Fluid Management with CRRT

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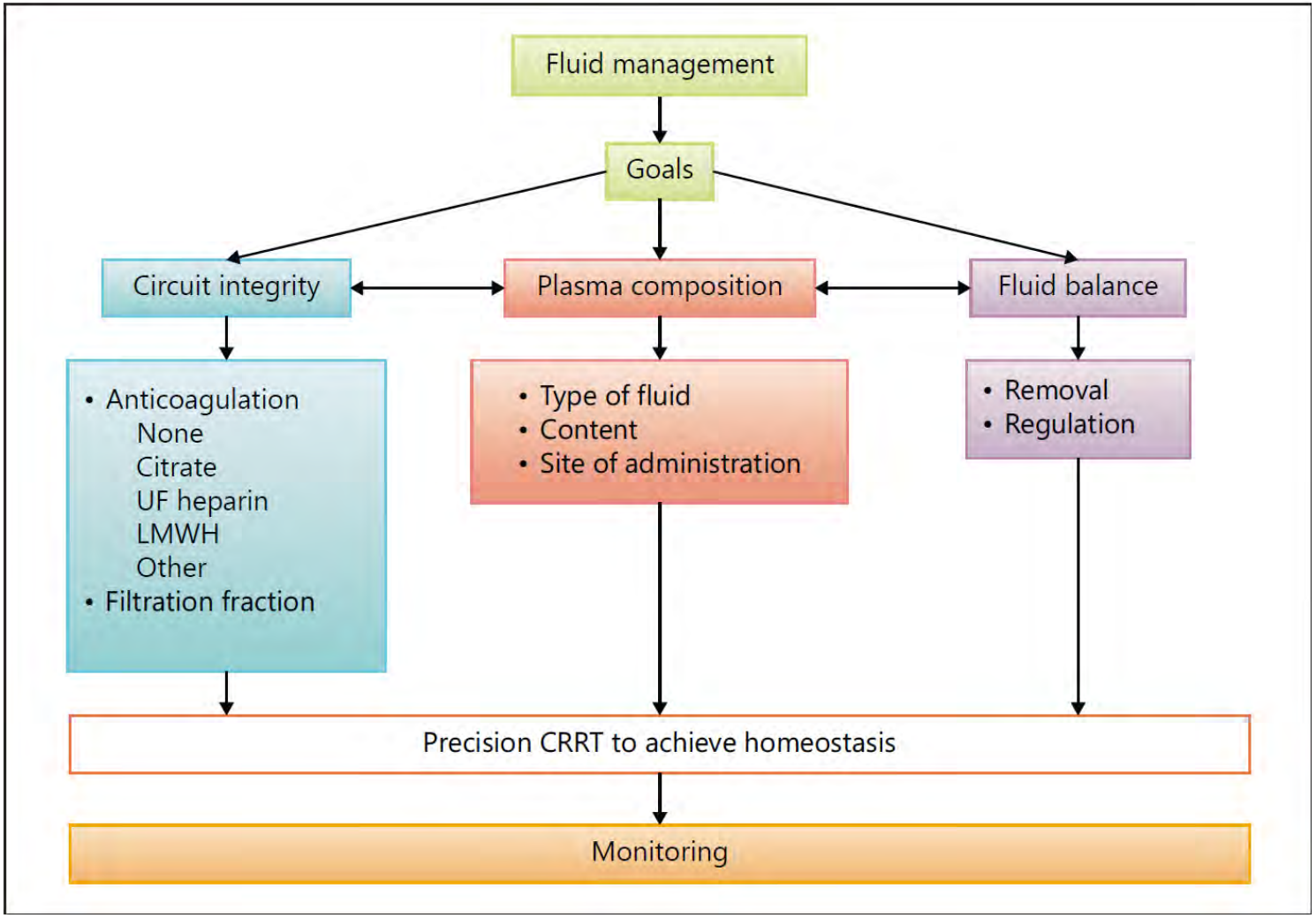
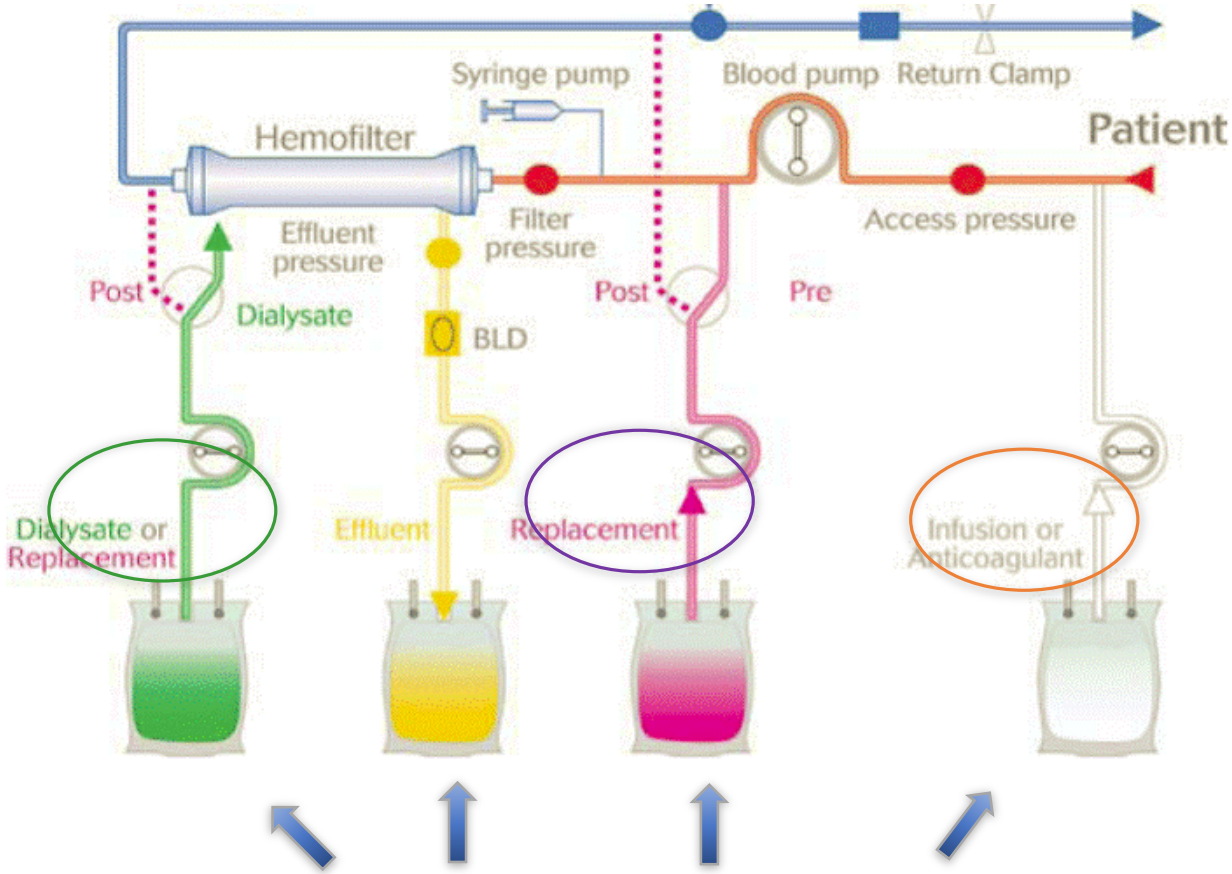
Fluid Management with CRRT



Practical Issues with Fluid Management for CRRT

- Maintaining the Circuit
- Enabling solute clearances and achieving homeostasis
- Volume control and balance with fluid regulation
- Monitoring for and preventing complications

Hydraulic Circuit for PrismaFlex: Sites for Fluid Administration

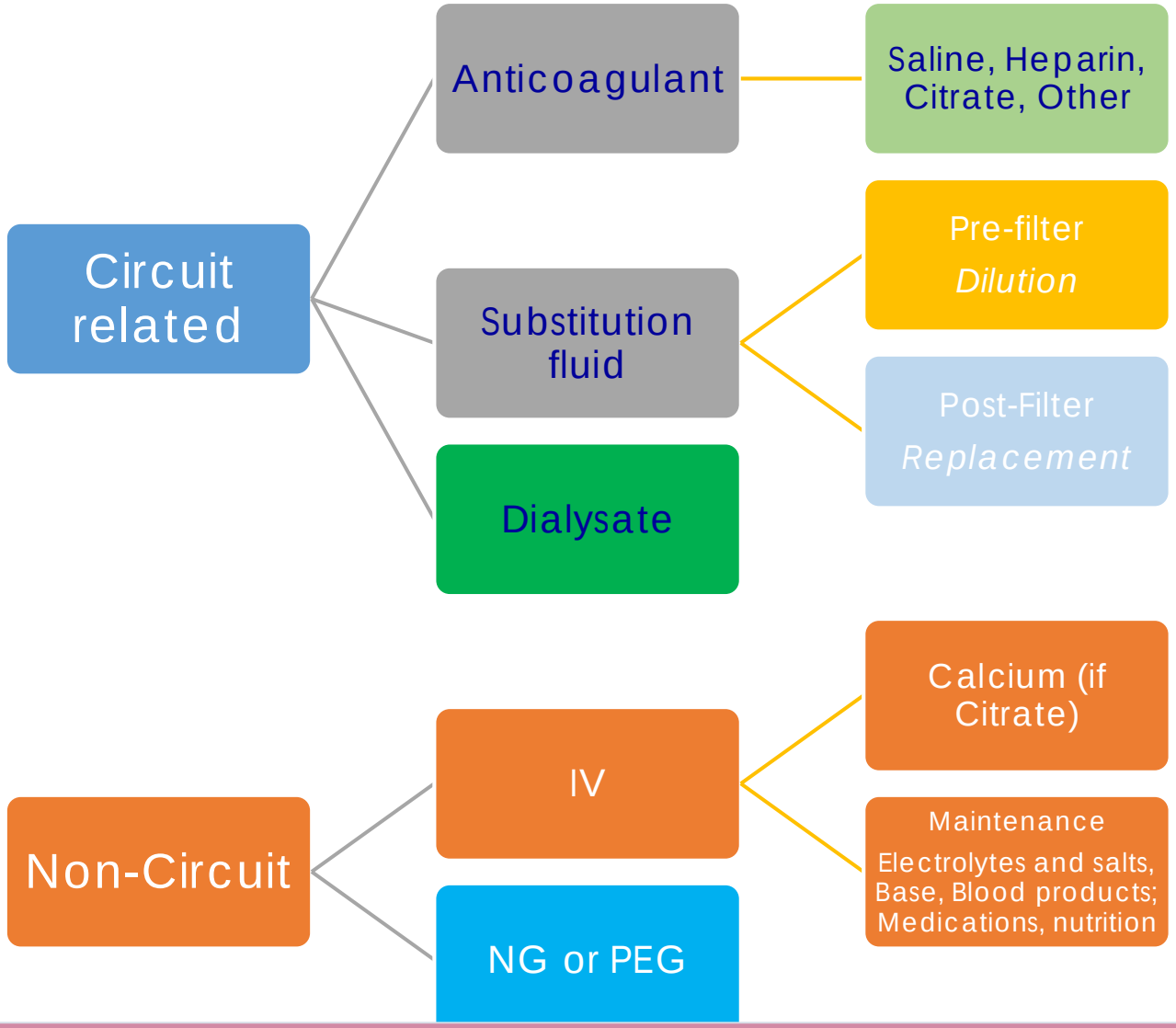


External Pumps

- Circuit related
- Non-Circuit

Integrated Pumps

Fluid Delivery in CRRT



Amount and Composition of each of these fluids can be varied to achieve homeostasis

CRRT Circuit

Maintaining the CRRT circuit is crucial for delivering CRRT effectively

- Catheter
- Filter
- Lines

Maintaining the Circuit: Access Issues

- Catheter characteristics
- Placement position
- Dysfunction
  - Clots
  - Kinks
  - Infection
  - Fibrin sheath

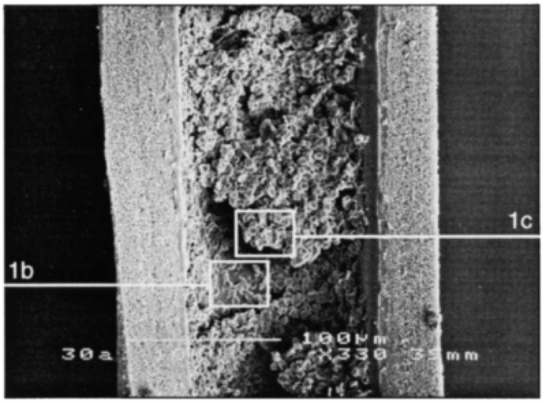
KDIGO Guidelines for Vascular Access

- 5.4.1 – Use a non-tunneled temp HD catheter in AKI.
- 5.4.2 – Preferred Insertion Sites: RIJ – Femoral – LIJ –SC
  - Catheter Length:
    - RIJ 12-15 cm
    - LIJ 15-20
    - Fem 19 - 24
- 5.4.3 – Recommendation: Ultrasound guided placement – Maximum barrier precautions – Chlorhexidine (2%) skin antiseptic
- 5.4.4 – Recommendation: Confirm placement of chest catheters with CXR.
- 5.4.5 – We suggest <u>NOT</u> using topical antibiotics over the skin insertion site of a nontunneled HD catheter in ICU patients.
- 5.4.6 – We suggest <u>NOT</u> using antibiotic locks for prevention of Catheter-related infections of nontunneled HD catheters.

Maintaining the Circuit: Filter Integrity

- Catheter
- Filter
  - Down time due to *filter clotting* is the major reason for reduced RRT dose

Anticoagulation for Extracorporeal Therapies



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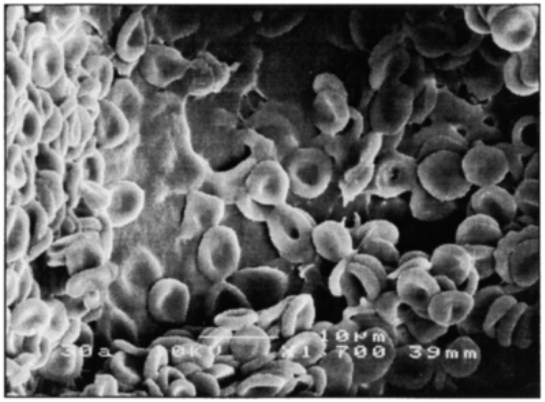

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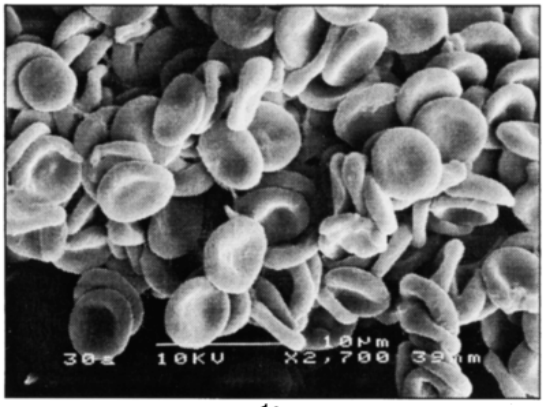

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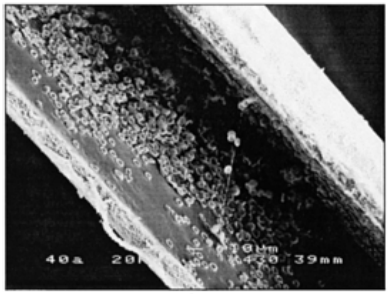
Heparin



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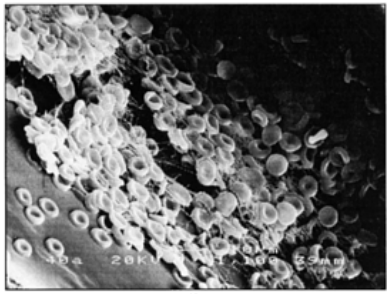
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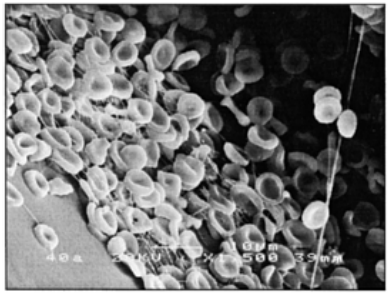
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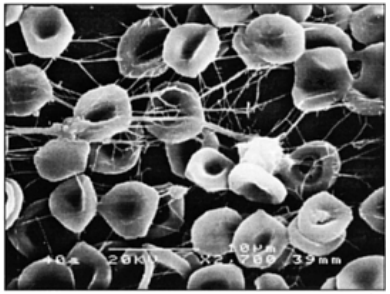
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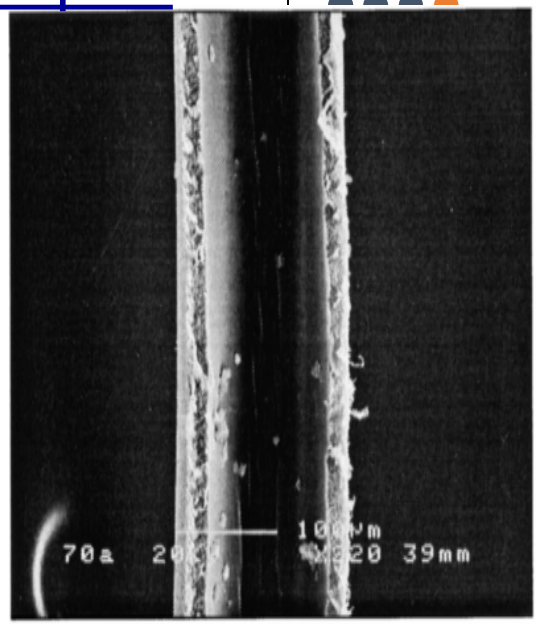
LMW Heparin

Scanning electron micrographs of the inner surface of a polysulfone hollow fiber dialyzer membrane during hemodialysis therapy.



