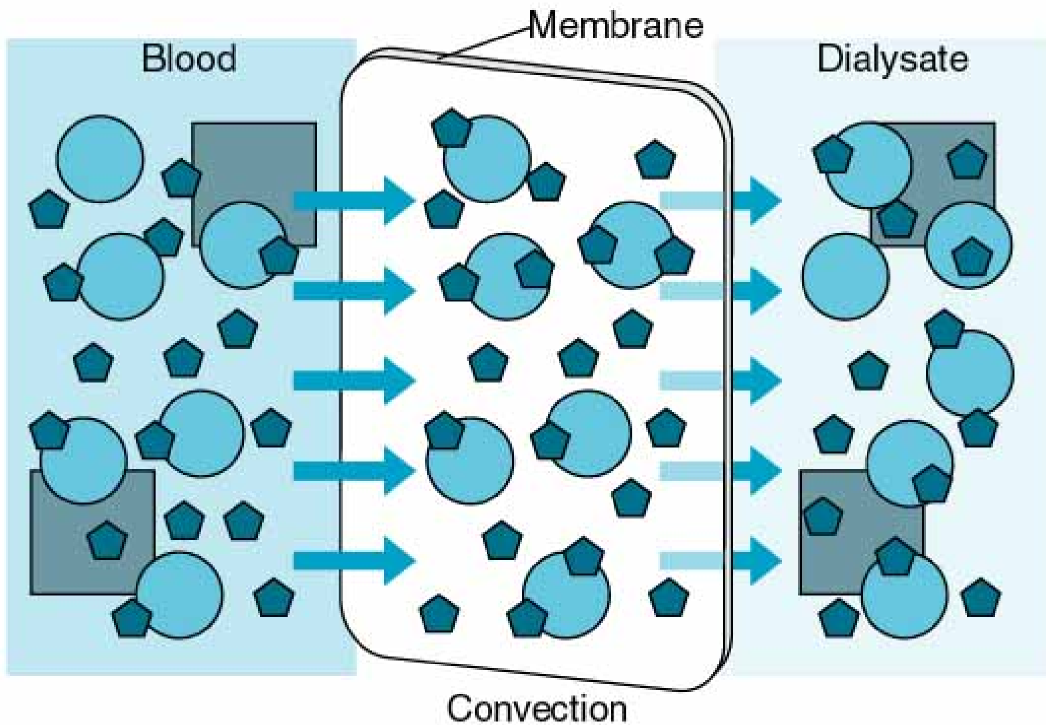


- small molecular wt substances (< 1 kD)
- large molecular wt substances (5 - 50 kD)

Diffusive Clearance



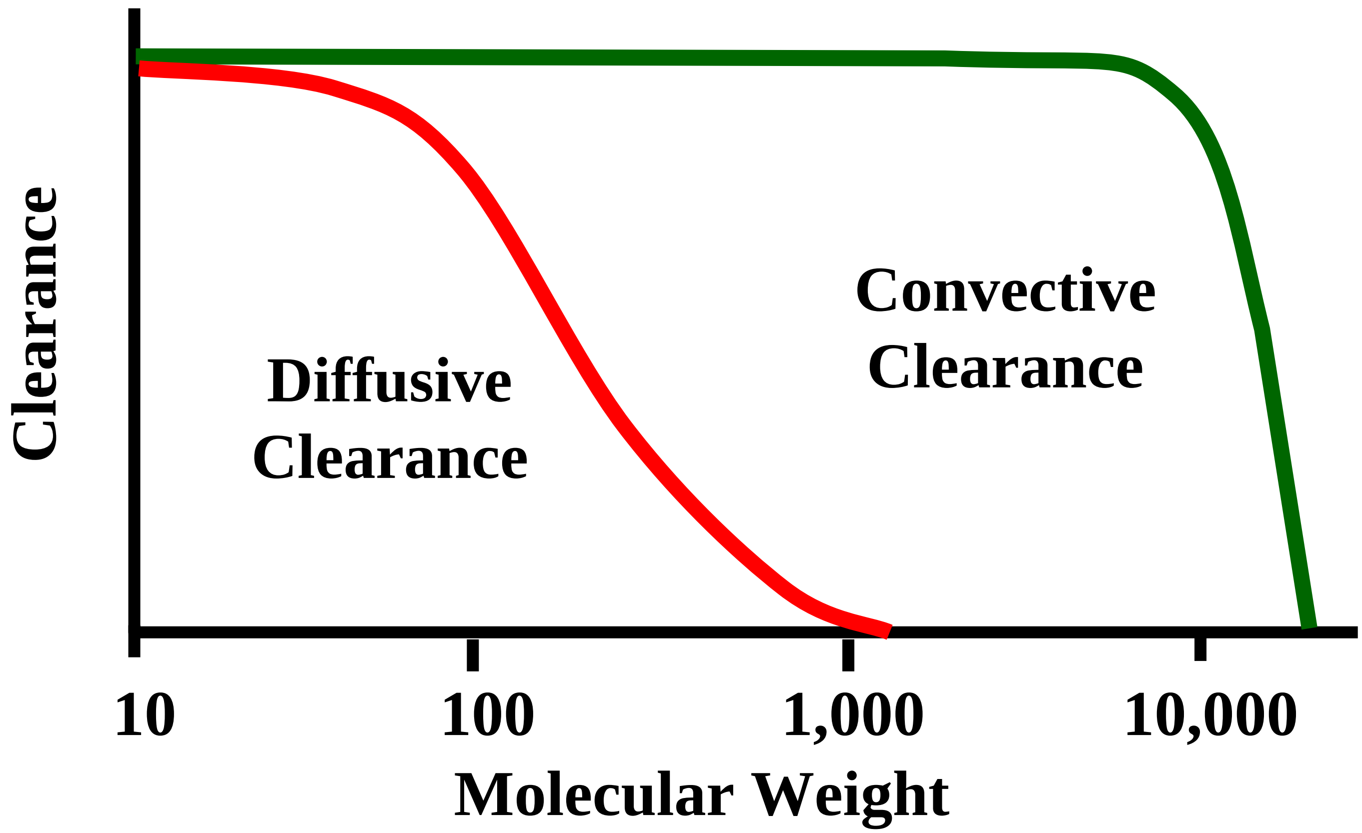
Convective Clearance



Movement of water across the membrane
carries solute across the membrane.
Middle molecules are removed more efficiently.

B

Convection vs. Diffusion



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