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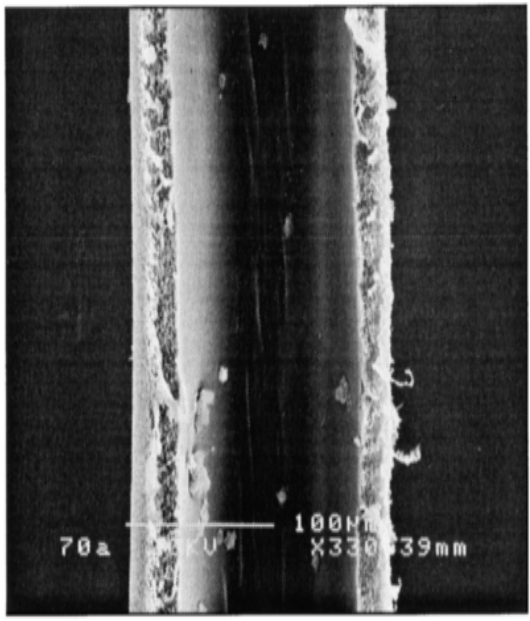


3b

Citrate

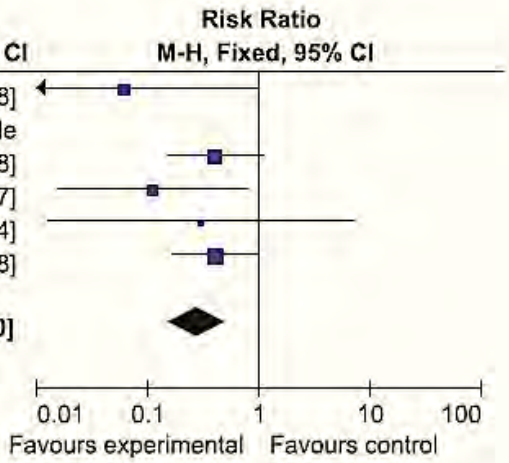
Why Citrate?

Citrate and Bleeding

Study or Subgroup	citrate Events	citrate Total	control Events	control Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Betjes MG 2007	0	21	10	27	19.6%	0.06 [0.00, 0.98]
Fealy N 2007	0	10	0	10		Not estimable
Hetzel GR 2011	5	87	12	83	26.0%	0.40 [0.15, 1.08]
Kutsogiannis DJ 2005	1	16	8	14	18.1%	0.11 [0.02, 0.77]
Monchi M 2004	0	26	1	23	3.4%	0.30 [0.01, 6.94]
Oudemans-van Straaten HM 2009	6	97	16	103	32.9%	0.40 [0.16, 0.98]
Total (95% CI)		**257**		**260**	**100.0%**	**0.28 [0.15, 0.50]**
Total events	12		47			

Heterogeneity: Chi² = 3.16, df = 4 (P = 0.53); I² = 0%

Test for overall effect: Z = 4.27 (P < 0.0001)

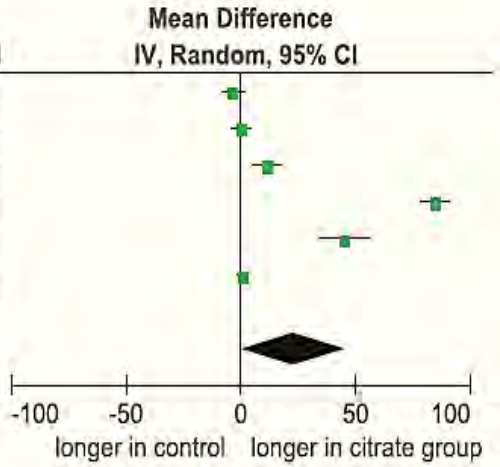


Citrate and Circuit Patency

Study or Subgroup	citrate Mean	citrate SD	citrate Total	control Mean	control SD	control Total	Weight	Mean Difference IV, Random, 95% CI
Betjes MG 2007	39	15.7	70	42.3	13.6	72	16.8%	-3.30 [-8.14, 1.54]
Fealy N 2007	16.3	2.4	10	16	6.3	10	16.8%	0.30 [-3.88, 4.48]
Hetzel GR 2011	37.5	23	87	26.1	19	81	16.7%	11.40 [5.04, 17.76]
Kutsogiannis DJ 2005	125.5	16.8	36	40.9	9.9	43	16.7%	84.60 [78.37, 90.83]
Monchi M 2004	81.4	27	26	36.1	8.9	23	16.2%	45.30 [34.30, 56.30]
Oudemans-van Straaten HM 2009	28.5	8.8	97	27.5	7.2	103	16.9%	1.00 [-1.24, 3.24]
Total (95% CI)			**326**			**332**	**100.0%**	**23.03 [0.45, 45.61]**

Heterogeneity: Tau² = 785.58; Chi² = 696.77, df = 5 (P < 0.00001); I² = 99%

Test for overall effect: Z = 2.00 (P = 0.05)



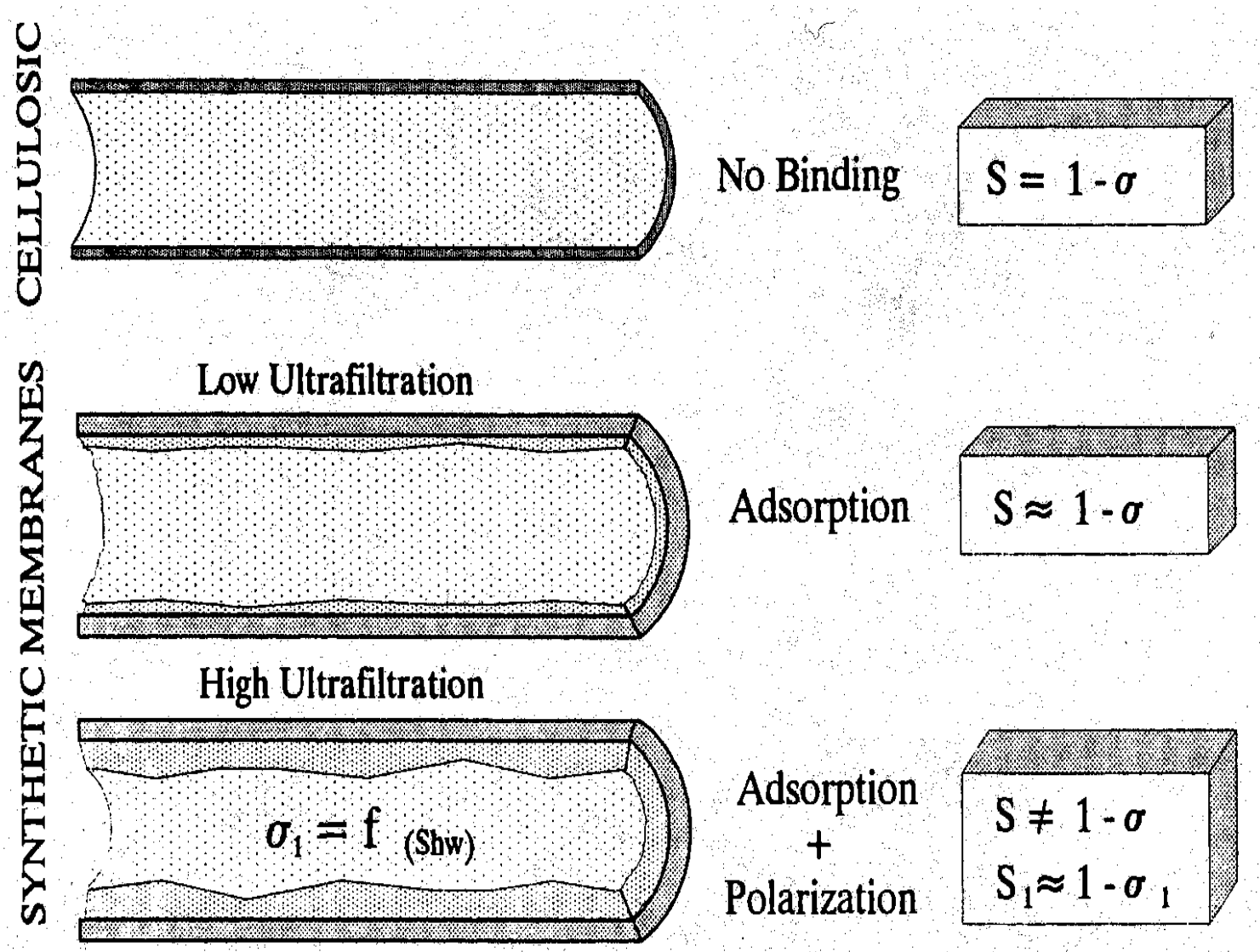
Recent RCTS for Citrate vs Heparin

	Shilder et al	Gattas et al	Stucker et al
Year	2014	2015	2015
Center	Multi	Multi	Single
No. of patients	C: 66 H: 73	C: 105 H: 107	C: 54 H: 49
Treatment	Citrate vs. UFH	Citrate vs. heparin/protamine	Citrate vs. UFH
Circuit lifespan (hrs)	C: 46 ($p = 0.02$) H: 32	C: 39.2 ($p = 0.004$) H: 22.8	C: 49 ($p = 0.004$) H: 28
Bleeding / Adverse events	C: 0% ($p < 0.001$) H:33%	C: 2 ($p = 0.011$) H: 11	C: 0 H: 8%
Metabolic alkalosis (%)	C: 2 H: 0	NR	C: 6 H: 0
Hypocalcemia	C: 12% (iCa <0.9 mmol/L) H: NR	NR	C: 11% (severe) H: 2%
Mortality	No difference	No difference	No difference

Maintaining the Circuit: Filter Integrity

- Catheter
- Filter
  - Down time due to *filter clotting* is the major reason for reduced RRT dose
  - *Concentration polarization* reduces ultrafiltration rate and the filtrate concentrations of several medium / large sized proteins

Mechanisms of Blood Membrane Interactions in Dialysis



Modified from Ronco et al NDT 1998, 13

Reasons for Discontinuing CRRT and Filter efficacy

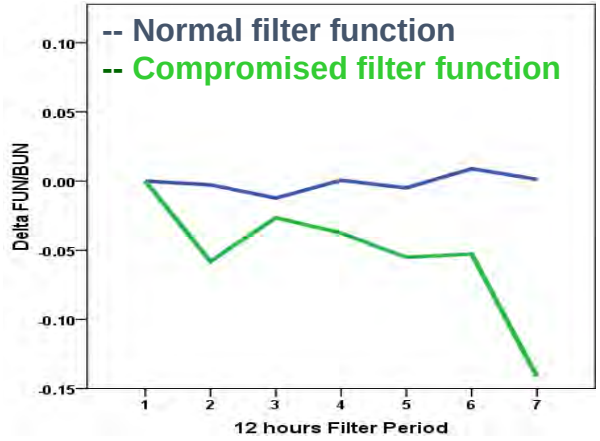
Table 3. Reasons for stopping CRRT

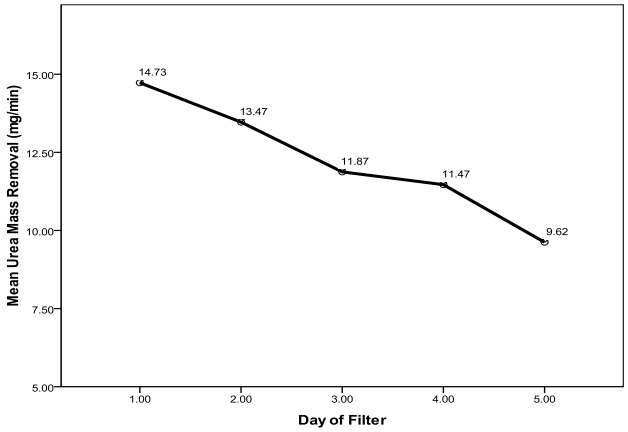
Reasons	Number of Filters	Percentage (%)	FUN/BUN Ratio
Factors affecting treatment time without affecting filter function			
D/C for surgical procedures	10	6.3	0.93 (0.92 to 0.99)
D/C for medical procedures	9	5.7	1.0 (0.95 to 1)
routine filter changes	16	10.1	0.95 (0.84 to 1.0)
machine problems	8	5.0	0.97 (0.85 to 1.0)
transition to IHD	17	10.7	0.96 (0.82 to 0.97)
venous access clot	6	3.8	0.97 (0.96 to 0.98)
physician decision	10	6.3	0.98 (0.94 to 1)
patient or family decision	11	6.9	0.96 (0.94 to 1)
patient recovery	6	3.8	0.95 (0.92 to 0.99)
death	3	1.9	0.98 (0.87 to 1.0)
access change	9	5.7	0.9 (0.87 to 0.95)
Factors affecting filter function			
filter clotted	41	25.8	0.89 (0.83 to 0.94)
filter leak	1	0.63	0.745
low-sieving concentration polarization	12	7.5	0.86 (0.79 to 1.0)

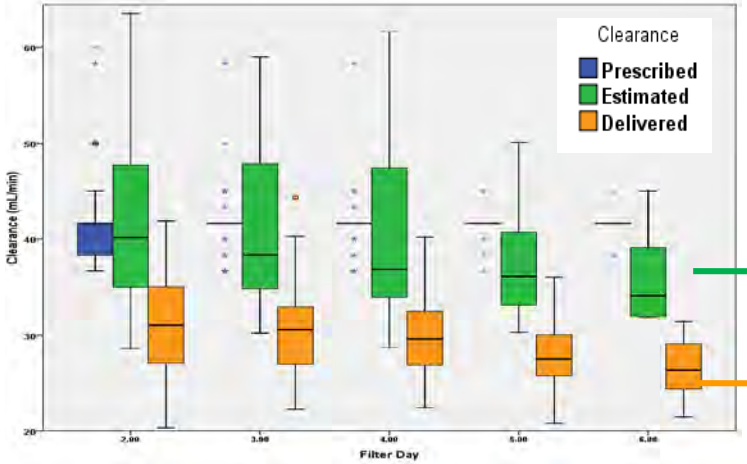
Claure-Del Granado et al. CJASN, 2011

Dialysis or Blood side Measurements for Dialysis Dose Determination in Continuous Renal Replacement Therapies?

Rolando Claure-Del Granado, MD[1], Etienne Macedo, MD[1], Sharon Soroko, MS[1], Glenn M. Chertow, MD, MPH[2], Jonathan Himmelfarb, MD[3], T. Alp Ikizler, MD[4], Emil P. Paganini, MD[5], Ravindra L Mehta, MD[1].
Program to Improve Care in Acute Renal Disease (PICARD) study







84 58 37 19 7

Time effect

Filter efficacy effect

Filter duration effect

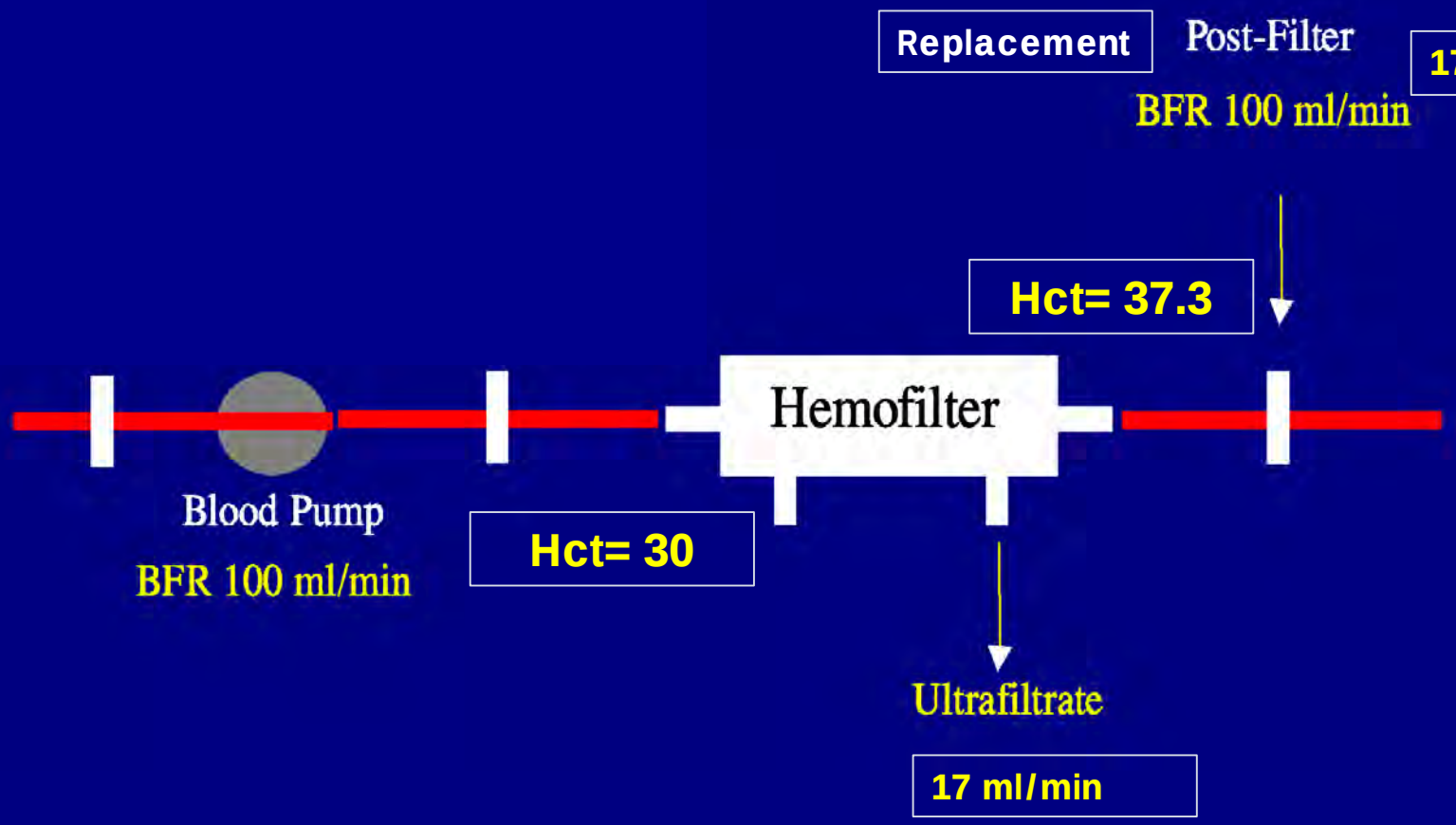
Maintaining the Circuit

- Catheter performance
- Filter (CRRT) performance
  - Down time due to *filter clotting* is the major reason for reduced CRRT dose
  - *Concentration polarization* reduces ultrafiltration rate and the filtrate concentrations of various medium / large sized proteins
  - *High filtration fraction* (high UF + low QB *OR* post dilution) is associated with both of above
  - *Pre-dilution* versus post-dilution

Fluid Management in Continuous Renal Replacement Therapy

Pre-Filter vs Post-Filter Replacement Fluid

Modality: CVVH with UFR 1L/hr



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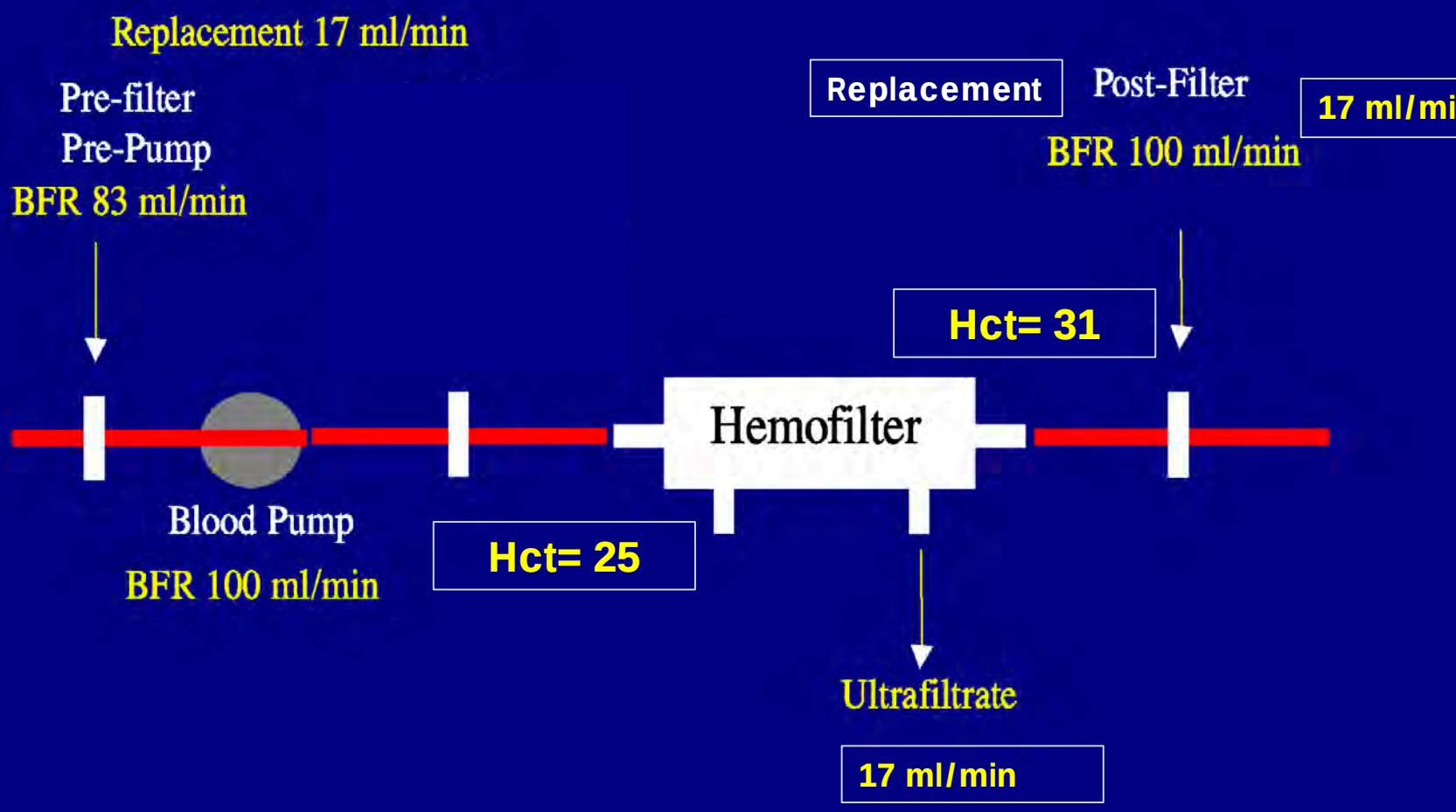

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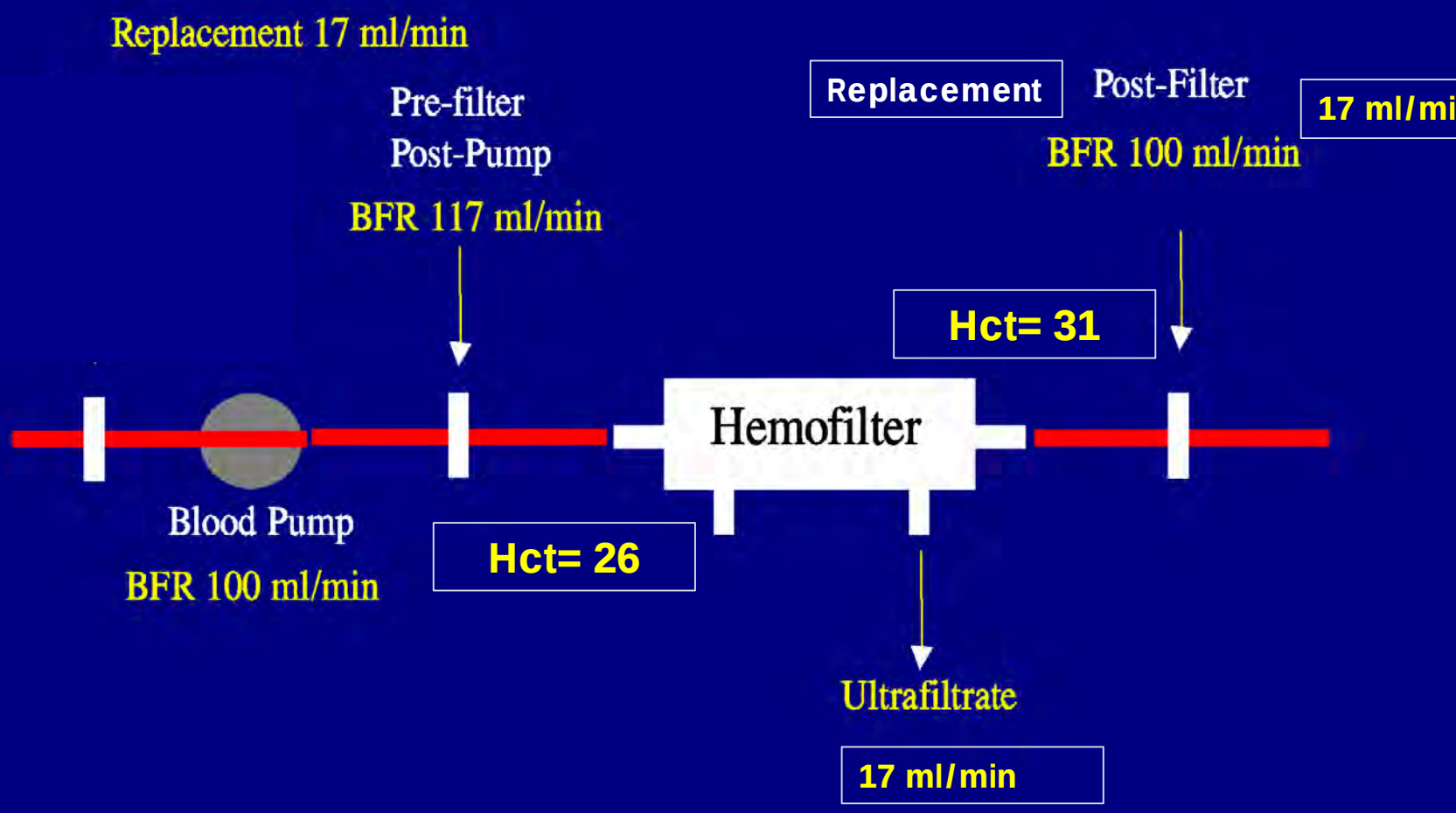


Pre-Dilution vs Post-Dilution CVVH

Filtration fraction (FF) = ultrafiltration rate/ plasma water flow rate

- FF values > 0.20 undesirable due to hemoconcentration-related effects on filter performance
  - major limitation of post-dilution CVVH
  - dependent on blood flow rate (Q_B) and hematocrit (Hct)

Fluid Management in CRRT

Pre-Filter vs Post-Flter Replacement Fluid

Modality	Fluid Location	BFR (ml/min)	PF (ml/min)	UF (ml/min)	FF (%)
CVVH 1L/hr	Post-filter	100	70	17	23.9
CVVH 3L/hr	Post-Filter	200	140	50	35.7
CVVH 6L/hr	Post-Filter	300	210	100	47.6
CVVH 1L/hr	Pre-filter pre-pump	83	58.1	17	22.6
CVVH 3L/hr	Pre-Filter pre-pump	150	105	50	32.2
CVVH 6L/hr	Pre-Filter pre-pump	200	140	100	41.6
CVVH 1L/hr	Pre-Filter Post-pump	117	70	17	19.5
CVVH 3L/hr	Pre-Filter Post Pump	250	140	50	26.3
CVVH 6L/hr	Pre-Filter Post Pump	400	210	100	32.2

Table 2. FF at various blood (Qb) and dialysate flow rates as well as varying UF rates

Hct	Qb	QP	UF	FF
0.25	150	112.5	1,000	0.15
0.35	150	97.5	1,000	0.17
0.4	150	90	1,000	0.19
0.25	200	150	2,000	0.22
0.35	200	130	2,000	0.26
0.4	200	120	2,000	0.28
0.25	150	112.5	2,000	0.30
0.35	150	97.5	2,000	0.34
0.4	150	90	2,000	0.37
0.25	200	150	1,000	0.11
0.35	200	130	1,000	0.13
0.4	200	120	1,000	0.14
0.25	100	75	1,000	0.22
0.35	100	65	1,000	0.26
0.4	100	60	1,000	0.28
0.25	100	75	2,000	0.44
0.35	100	65	2,000	0.51
0.4	100	60	2,000	0.56

$$FF = \frac{\text{UF rate (ml/min)}}{\text{plasma flow rate } (Q_P) \text{ (ml/min)}}$$

Table 3. Plasma flow and FF for different Q_Bs, UF rates and Hct

Hct, %	Q_B = 150 ml/min		Q_B = 200 ml/min	
	Q_P	FF	Q_P	FF
UF = 1,000 ml/h				
Hct = 25	112.5	0.15	150	0.11
Hct = 35	97.5	0.17	130	0.13
Hct = 40	90	0.19	120	0.14
UF = 2,000 ml/h				
Hct = 25	112.5	0.30	150	0.22
Hct = 35	97.5	0.34	130	0.26
Hct = 40	90	0.37	120	0.28

Q_P = Plasma flow rate in ml/min.

$$FF = \frac{\text{UF rate (ml/min)}}{\text{plasma flow rate } (Q_P) \text{ (ml/min)}}$$

Table 4. Advantages and disadvantages of pre- and post-filter substitution

Pre-filter	Post-filter
Advantages	
UF rate is not limited by Q_B	Clearance of solutes is directly related to UF rate
Enhanced elimination of urea from RBC's	A higher solute clearance rate is produced
Filter life is increased as the Hct throughout the filter remains low	Delivery of specified solutes and concentrations directly to the solution
Filter life is increased which may increase filter lifespan and solute clearance, even though hourly solute clearance is decreased	
Disadvantages	
Solute concentrations are decreased and thus clearance is decreased	UF rate is limited by Qb. You cannot order too much UF because the end-filter Hct will be too high
	Because UF rate is limited by FF you may not reach optimal dose
	Filter life may be decreased by high end-filter Hct

RBC = Red blood cell. Adapted from Huang et al. [32].

Maintaining the Circuit: Summary

- Select appropriate size catheter and position for individualized therapy
- For Access requirements > 7 days consider tunnelled catheters
- For CRRT, *avoid high filtration fraction* and consider pre-dilution to minimize concentration polarization and hemoconcentration
- Select Anticoagulant based on expertise and available resources. Citrate has best results for circuit and filter integrity
- For CRRT, *adjust prescription for pre-dilution* with either a FUN/BUN ratio or an empirical 15% particularly for CVVH

Practical Issues with CRRT

- Maintaining the Circuit
- Enabling solute clearances and achieving homeostasis
- Volume control and balance with fluid regulation
- Monitoring for and preventing complications

CRRT Operational Characteristics

CVVHDF

CVVHD

CVVH

Clearance in CRRT = SC or equivalent x effluent volume (UF, dialysate, UF + dialysate) + membrane adsorption

Dialysate

Diffusive clearance

Ultrafiltrate

Convective Clearance

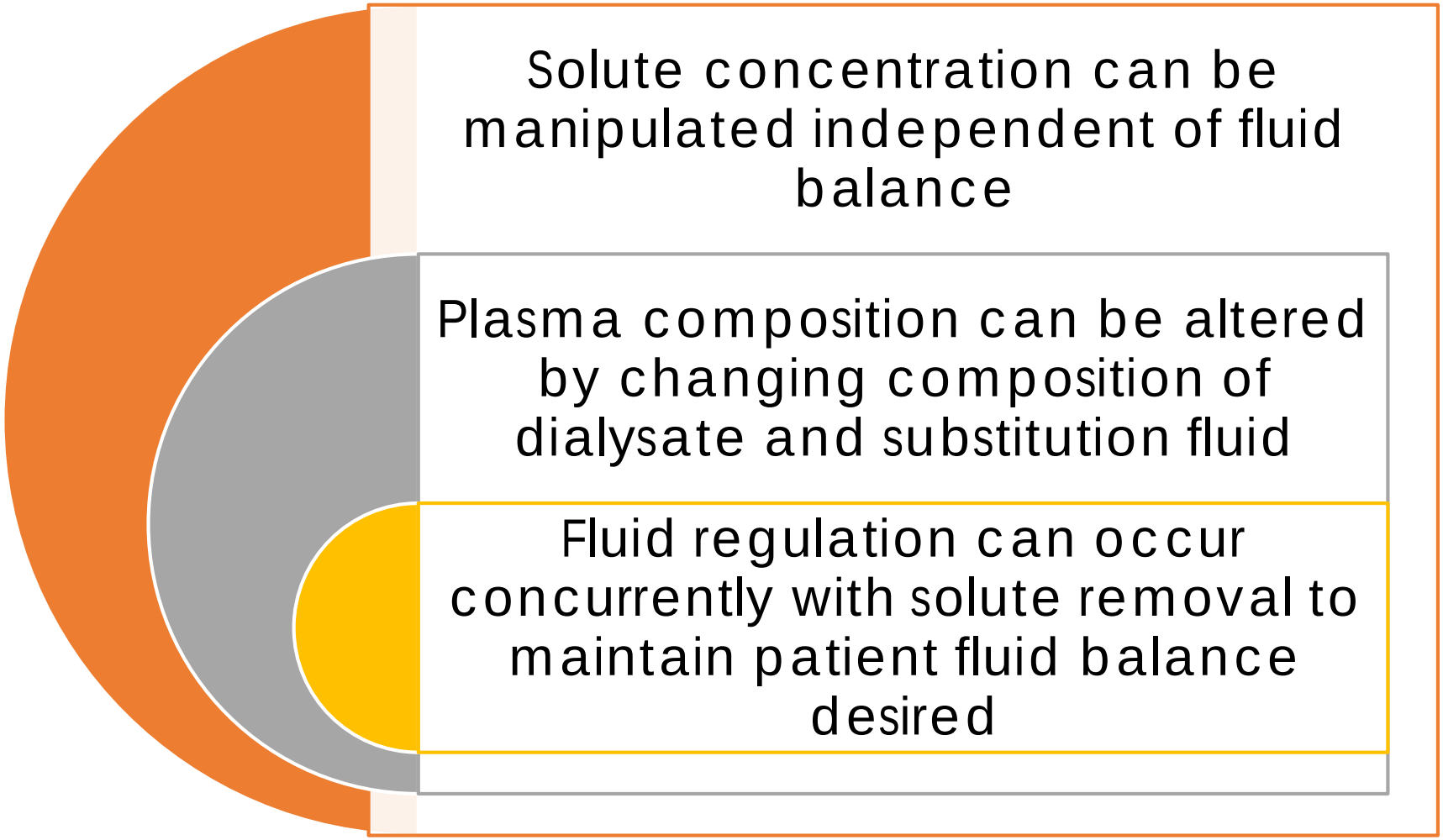
Effluent

Sieving Coefficient = UF/Plasma concentration of solute

(1= freely permeable, 0+ not permeable).