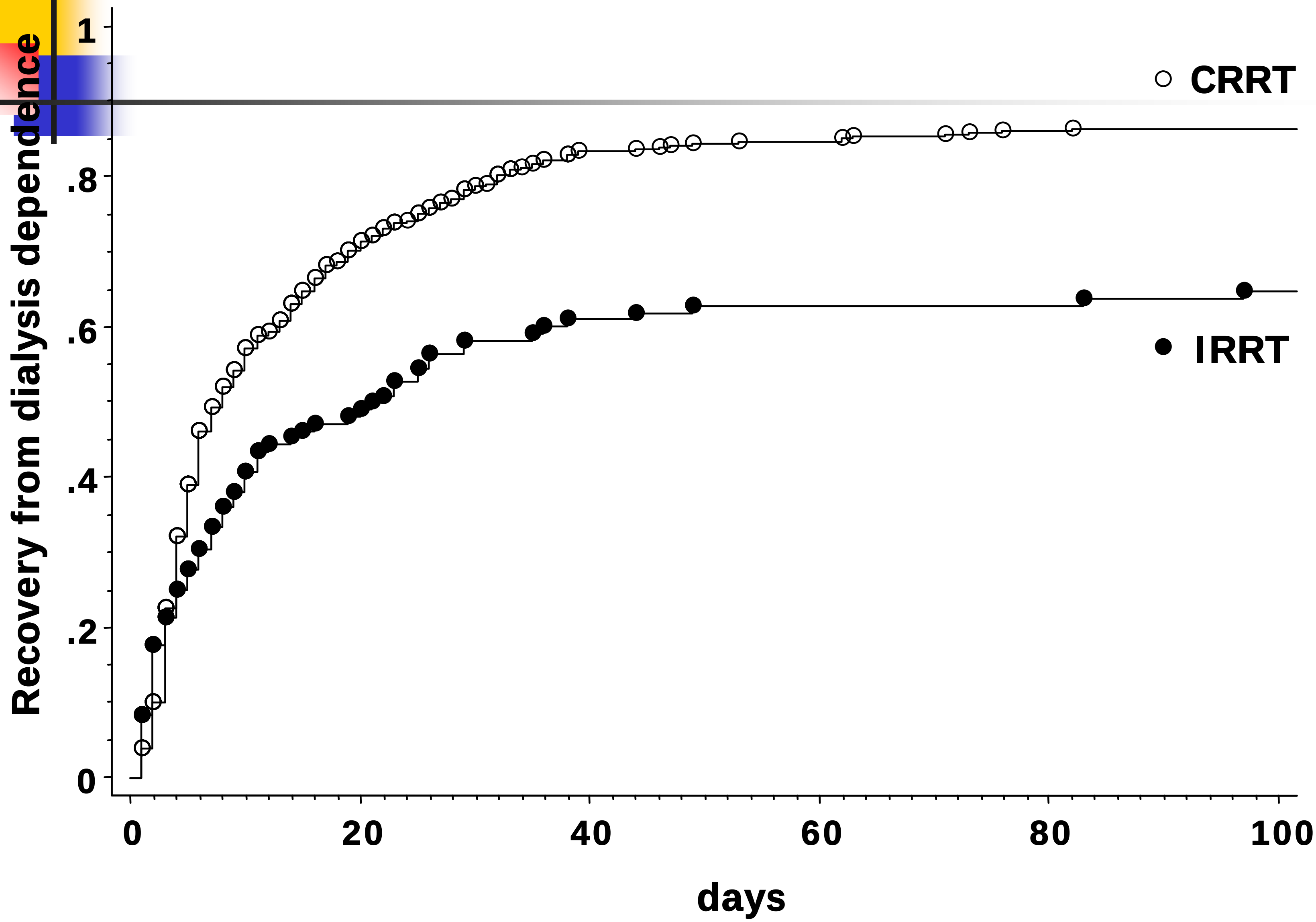
- Special Considerations for the ICU Patient
  - adequacy of dialysis
  - risk of prolongation of ARF
    - hemodynamic factors
    - membrane bioincompatibility
- Vascular Access
  - Subclavian/IJV vs common femoral
  - Recirculation 4% vs 16%
    - Retards dialysis efficiency