Dialyzer and blood clearance differ based on solute and membrane characteristics

CRRT Operational Characteristics Summary of Features



Regulation of fluid composition

	CVVHF	CVVHD	CVVHDF
Target plasma solute concentration	Composition of Replacement Fluid	Composition of Dialysate	Composition of Dialysate and Replacement Fluid
Rate of change in plasma concentration	Difference in concentration between Replacement Fluid and plasma Exchange Rate Sieving coefficient	Dialysate Flow Rate (At low Q_D) Blood Flow Rate (At high Q_D) Dialyzer Size (At high Q_B) Molecular weight Dialyzer permeability	Combined effect of replacement fluid and dialysate fluid rates and composition

Practical Issues with Fluid Management for CRRT

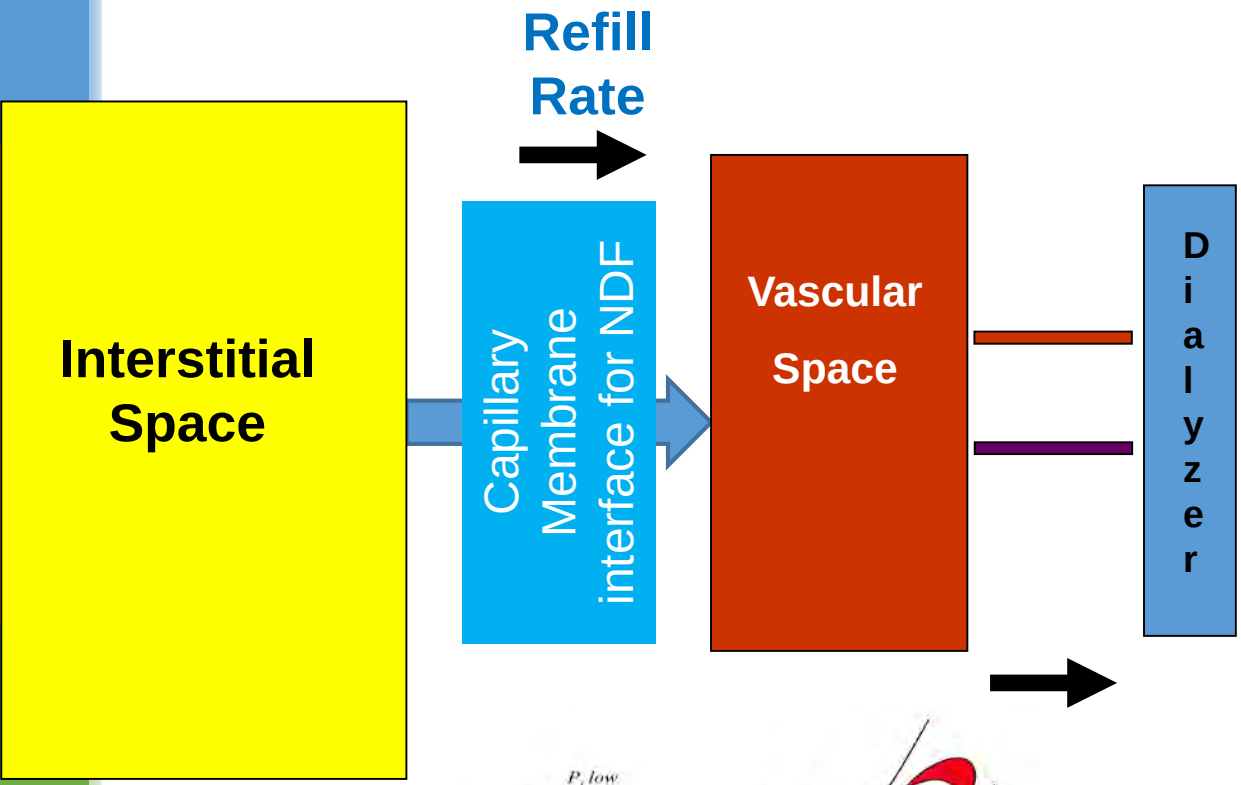
- Maintaining the Circuit
- Enabling solute clearances and achieving homeostasis
- **Volume control and balance with fluid regulation**
- Monitoring for and preventing complications

Fluid Management in the Critically Ill Patient

Strategies for intervention role of CRRT

- Fluid Removal
- Fluid Regulation

Fluid Removal on Dialysis



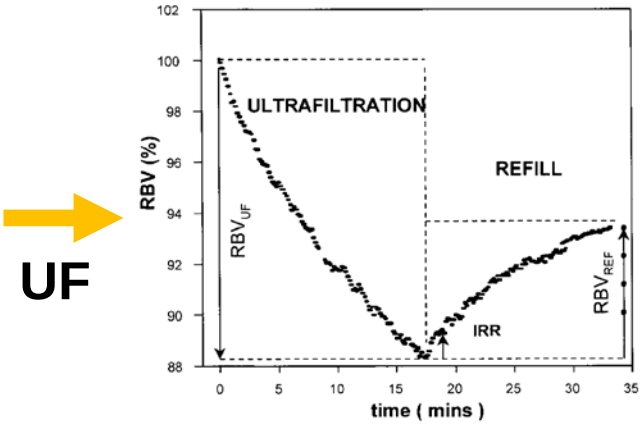
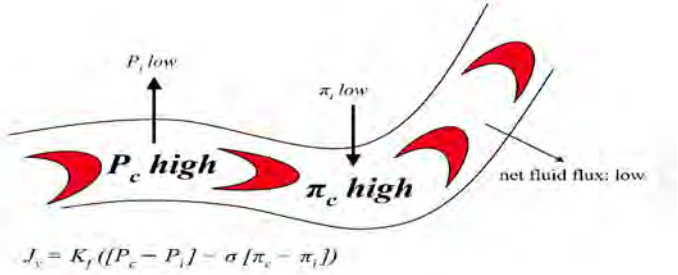


Fig 1. A typical RBV profile obtained in response to a UF pulse showing decay, subsequent refill phase, and measured parameters. Values for ΔRBV in percentage, and for IRR, in percentage per minute. Abbreviation: ΔRBV_{ref}, the magnitude of RBV change during the refill phase, in percentage.



Mitra S et al *Am J of Kid Dis,* 40, 2002

Principles For Fluid Removal with Dialysis

Removal

Fluid is primarily removed from intravascular compartment

Refill

Plasma refilling rates from interstitial compartment determine rate of change of intravascular blood volume

Balance

If ultrafiltration rate exceeds plasma refilling rate decreased blood volume ensues and contributes to hemodynamic instability

Principles For Fluid Management With Intermittent Hemodialysis

- Fluid is removed by ultrafiltration governed by transmembrane pressure
- Volume of fluid removed is precisely regulated by volumetric balance chambers in machine
- Rate of fluid removal dictated by prescription
- Maximum fluid removal rate per hour dictated by machine limits (generally 2 L/hr)
- Fluid replacement generally not required

Since time is rate limiting factor goal is to find maximally tolerated ultrafiltration rate

Principles For Fluid Management With Continuous Dialysis

Fluid is removed by ultrafiltration governed by transmembrane pressure

Volume of fluid removed is precisely regulated by *Gravimetric* scales outside machine (Prisma, Prismaflex, Aquarius, B. Braun) or *Volumetric* balancing chamber inside machine (NxStage)

Rate of fluid removal dictated by prescription and operational characteristics

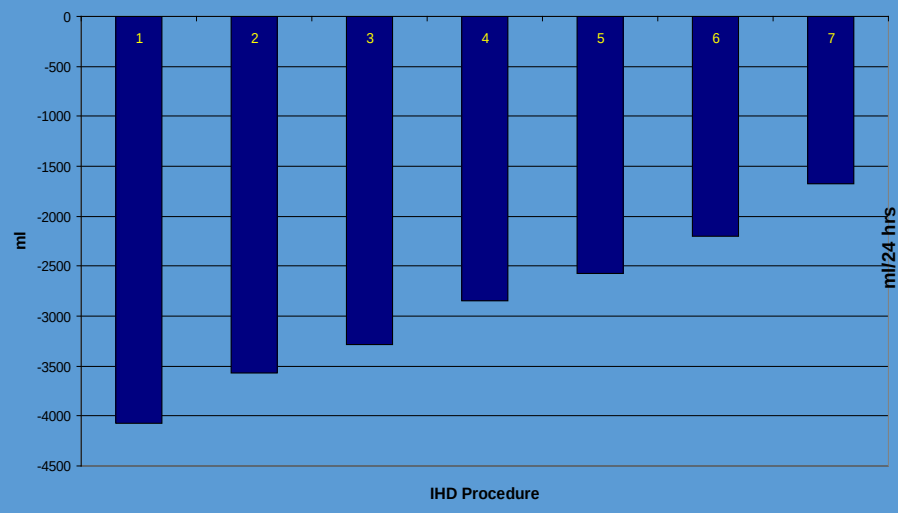
Maximum fluid removal rate per hour dictated by machine limits (2-12 L/hr)

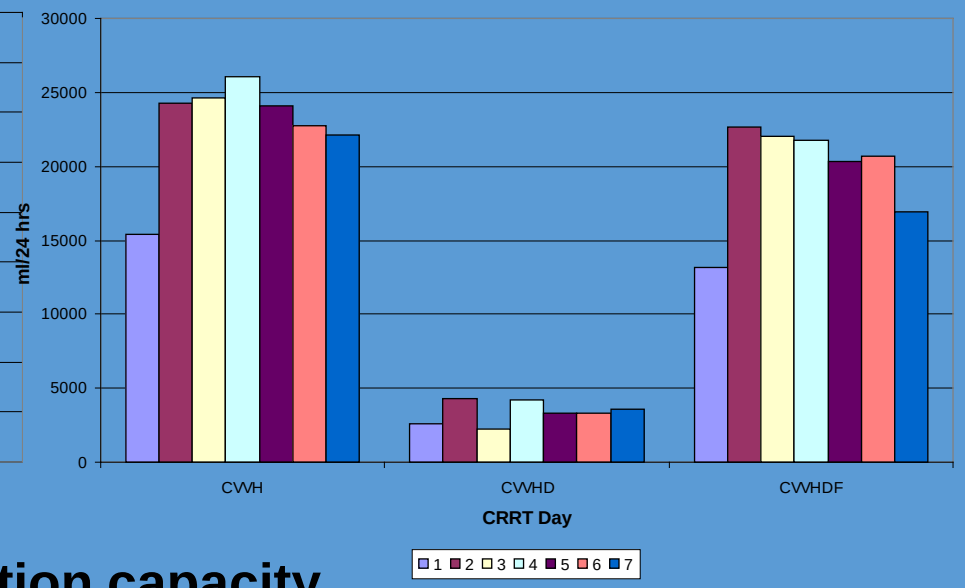
Fluid replacement is required

As procedure is continuous, goal is to target ultrafiltration to achieve fluid balance over time

Comparisons of Fluid Management Capability

	Normal Kidney	Intermittent HD*	Peritoneal Dialysis	CRRT#
Ultrafiltration (ml/min)	120	34	14	100
Volume of Filtrate /day (L)	173	8	14	144
Volume removed /Day (L)	0.1-1.5	0-8	0-14	0-100





Net Ultrafiltration capacity

Comparisons of Fluid Management Capability

	Normal Kidney	Intermittent HD*	Peritoneal Dialysis	CRRT#
Ultrafiltration (ml/min)	120	34	14	100
Volume of Filtrate /day (L)	173	8	14	144
Volume removed /Day (L)	0.1-1.5	0-8	0-14	0-100
Regulatory mechanism	GFR Control	UFR Control	UFR control	UFR Control
	Reabsorption	-	-	Replacement Fluid
Sensing mechanism	Hemodynamic	-	-	-? hemodynamic
	Volume status	-	-	? volume status

* 4 hours /day

High volume HF 6L/hr

Fluid Management Comparisons

	Fluid Removal	Fluid Regulation
Normal Kidney	++++	++++
IHD	+++	-
PD	++	-
CRRT	+++	+++

Table 5. Operating characteristics of CRRT – fluid removal versus fluid regulation

Characteristics	Fluid removal	Fluid regulation
UF rate	To meet anticipated needs based upon static weight at beginning of treatment as compared to target weight	Variable and reassessed frequently depending upon patient needs and goals of therapy
Fluid management	Adjust UF	Adjust amount of replacement fluid and/or UF
Fluid balance	Even or negative	Positive, even, or negative
Volume removed	Based on physician estimate	Driven by patient characteristics and goals
Application	Easy, similar to IHD	Requires specific tools and training

IHD = Intermittent hemodialysis.