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

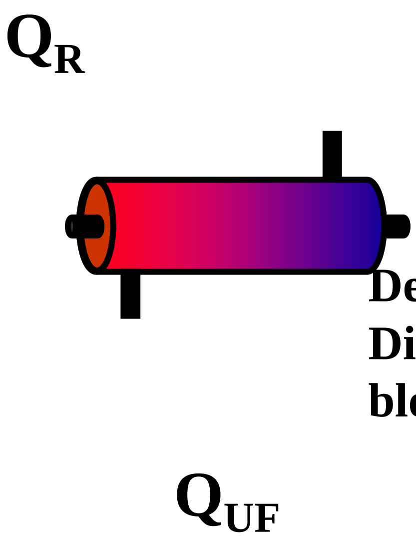
- Advantages
  - Well tolerated hemodynamically
  - (More) Biocompatible membrane
  - Continuous therapy
  - High solute clearance and ultrafiltration rate
  - Cytokine clearance
- Disadvantages
  - Labor intensive
  - Training of ICU nurses
  - Vascular access
  - Anticoagulation

CRRT Techniques

- Slow Continuous Ultrafiltration (SCUF)
  - volume control; minimal solute clearance
  - Arterio-venous circuit
- Continuous Hemofiltration (CVVH)
  - convective solute removal
- Continuous Hemodialysis (CVVHD)
  - diffusive solute removal
- Continuous Hemodiafiltration (CVVHDF)
  - convective and diffusive solute removal

Continuous Hemofiltration Pre-Dilution vs. Post-Dilution

Pre-Dilution



Decreases filtration fraction

Diminished solute clearance due to dilution of blood reaching hemofilter

$$C_B' = C_B \times \frac{Q_B}{Q_B + Q_R}$$

Continuous Hemofiltration Pre-Dilution vs. Post-Dilution

Post-Dilution

Q_R

Q_{UF}

Higher filtration fraction
Solute concentration within hemofilter unchanged from systemic concentration

Replacement Fluid/Dialysate

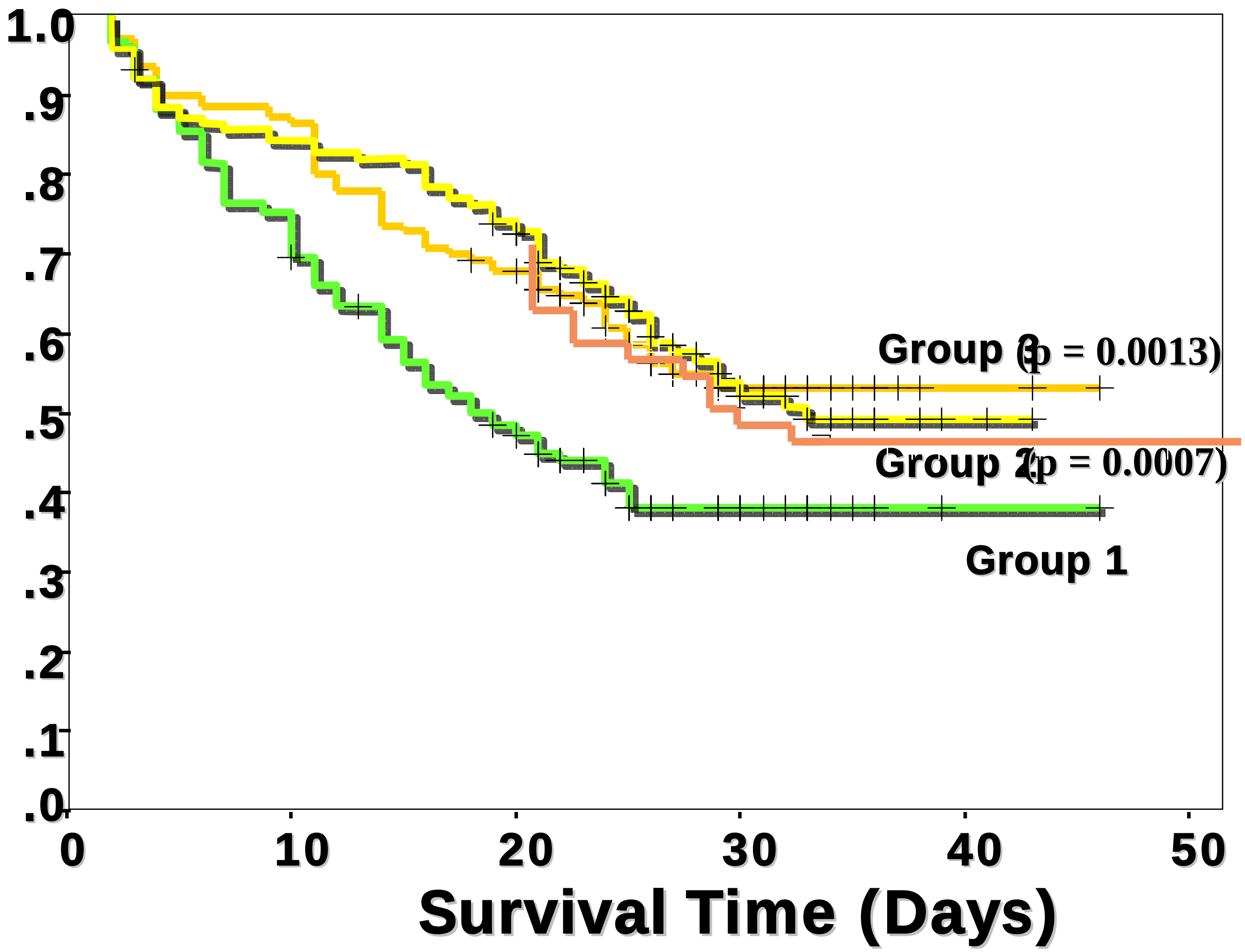
- Electrolyte composition
- Glucose concentration
- Buffer selection
  - acetate
  - lactate
  - citrate
  - bicarbonate