Principles of Fluid Management in CRRT

CRRT Fluid Balance

Provides a mechanism for achieving the patient fluid balance goals

Two approaches

- Fluid removal
- Fluid regulation

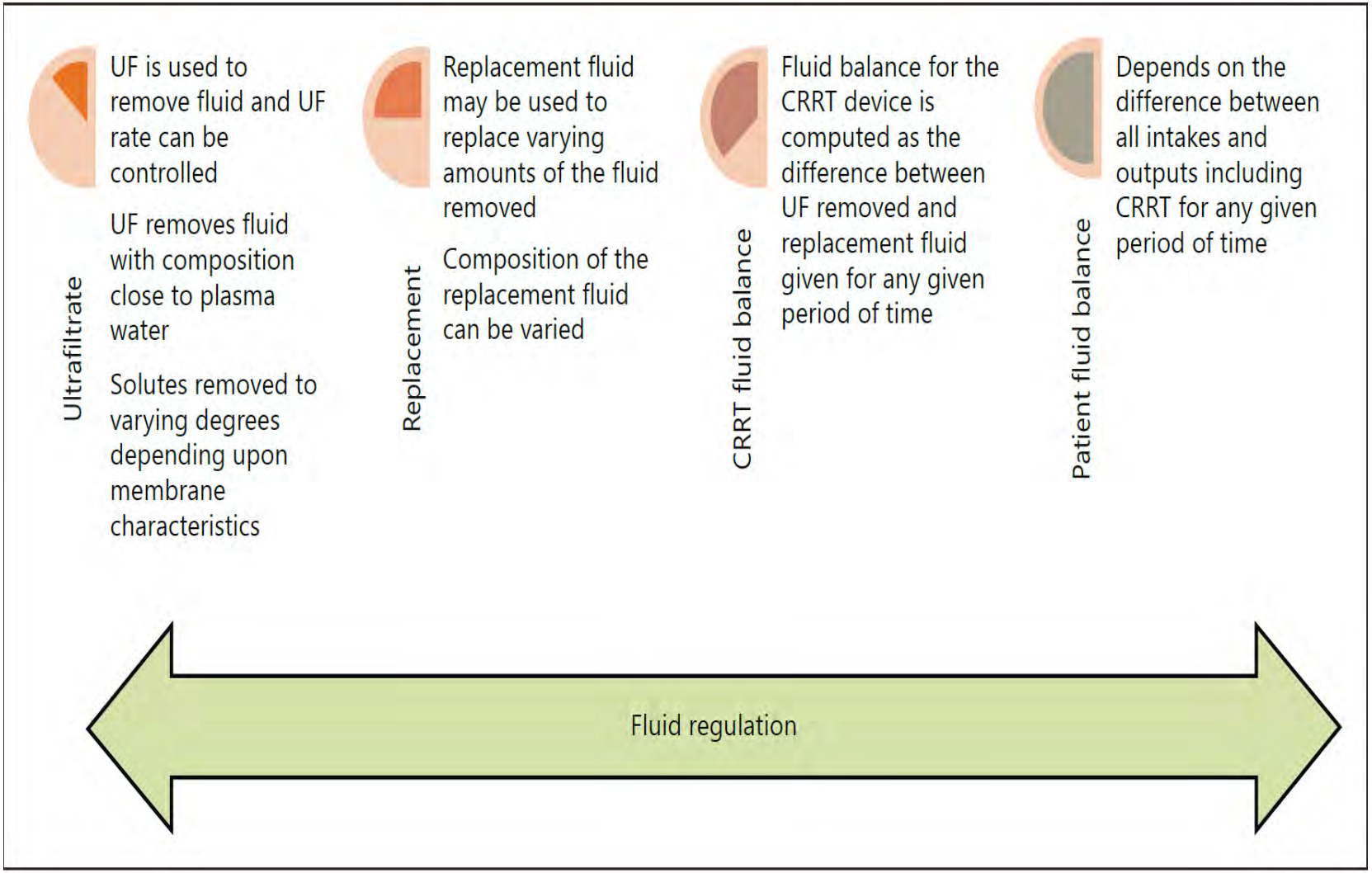
Patient Fluid Balance

Depends on goals for patient

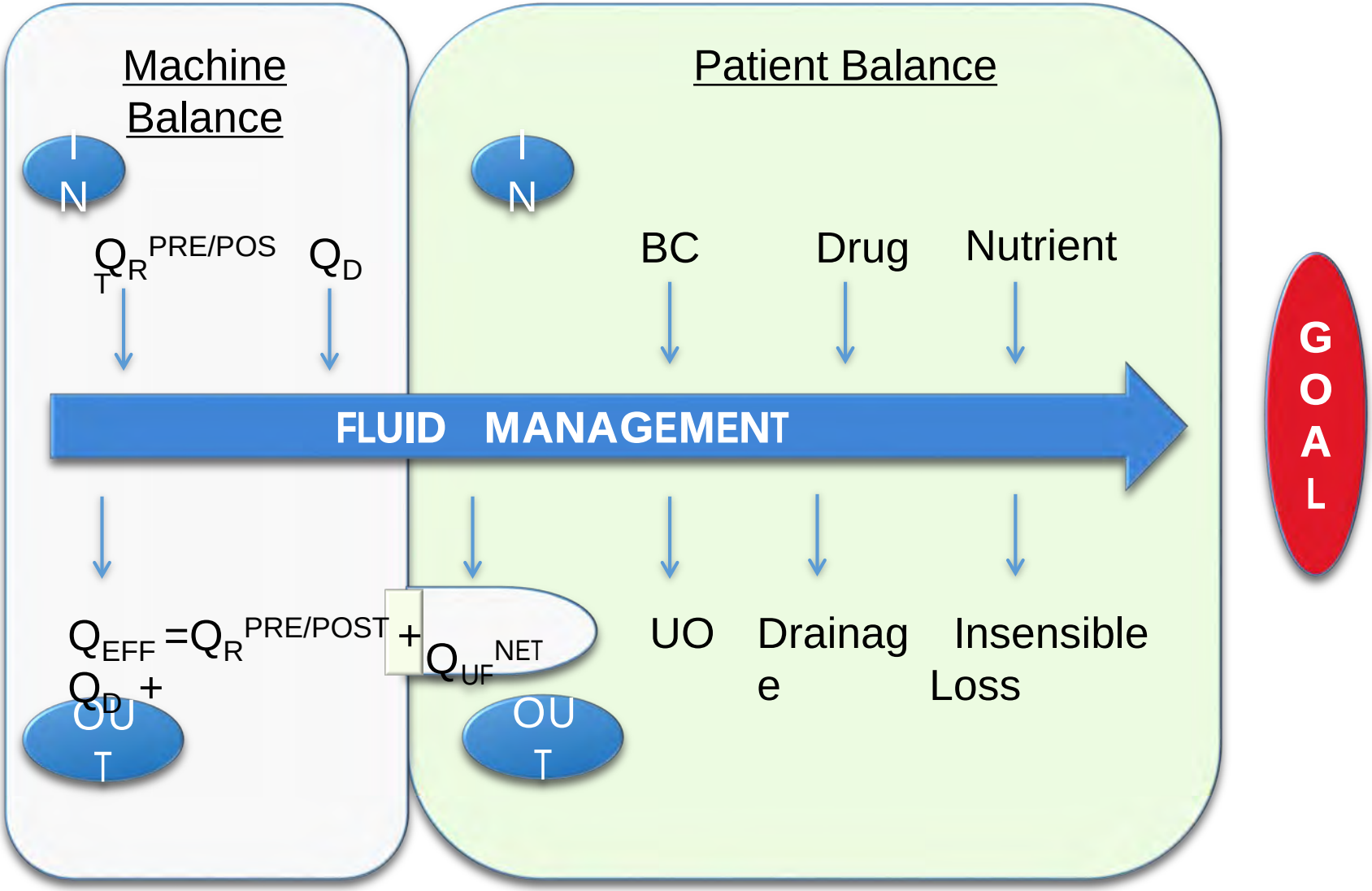
Goals may range from removing fluid, keeping even or giving fluid.

Fluid balance goals require adjustment frequently and will often determine the operational parameters.

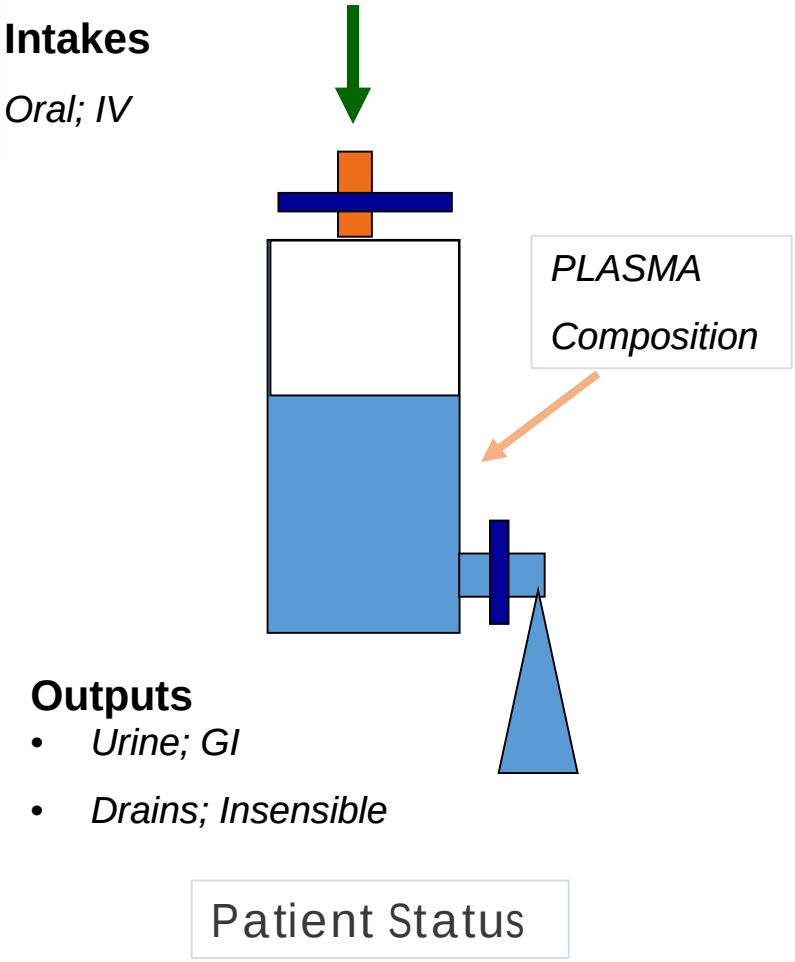
Principles of Fluid Management with CRRT



Approaches to Fluid Balance with CRRT Fluid Regulation



Approaches to Fluid Balance with CRRT Principles



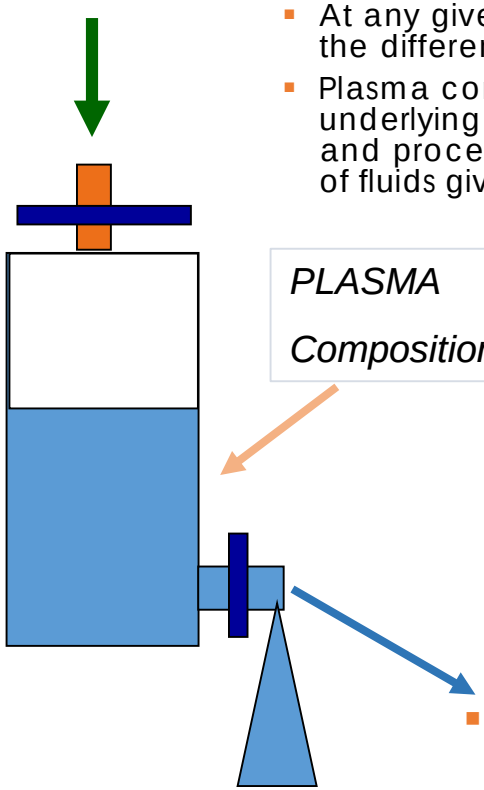
- Patient Balance
  - At any given point in time depends on the difference in intakes and outputs
  - Plasma composition determined by underlying pathophysiologic processes and process of care (amount and types of fluids given)

Approaches to Fluid Balance with CRRT Fluid Removal

- Patient Balance
  - At any given point in time depends on the difference in intakes and outputs
  - Plasma composition determined by underlying pathophysiologic processes and process of care (amount and types of fluids given)

Intakes

Oral; IV



PLASMA

Composition

Key is to integrate CRRT balance with patient fluid balance

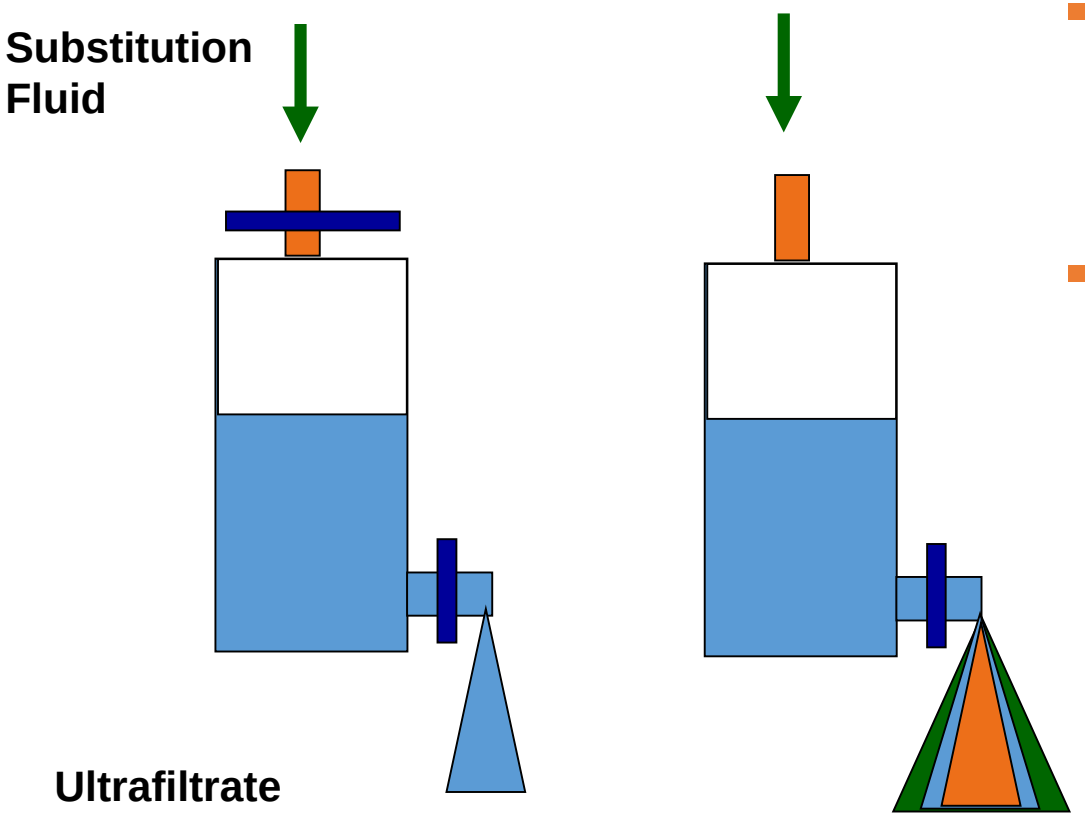
Outputs

- *Urine; GI*
- *Drains; Insensible*

Patient Status

- CRRT Addition
  - Provides a new source of fluid removal that can be adjusted
- CRRT Balance
  - Negative if fluid removal rate > replacement fluid rate
  - Zero
    - if no fluid removed and no replacement given (CVVHD)
    - fluid removal rate = replacement fluid rate

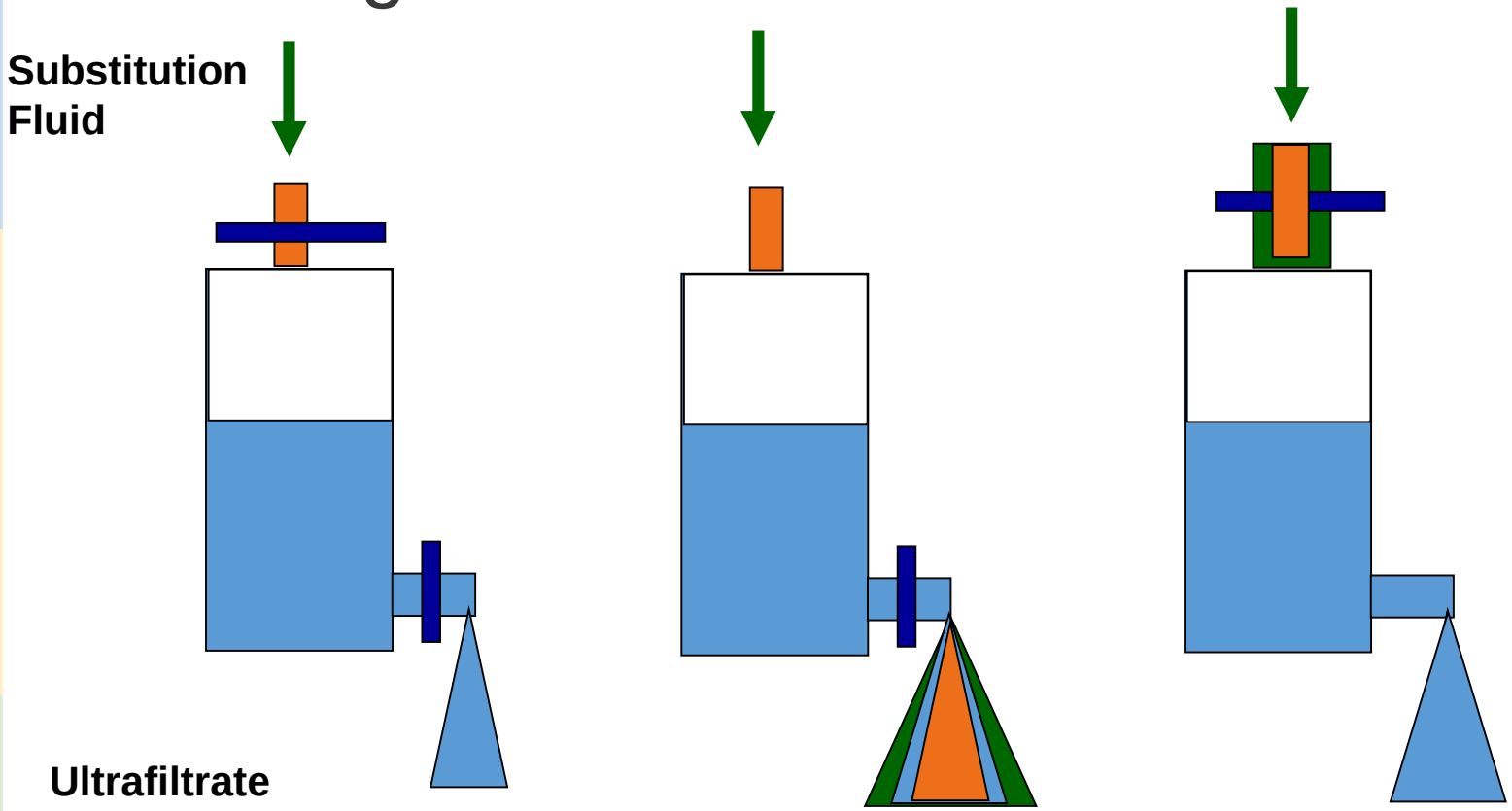
Approaches to Fluid Balance with CRRT Fluid Regulation