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

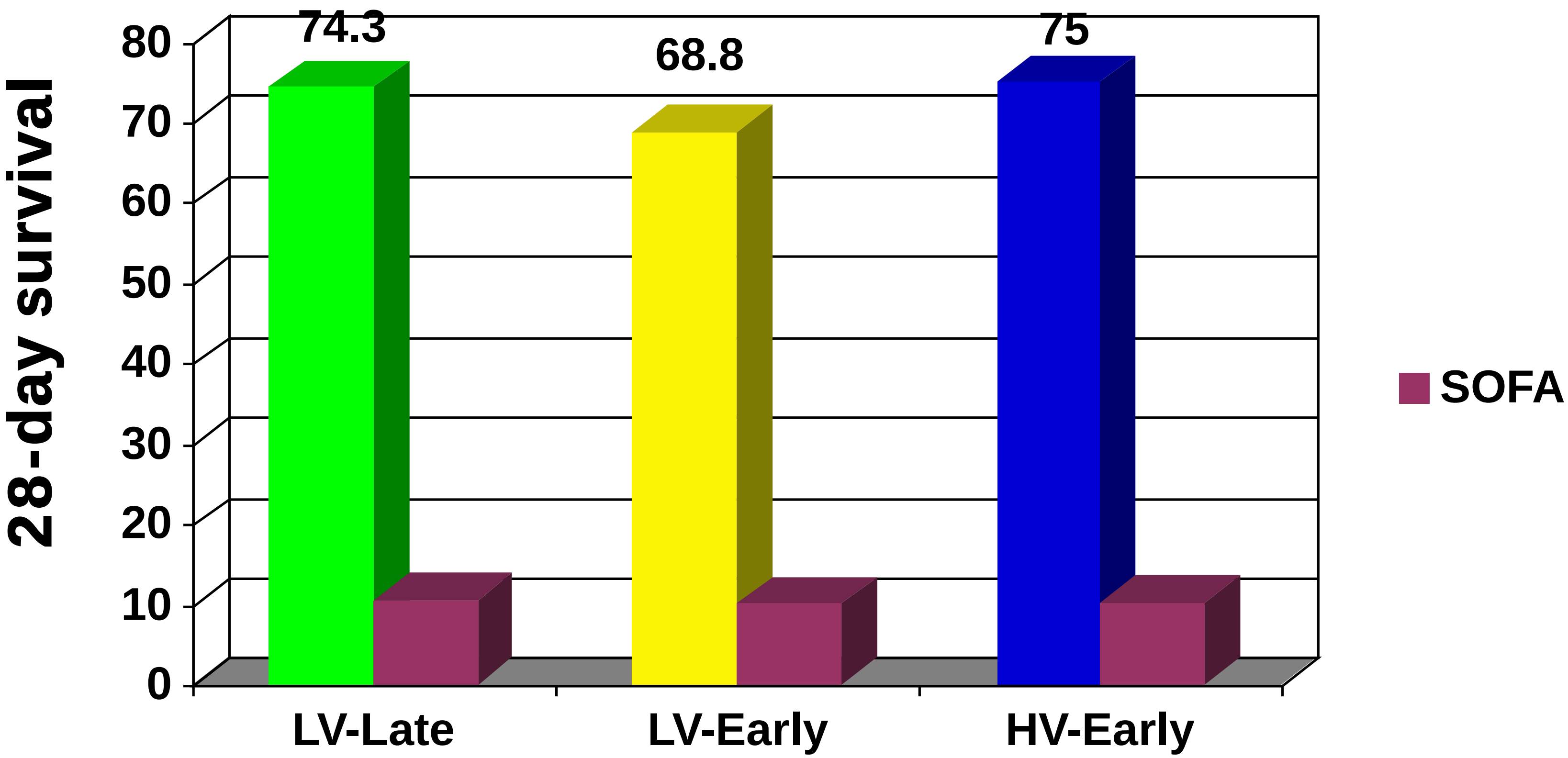
Cumulative Proportional Survival

Ronco et al. Lancet 2000 355:26-30



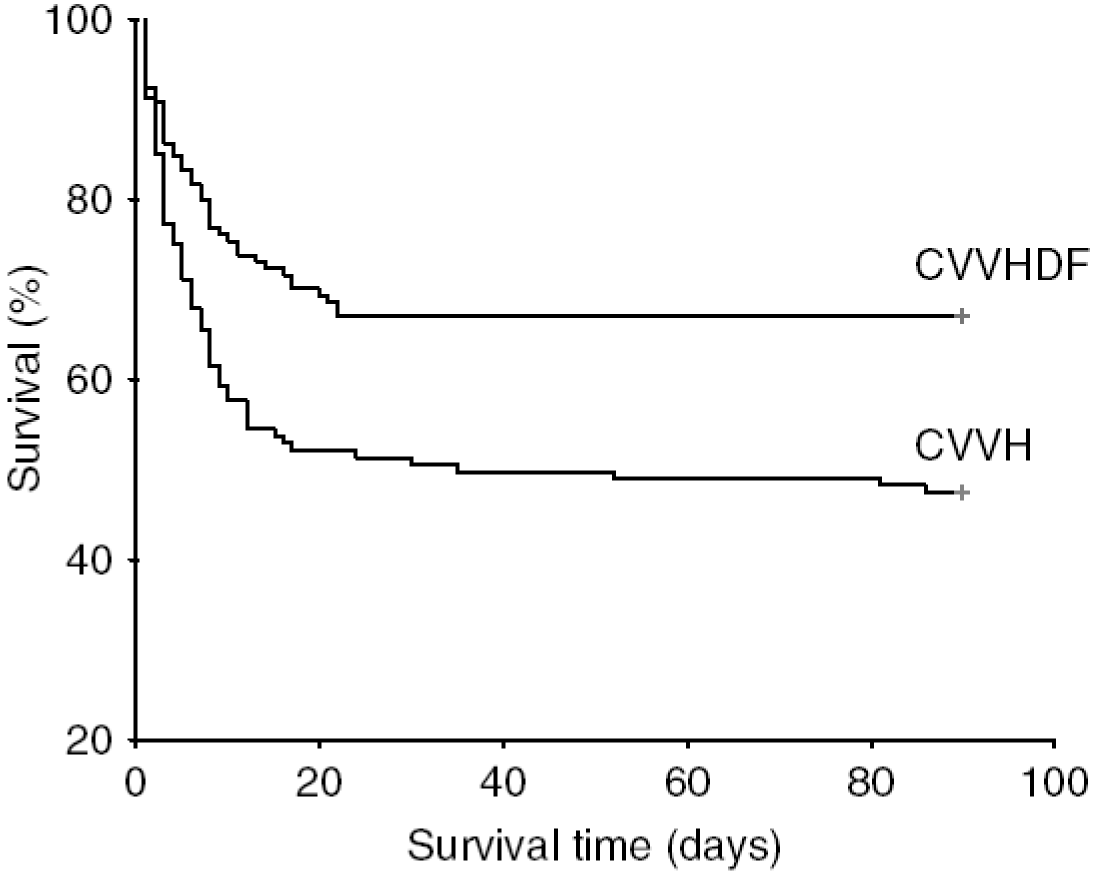
High
45
Medium
35
Low
20

Dose of CVVH in ARF



Bouman CS, et al. *Crit Care Med* 2002; 30:2205-2211

CVVH vs CVVHDF

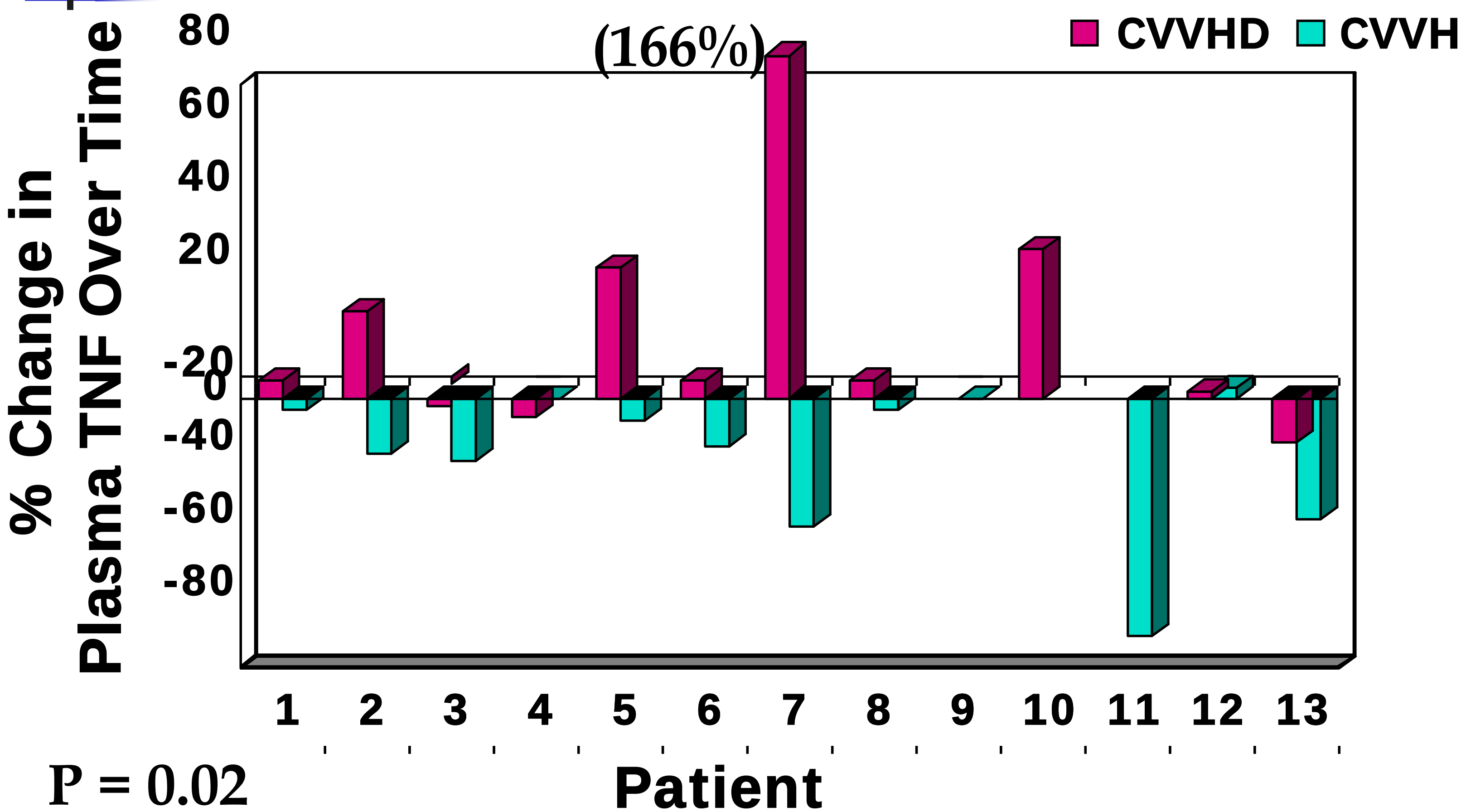


42 ml/kg/hr

25 ml/kg/hr

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

Effect of CVVH-D vs CVVH on Plasma TNF levels



P = 0.02
Kruskal Wallis

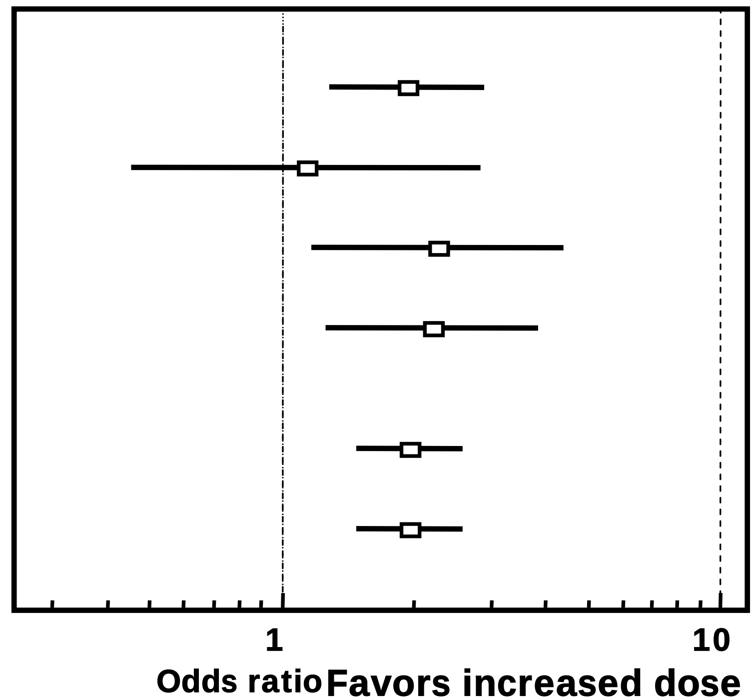
Kellum et al. *Crit Care Med* 1998;26: 1995-

Influence of Dose Escalation

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

Total (fixed effects)