Common Strategy

- Adjust patient fluid balance using CRRT as a tool for fluid management
- Goal is to adjust fluid removal/administration to achieve patient needs

Approaches to Fluid Balance with CRRT Fluid Regulation



Common Strategy

UF is Varied

Alternate Strategy

UF is fixed
Replacement is varied

Approaches to Fluid Balance with CRRT
Fluid Removal vs. Regulation

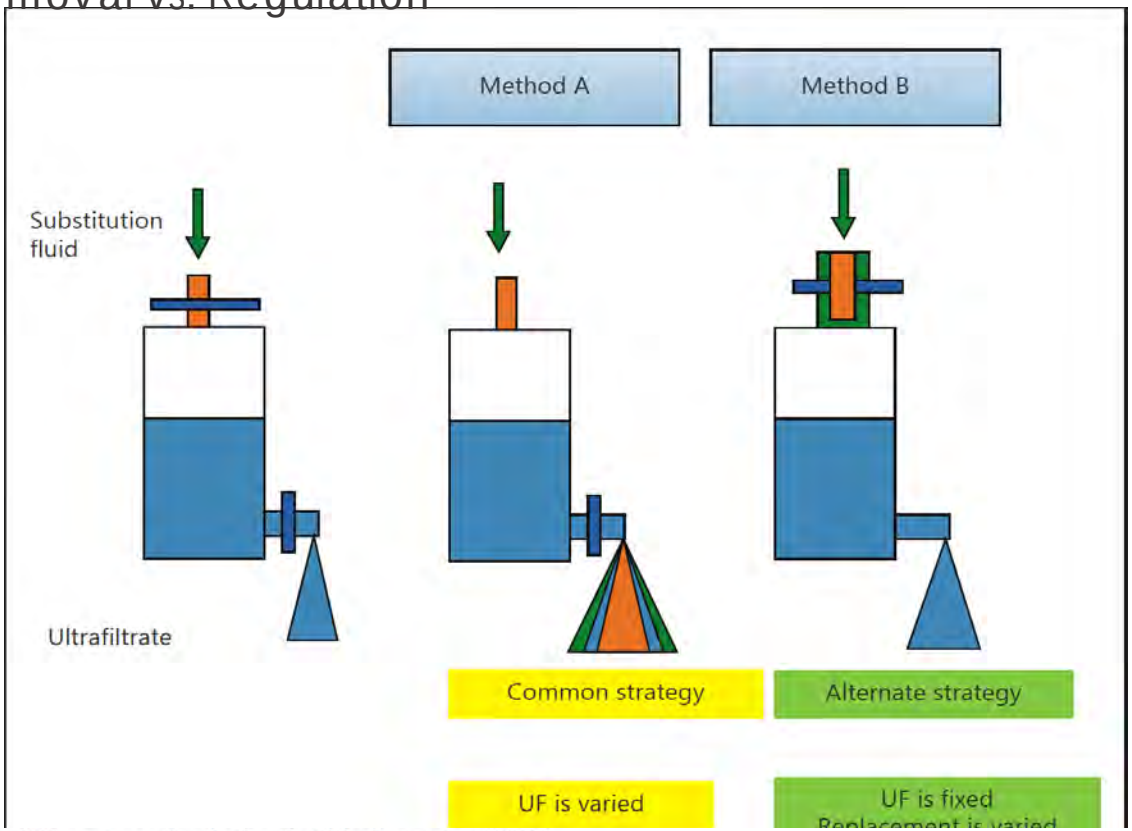


Table 6. Two different methods for fluid balance in CRRT

Variable	Ultrafiltration technique	Replacement fluid technique
Fluid balance	Achieved by varying UF rate	Achieved by adjusting amount of replacement fluids
Differences	Output is varied to accommodate changes in intake and output to reach a fluid removal goal	Output is fixed to achieve solute clearance goal and replacement fluid rates are changed to allow flexibility in reaching net fluid balance goals
Advantages	Familiar strategy from intermittent HD Can allow for fluid balance calculations over an extended period with calculation of a rate per unit time	Allows for constant solute clearance Dissociates clearance parameters from fluid balance
Disadvantages	Solute clearance may fluctuate Requires frequent interactions with CRRT machine to adjust UF rates to meet patient needs	Requires hourly calculations of the amount of replacement fluid to be given with risk for fluid imbalance if rate not calculated correctly with clear appreciation of all of the inputs and outputs for the patient

Case:

74 yo HF was admitted with 25% total body surface area burns in a structure fire, smoke inhalation.

She was in the structure fire for unknown time, her husband died in the fire.

She has burn injury to face, dorsum of both arms and legs.

She received large volume resuscitation and is about 40 L + since admission

She is intubated and sedated in the burn unit on a fentanyl and versed drip

HR 90, BP 135/80 , Temp 99, FiO2 70%

Burns on face, back, arms

S1S2, Lungs bilateral diffuse rhonchi

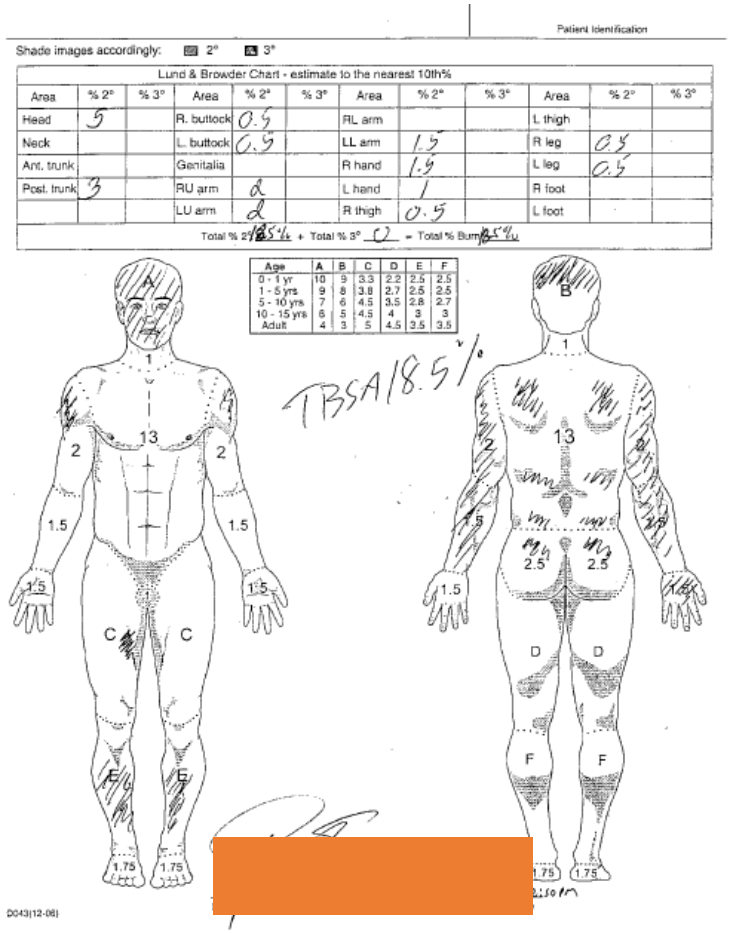
Abdomen obese marked edema and bowel sounds present

Legs marked edema to thighs

Labs: Sodium 146, Potassium 4, Chloride 109, Bicarb 35, BUN 18, Creatinine 0.54, Glucose 154, Calcium 8.6

WBC 9.7, hemoglobin 9, platelet 144

Case:



Patient Identification

Shade images accordingly: 2° 3°

Lund & Browder Chart - estimate to the nearest 10th%

Area	% 2°	% 3°	Area	% 2°	% 3°	Area	% 2°	% 3°	Area	% 2°	% 3°
Head	5		R. buttock	0.5		RL arm			L thigh		
Neck			L. buttock	0.5		LL arm	1.5		R leg	0.5	
Ant. trunk			Genitalia			R hand	1.5		L leg	0.5	
Post. trunk	3		RU arm	2		L hand	1		R foot		
			LU arm	2		R thigh	0.5		L foot		

Total % 2° 18.5% + Total % 3° 0 = Total % Burn 18.5%

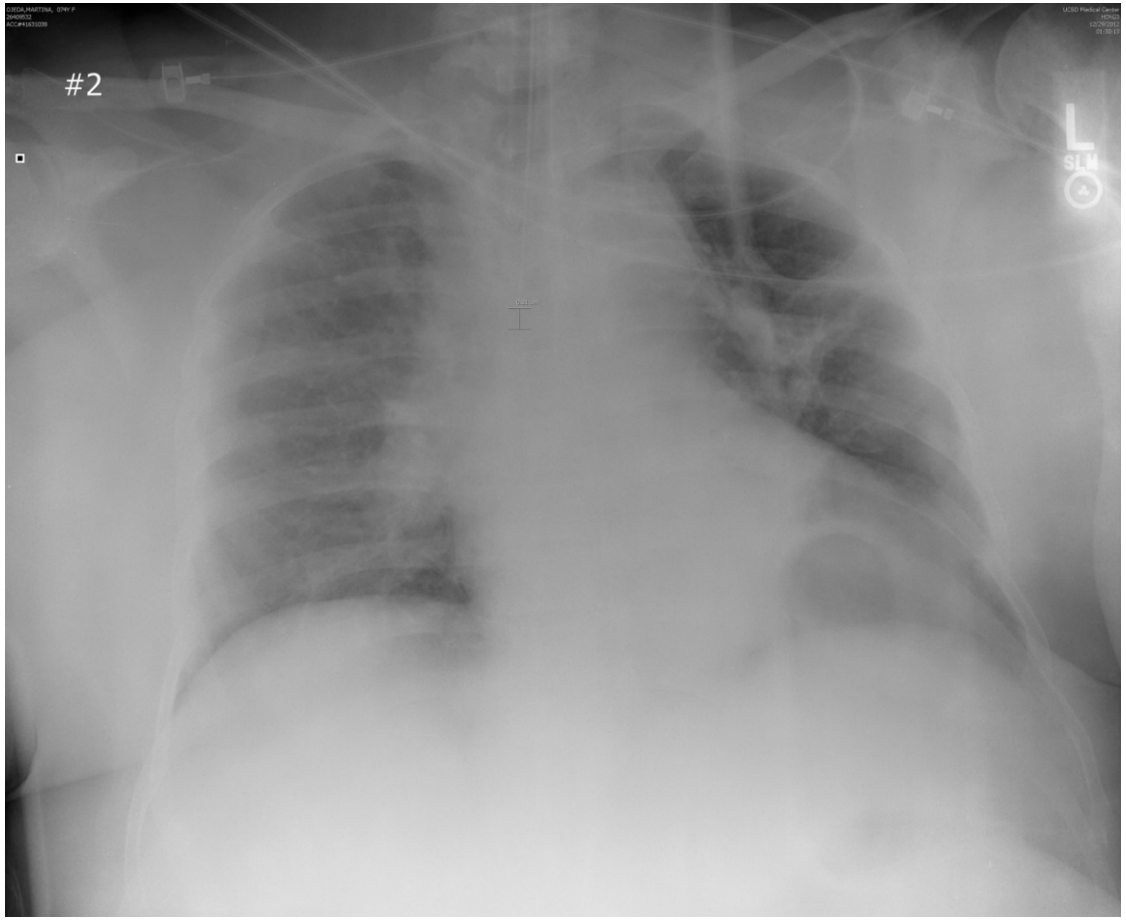
Age	A	B	C	D	E	F
0 - 1 yr	10	9	3.3	2.2	2.5	2.5
1 - 5 yrs	9	8	3.8	2.7	2.5	2.5
5 - 10 yrs	7	6	4.5	3.5	2.8	2.7
10 - 15 yrs	6	5	4.5	4	3	3
Adult	4	3	5	4.5	3.5	3.5

TBSA 18.5%

[redacted]

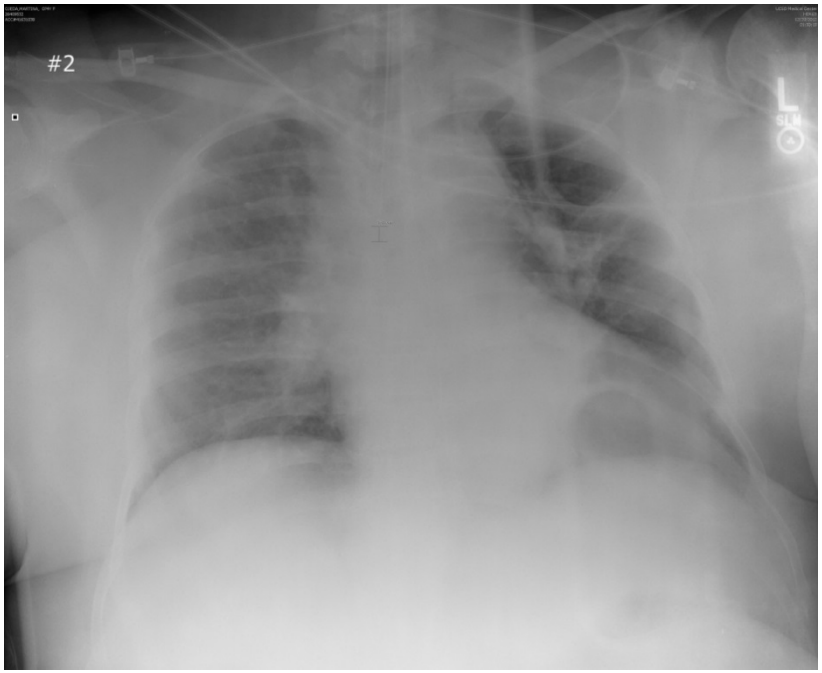
D043(12-06)

Case:

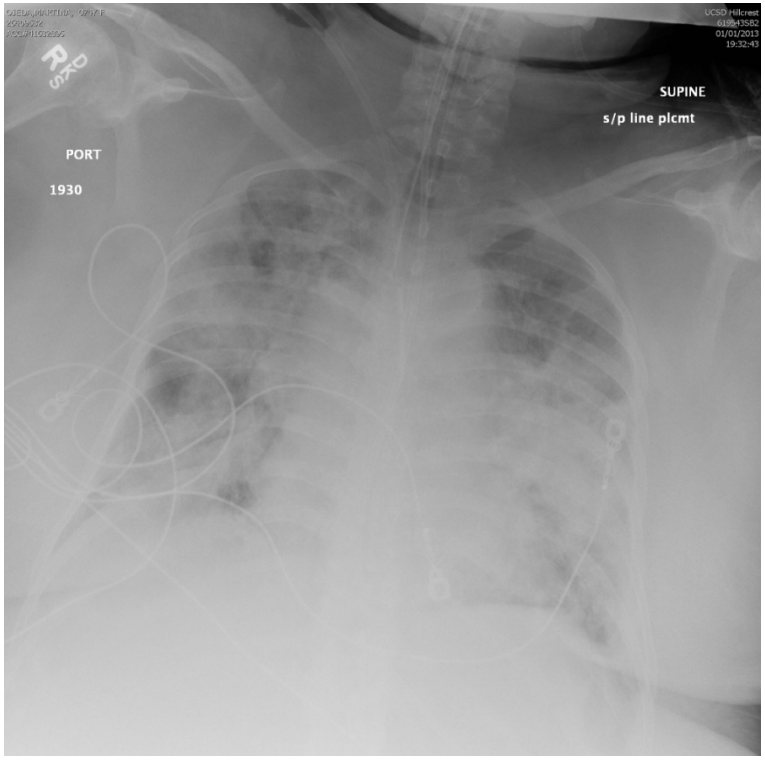


Case:

Dec 29



Jan 1



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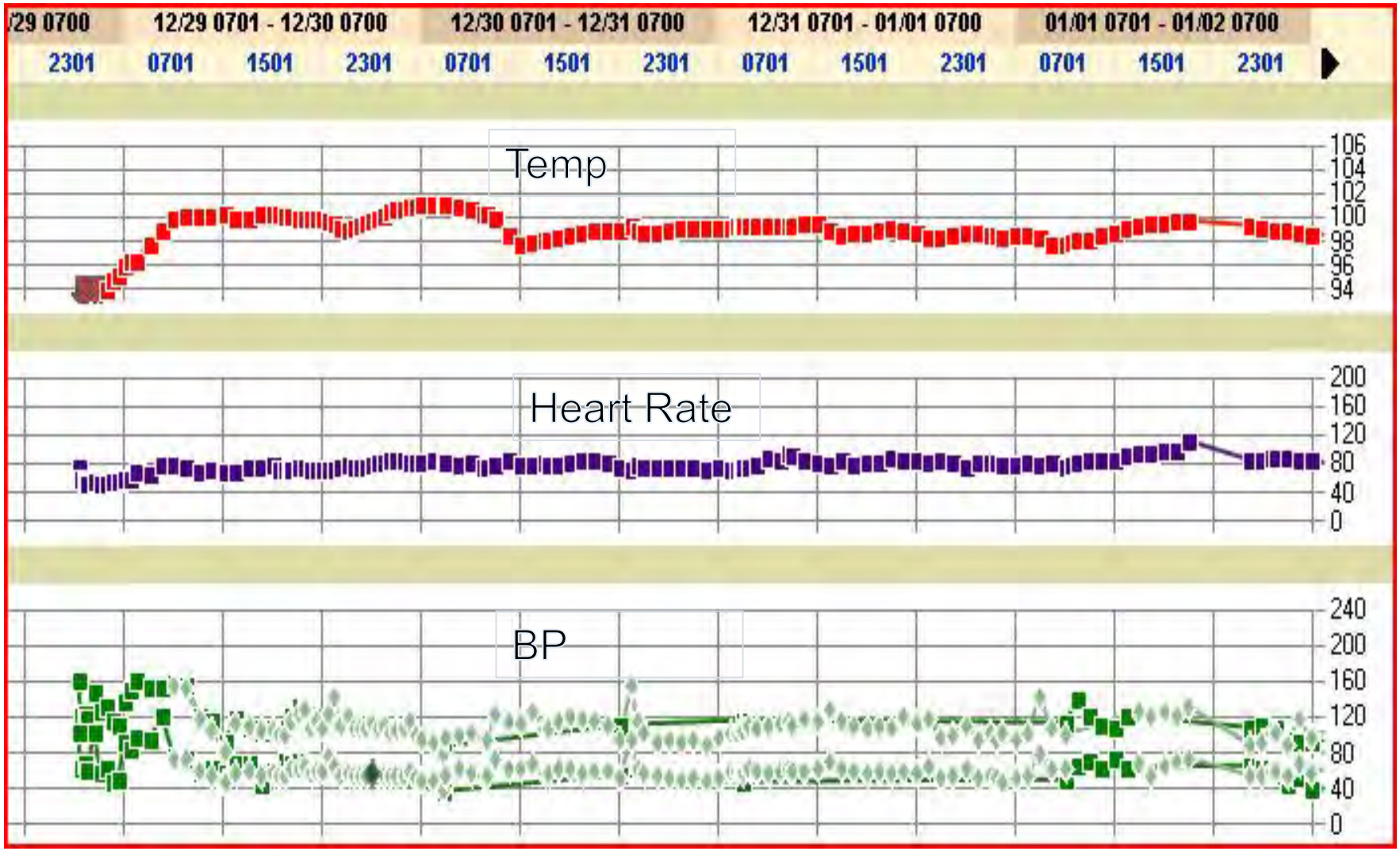
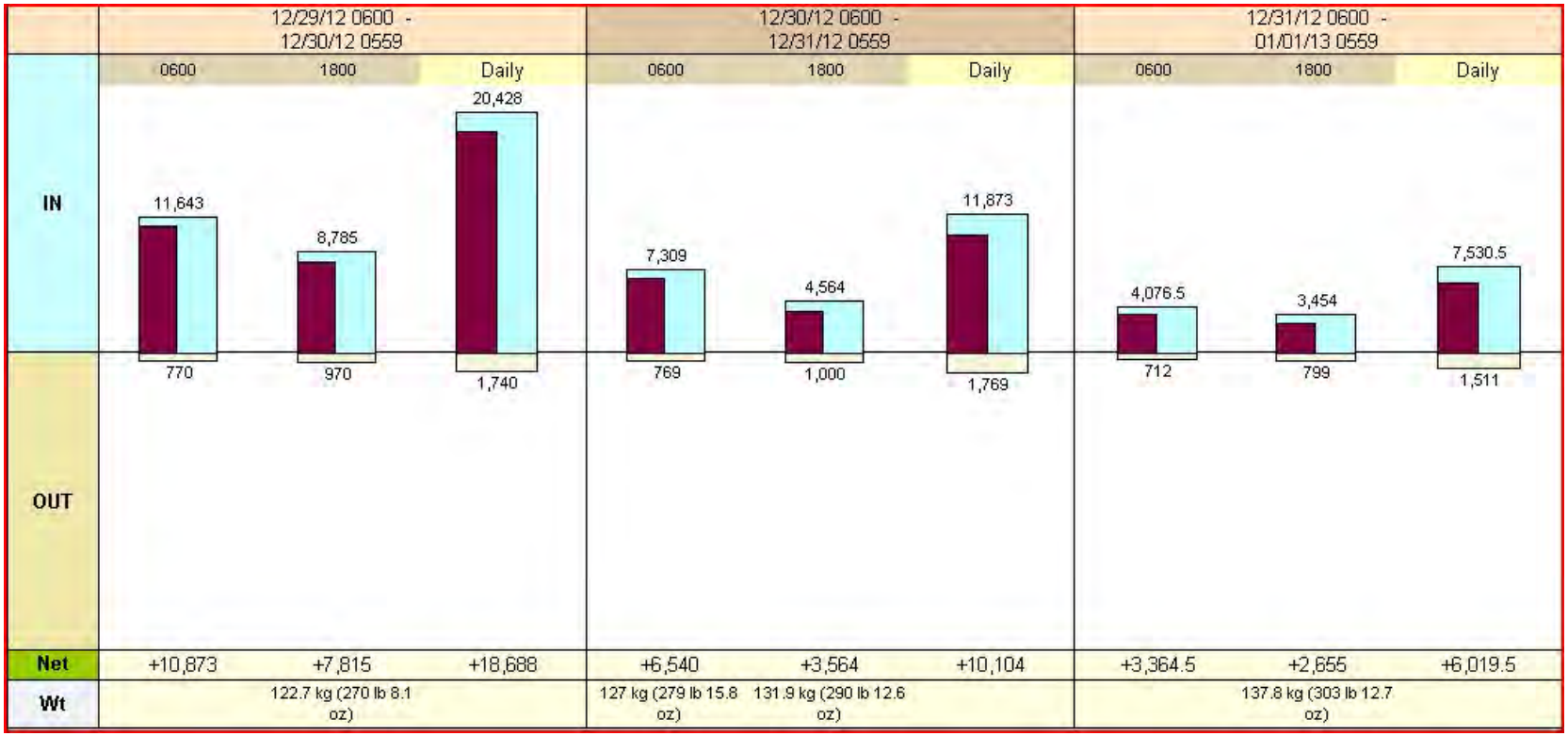

/29 0700
12/29 0701 - 12/30 0700
12/30 0701 - 12/31 0700
12/31 0701 - 01/01 0700
01/01 0701 - 01/02 0700
2301 0701 1501 2301 0701 1501 2301 0701 1501 2301 0701 1501 2301
Temp
106 104 102 100 98 96 94
Heart Rate
200 160 120 80 40 0
BP
240 200 160 120 80 40 0

Case:

	12/29/12 0600 - 12/30/12 0559			12/30/12 0600 - 12/31/12 0559			12/31/12 0600 - 01/01/13 0559		
	0600	1800	Daily	0600	1800	Daily	0600	1800	Daily
IN	11,643	8,785	20,428	7,309	4,564	11,873	4,076.5	3,454	7,530.5
OUT	770	970	1,740	769	1,000	1,769	712	799	1,511
Net	+10,873	+7,815	+18,688	+6,540	+3,564	+10,104	+3,364.5	+2,655	+6,019.5
Wt	122.7 kg (270 lb 8.1 oz)			127 kg (279 lb 15.8 oz)	131.9 kg (290 lb 12.6 oz)		137.8 kg (303 lb 12.7 oz)		

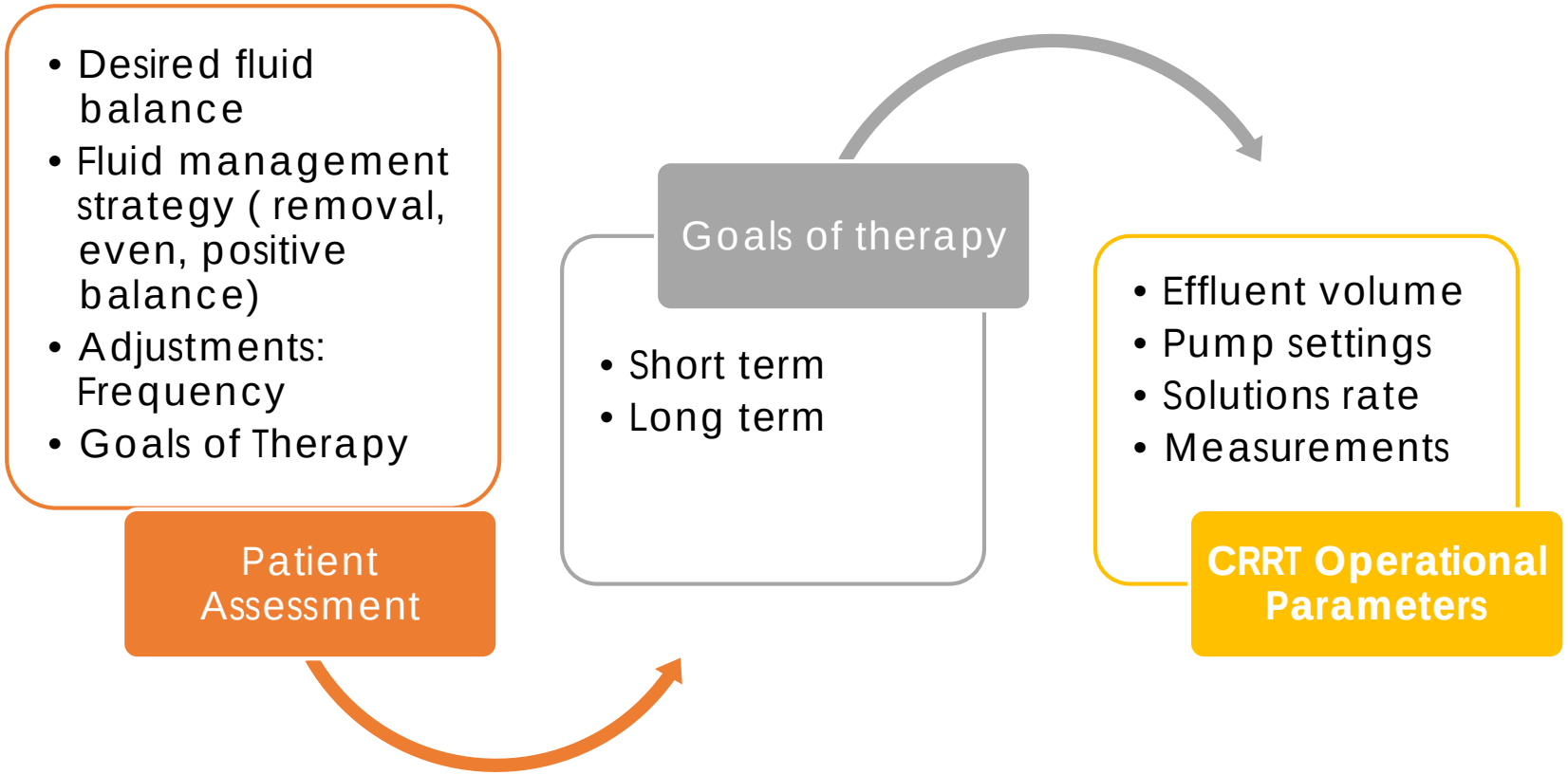
Case Study


12/29/12 0600 - 12/30/12 0559
12/30/12 0600 - 12/31/12 0559
12/31/12 0600 - 01/01/13 0559
0600
1800
Daily
IN
OUT
Net
Wt
11,643
8,785
20,428
770
970
1,740
7,309
4,564
11,873
769
1,000
1,769
4,076.5
3,454
7,530.5
712
799
1,511
+10,873
+7,815
+18,688
+6,540
+3,564
+10,104
+3,364.5
+2,655
+6,019.5
122.7 kg (270 lb 8.1 oz)
127 kg (279 lb 15.8 oz)
131.9 kg (290 lb 12.6 oz)
137.8 kg (303 lb 12.7 oz)

Case:

- What should you do for fluid management at this time?
  - A. Start a vasopressor to optimize BP
  - B. Start a diuretic drip
  - C. Stop IV fluids
  - D. Start IHD
  - E. Start PD
  - F. Start CRRT
  - G. Talk to the family and withdraw care

Optimizing Renal Support for Fluid Management with CRRT



Fluid Management in CRRT

Key Decisions

How much UF volume is required to provide solute clearance

How much UF is needed to achieve fluid balance

What fluid composition is needed to replace fluid removed

Practical Issues

Prescription

Implementing fluid management with different pumped systems

Monitoring and charting

Roles and responsibilities

Fluid management in CRRT Prescription

Step 1: Determine the effluent rate (dialysate and/or ultrafiltrate) needed to meet clearance goals (recommend starting at 30 ml/kg/h)

- Monitor clearance
- Adjust effluent rate to meet clearance goals
- Monitor hemofilter performance (FUN/BUN)

Step 2: Determine fluid balance needs for the patient and determine the iBalance by incorporating machine and patient fluid balance to determine net goals

- Monitor hemodynamic response to fluid removal
- Frequent clinical assessment of fluid removal goal
- Flow sheets to monitor machine/patient balance
- Consider measures of dynamic fluid assessment

Step 3: Determine composition of replacement and/or dialysate solutions to meet goals of maintaining electrolyte and acid-base homeostasis

- Monitor serum electrolytes
- Monitor acid-base status
- Adjust fluids accordingly to meet goals

Step 4: Determine the timing for achievement of goal and monitoring parameters

- Timing based upon hemodynamic stability and imperatives based upon clinical goals
- Set fluid removal rate
- Determine best method to monitor changes

Fluid Management in CRRT Prescription Elements

Modality

- CVVH
- CVVHD
- CVVHDF

Operational Characteristics

Solute removal
- Membrane
- Blood flow
- Effluent volume (Dialysate, Ultrafiltrate)

Fluid Balance
- Ultrafiltrate
  - Substitution fluid
  - Dilution fluid
- Replacement fluid

Circuit
- Anticoagulation
- Filtration fraction
- Monitoring

Plasma Composition

- Solution content
- Flow rates
- Monitoring

Organ Support

- High Volume
- High cut off membranes and sorbents
- Temperature control

Fluid management in CRRT Prescription

Desired solute clearance

- Effluent volume
  - Dialysate
  - Ultrafiltrate

Desired Fluid balance

- Fluid removal
- Fluid regulation

Operational and safety parameters

- Monitoring and charting
- Problem avoidance and recognition

Fluid management in CRRT Prescription

How much solute clearance?

- Based on patient characteristics (catabolic state, nutritional support, underlying renal function etc)
- Calculated as desired clearance ml/min and expressed as L/hr

Compute minimal effluent volume

- Clearance requirement in L/hr = minimal effluent volume/hr
- Amount of dialysate and ultrafiltrate to meet minimal effluent volume (modality dependent)

$$FF = \frac{\text{UF rate (ml/min)}}{\text{plasma flow rate } (Q_P) \text{ (ml/min)}}$$

Table 3. Plasma flow and FF for different Q_Bs, UF rates and Hct

Hct, %	Q_B = 150 ml/min		Q_B = 200 ml/min	
	Q_P	FF	Q_P	FF
UF = 1,000 ml/h				
Hct = 25	112.5	0.15	150	0.11
Hct = 35	97.5	0.17	130	0.13
Hct = 40	90	0.19	120	0.14
UF = 2,000 ml/h				
Hct = 25	112.5	0.30	150	0.22
Hct = 35	97.5	0.34	130	0.26
Hct = 40	90	0.37	120	0.28

Q_P = Plasma flow rate in ml/min.

Fluid management in CRRT Prescription

How much solute clearance?