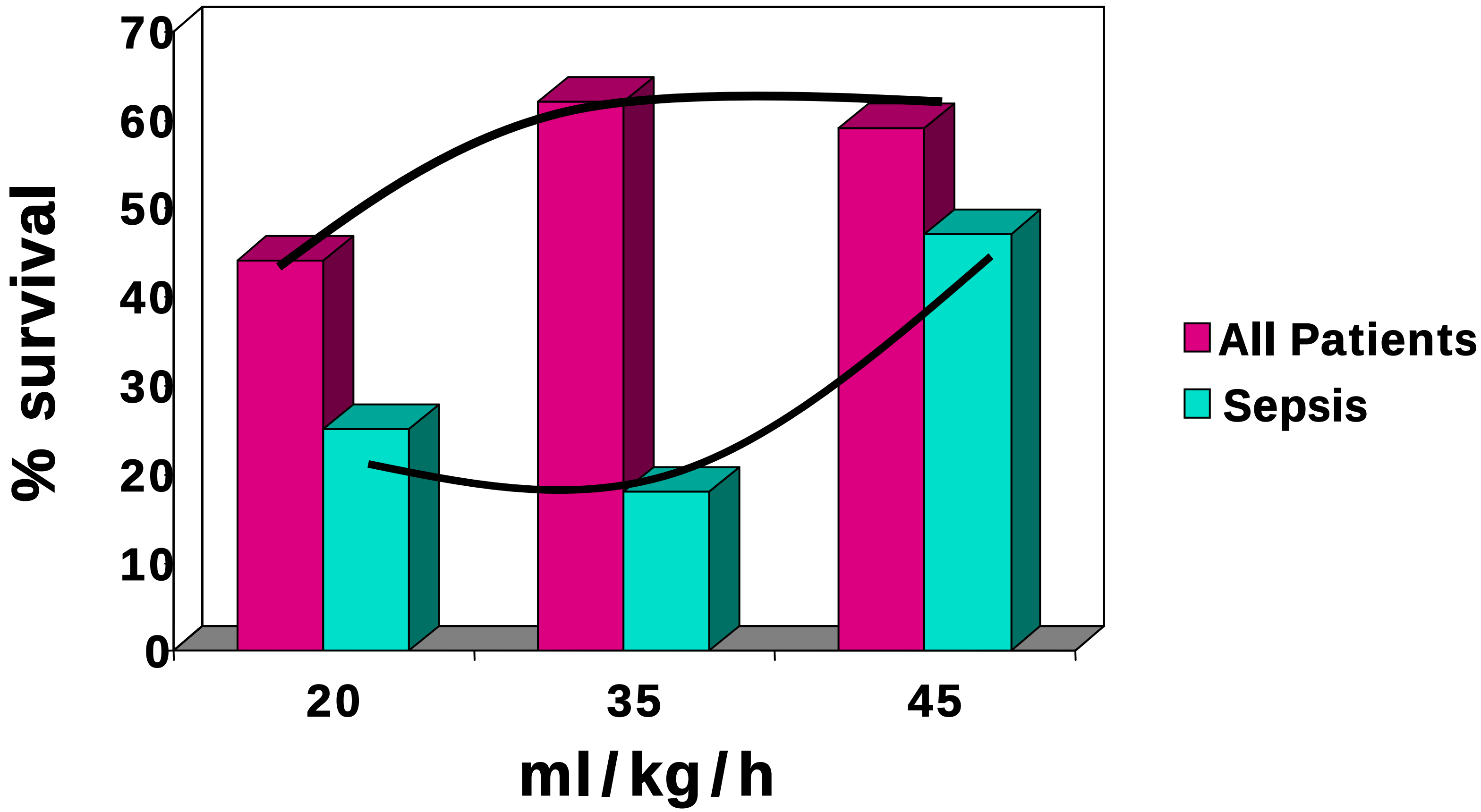
Total (random effects)



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

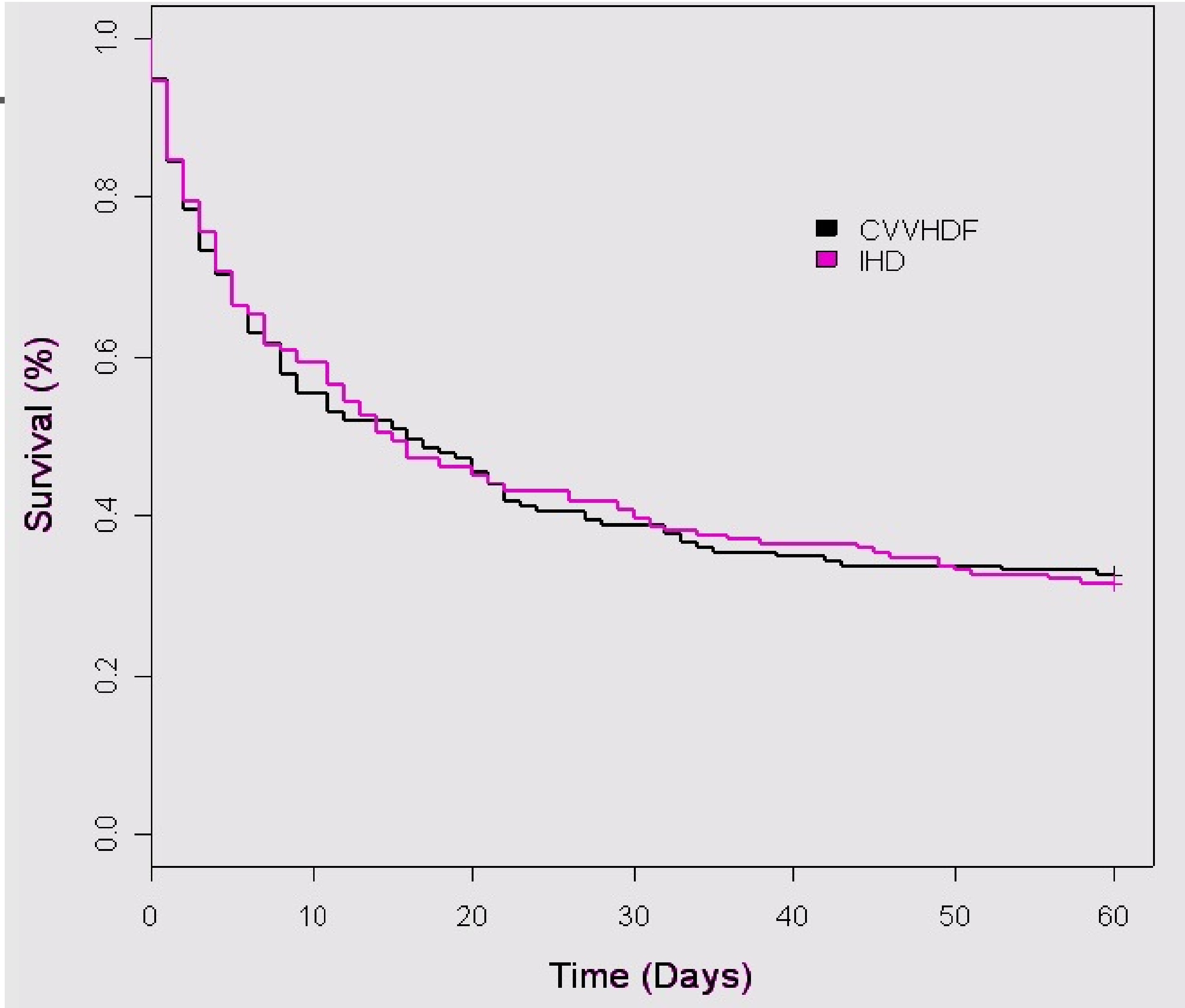
Kellum JA, *Crit Care Med* 2006

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



Ronco et al. *Lancet* 2000; 356:26-30

IHD vs. CRRT



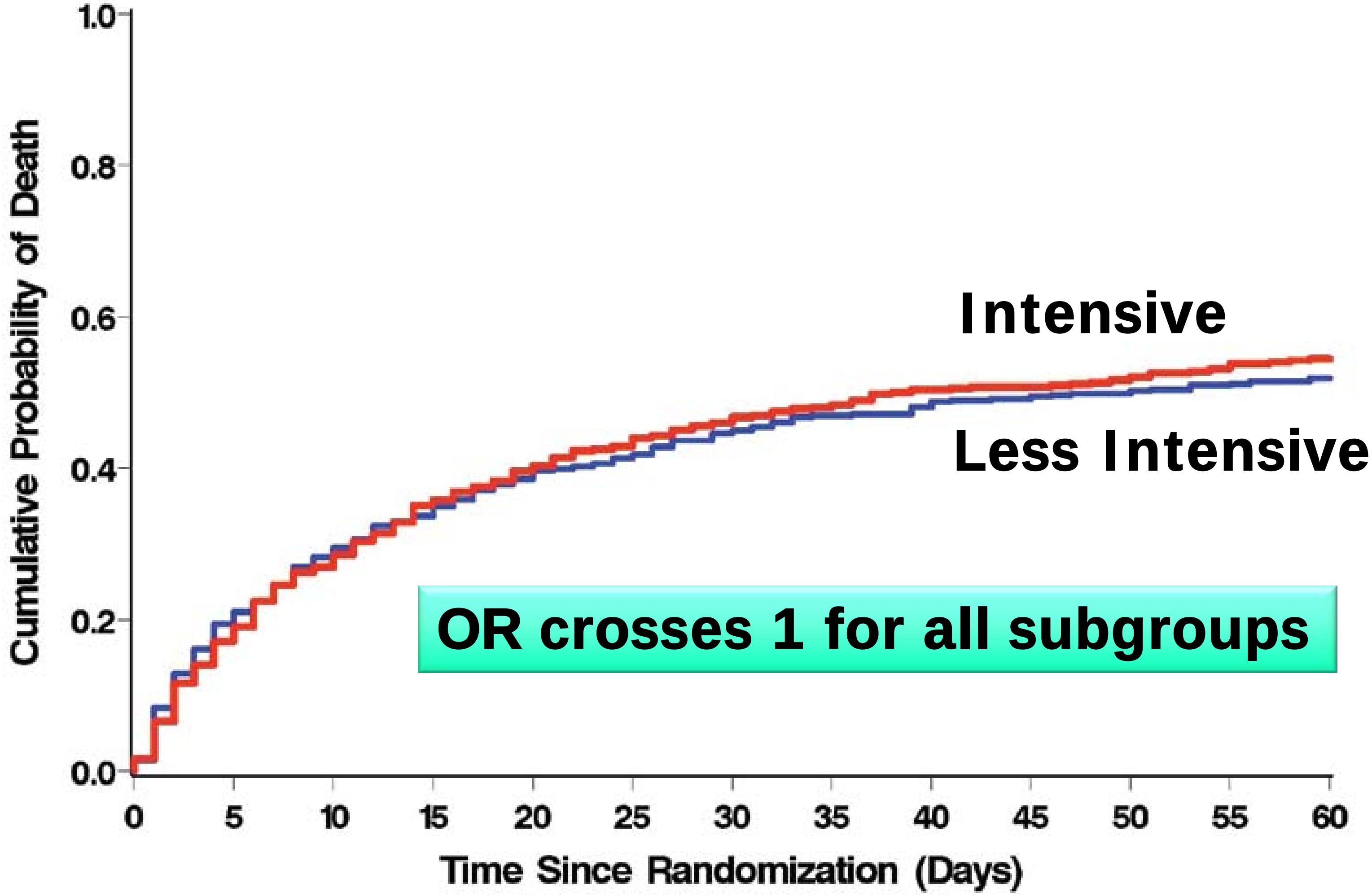
Vinsonneau, et al. *Lancet* 2006

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



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