- Based on patient characteristics (catabolic state, nutritional support, underlying renal function etc)
- Calculated as desired clearance ml/min and expressed as L/hr

Compute minimal effluent volume

- Clearance requirement in L/hr = minimal effluent volume /hr
- Amount of dialysate and ultrafiltrate to meet minimal effluent volume (modality dependent)

UF volume needed for fluid balance needs

- Define patient fluid balance requirements and estimate net (intake – output) amount of fluid to be removed
- Define intakes obligated to CRRT therapy e.g. citrate and calcium required for anticoagulation
- Add total fluid to be removed every hour to achieve goals
- Compute UF required for fluid balance = total fluid to be removed

Fluid management in CRRT Prescription

Total UF needed for solute removal and fluid balance

- Minimal UF for solute clearance + safety factor for fluid balance (usually 300-500 ml/hr))– (UF needed for fluid)
- Fluid needed for dilution (pre-filter and post)
- Determine final effluent volume

For example:
CVVHDF Effluent volume 2700 ml/hr
Dialysate 1000 ml/hr
Ultrafiltrate needs
    Fluid needs 500 ml/hr
    Dilution fluids 700 ml/hr (500 pre-filter and 200 post filter)
    Safety factor 500 ml/hr
Total UF vol needed
Total UF volume needed = 1700 ml
Net UF = (1700- 700 (dilution fluid) = 1000 ml/hr
Thus final effluent volume = UF 1700 ml + dialysate 1000 ml = 2700 ml/hr

Fluid management in CRRT Prescription

Set operational parameters

- Target is to achieve final effluent volume without increasing filtration fraction (FF) > 20%
  - Set BFR so that UF/plasma flow /min= < 20%
  - Set dialysate flow rate
  - Ascertain that effluent volume

For Example

a) Compute UF volume /min
b) Set UF flow rate
c) UF vol = 1000 ml/hr = 17 ml/min
d) Minimum plasma flow to achieve <20% FF = 17 x 5 = 85 ml/min
e) Minimum blood flow rate = plasma flow / (1-Hct)
f) = 85/.75 (for Hct 25) = 114 ml/min
g) Set BFR at 120 ml/min
h) Set dialysate flow rate at 1000 ml/hr
i) Set Dilution fluids at 700 ml/hr
j) UF rate at 1000 ml/hr
k) Effluent volume = 2700 ml/hr

Fluid management in CRRT Prescription

Set replacement fluid or UFR parameters for patient fluid balance

- Determine net fluid balance goal e.g. negative, zero or positive
- Determine CRRT fluid balance very hour
- Set replacement fluid rate or UFR to achieve patient fluid balance goal

Role of CRRT in Fluid Management How is it Done?

- Prescription
  - Machine PRISMAFLEX
  - Filter HF-1000 filter set
  - Mode: CVVHDF
  - BFR: 100 ml/min
  - Dialysate flow rate: 1000 ml/hr
  - Patient fluid removal 1000 ml/hr
  - Pre-filter replacement: 500 ml/hr
  - Post-Filter dilution 200 ml/hr
  - **Effluent volume 2700 ml/hr**
- Anticoagulation: Regional citrate
  - 4% tri-sodium citrate at 180 ml/hr
  - Calcium chloride 40 ml/hr
  - Monitoring: peripheral and post-filter ionized calcium
- Solutions:
  - Dialysate : Prismasate 32 bicarb + Mg 2 meq/L + K 4.0 meq/L
  - Pre-filter fluid for dilution: 0.9% saline
  - Post-filter for circuit patency: 0.9% saline
  - Post-filter replacement: to achieve target fluid balance: Prismasol 32

Fluid Management in CRRT

Orders

- Components
- Standardization

UCSD Medical Center Citrate CRRT Orders

Solutions and Flow Rate:

11. Blood flow: ❒ 100 mLs/min ❒ Other_____mLs/min (Max: 450 mLs/min)

12. (1B) Dialysate - Base solution: 0.45% NACL

*NaCL	mEq/L
*$NaHCO_3$	mEq/L
KCL	mEq/L
Magnesium Sulfate	mEq/L
Dextrose (0.1-1%)	%
Other 1	
Other 2	

*Total NaCl/HCO3 should equal 40 mEq/L

13.

FLOW RATES	Standard (mLs/hr)	Other (mLs/hr)
(1A) Total Effluent (total of all fluids)	2700	
(1B) Dialysate	1000	
(1C) Post filter (deaereation chamber via replacement pump)	200	
(1D) Pre filter (via Pre Blood Pump)	500	
(3A) Patient fluid removal (Max 2000 mLs/hr)	1000	

( ) refers to form D6037

14. (1C) Post filter: ❒ Normal Saline ❒ Other: _____

15. (1D) Pre filter: ❒ Normal Saline ❒ Other: _____

UCSD Medical Center Citrate CRRT Orders

14. Replacement fluid composition: ❒ 0.9% sodium chloride

❒ Other 1: _____ ❒ Other 2: _____

15. Replacement fluid flow rates: Choose **one** method below to maintain net fluid balance:

❒ Set hourly fluid removal rate:

❒ Net negative ___ ___ ___ mL/hour for ___ ___ ___ hours.

❒ Keep even for ___ ___ ___ hours.

❒ Net positive ___ ___ ___ mL/hour for ___ ___ ___ hours.

❒ Sliding scale (below):

Parameters:	Suggested Hourly Fluid Target Parameters	OTHER Hourly Fluid Target Parameters
❍ MAP ❍ PAWP		
❍ CVP ❍ Other _____		
_____	+ 200 mL	_____
_____	+ 150 mL	_____
_____	+ 100 mL	_____
_____	+ 50 mL	_____
_____	EVEN	_____
_____	- 50 mL	_____
_____	- 100 mL	_____
_____	- 150 mL	_____
_____	- 200 mL	_____

NOTE: For all machines other than PRISMA: infuse fluid into replacement fluid line (prefilter, postpump).
For PRISMA: give replacement fluid postfilter via venous return line.

Fluid Management in CRRT

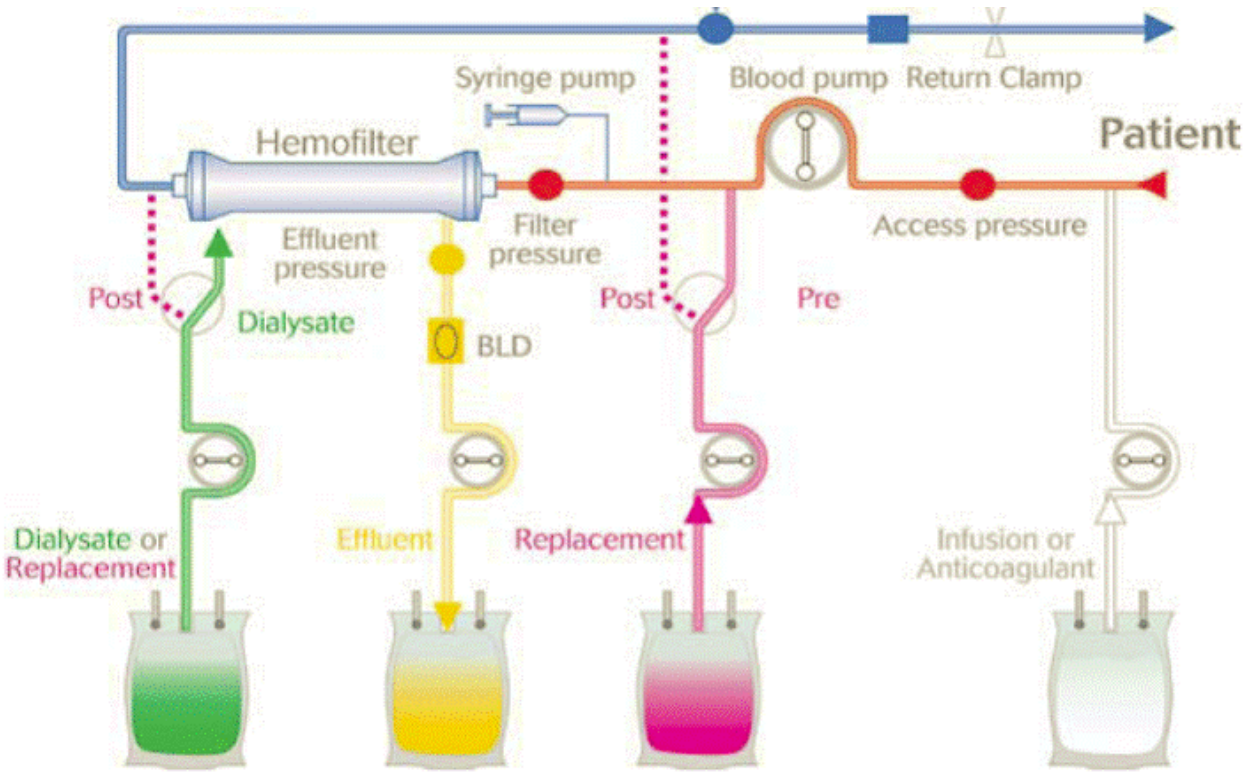
UF pump setting

- UF pump can be set independent of other pumps (Diapact, BM25)
- UF pump rate dictated by other pump settings (PRISMA, Aquarius, Prismaflex)

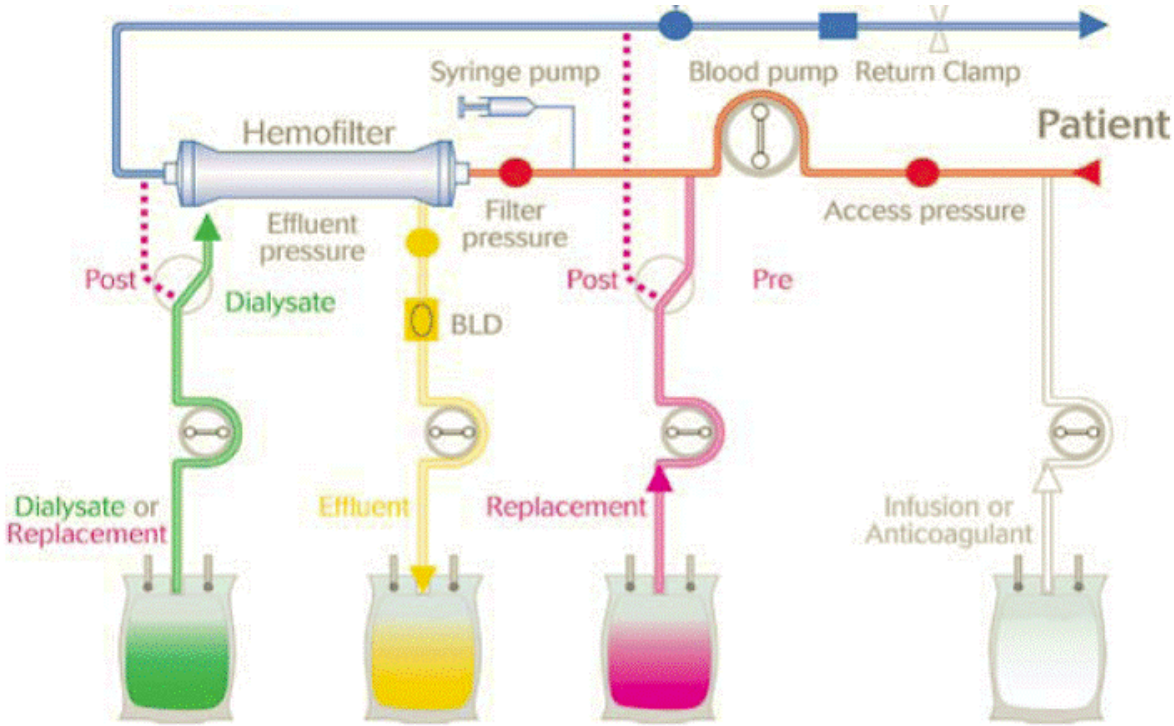
CRRT fluid balance computation

- Fluids hung on scale
- Fluids outside of system

Hydraulic Circuit for PrismaFlex



Hydraulic Circuit for PrismaFlex



Machine Programming Components:

Modality: CVVH, CVVHD, CVVHDF

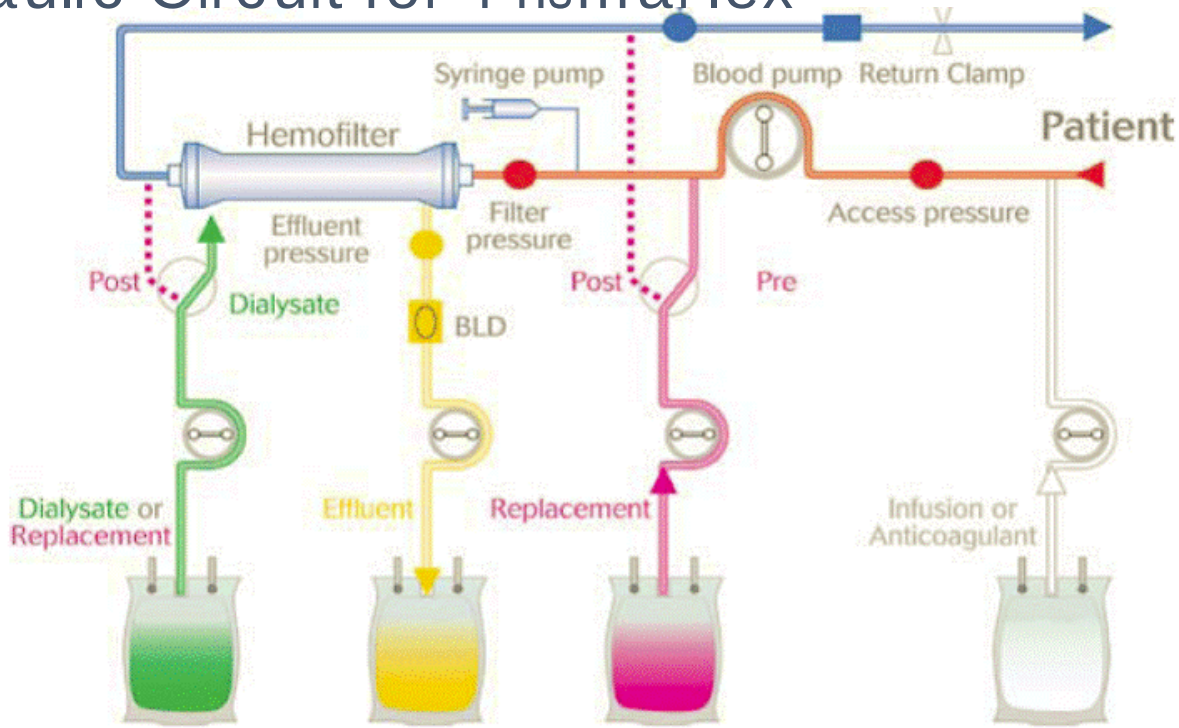
Negative fluid balance desired (Fluid removal rate)

Replacement fluid pre vs post filter

Dialysate flow rate

Anticoagulant flow rate

Hydraulic Circuit for PrismaFlex



Machine Programming Components:

Modality: CVVH, CVVHD, CVVHDF

Negative fluid balance desired (Fluid removal rate)

Replacement fluid pre vs post filter

Dialysate flow rate

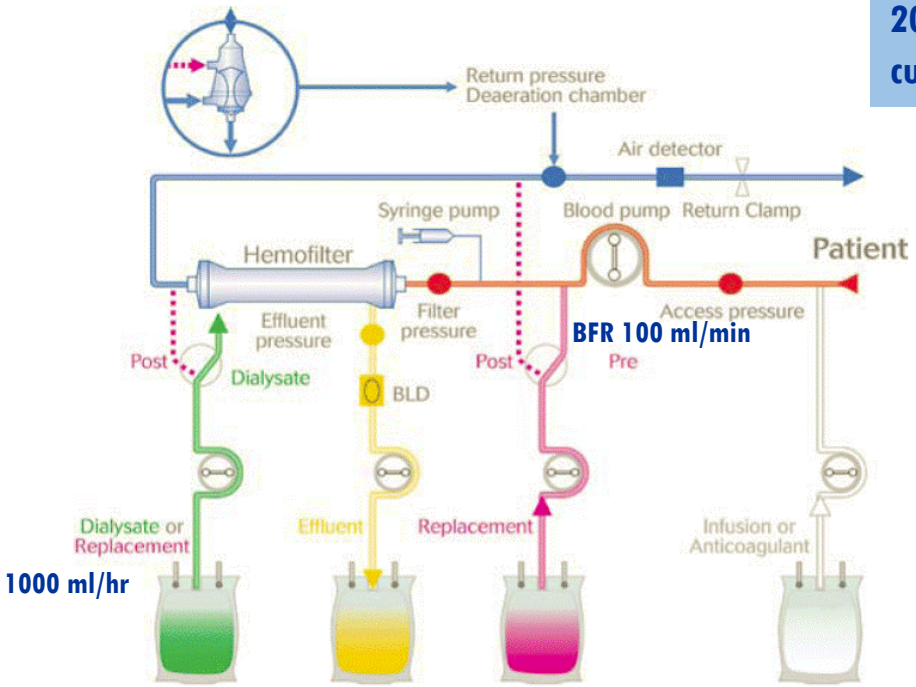
Anticoagulant flow rate

Effluent Pump Speed = RF + DF + AC + Fld removal

Citrate CVVHDF: UCSD Protocol

Substitution Fluid varying rate 200-1000 ml/hr (Prismasol, custom solution NaCl/NaHCO3)

$CaCl_2$ 0.1meq/ml 40-80 ml/hr *Adjusted based on Peripheral Ionized Ca*



4% Trisodium Citrate 120-200ml/hr

Citrate flow adjusted based on post filter Ionized Calcium

Dialysate Prismasate with Calcium and added Magnesium and Potassium

Effluent Pump 2700 ml/hr (net UFR 1000 ml/hr)

Post Dilution Fluid NaCl 200 ml/hr

Pre Dilution Fluid NaCl 500 ml/hr

Hydraulic Circuit for PrismaFlex

Fluid Management in CRRT

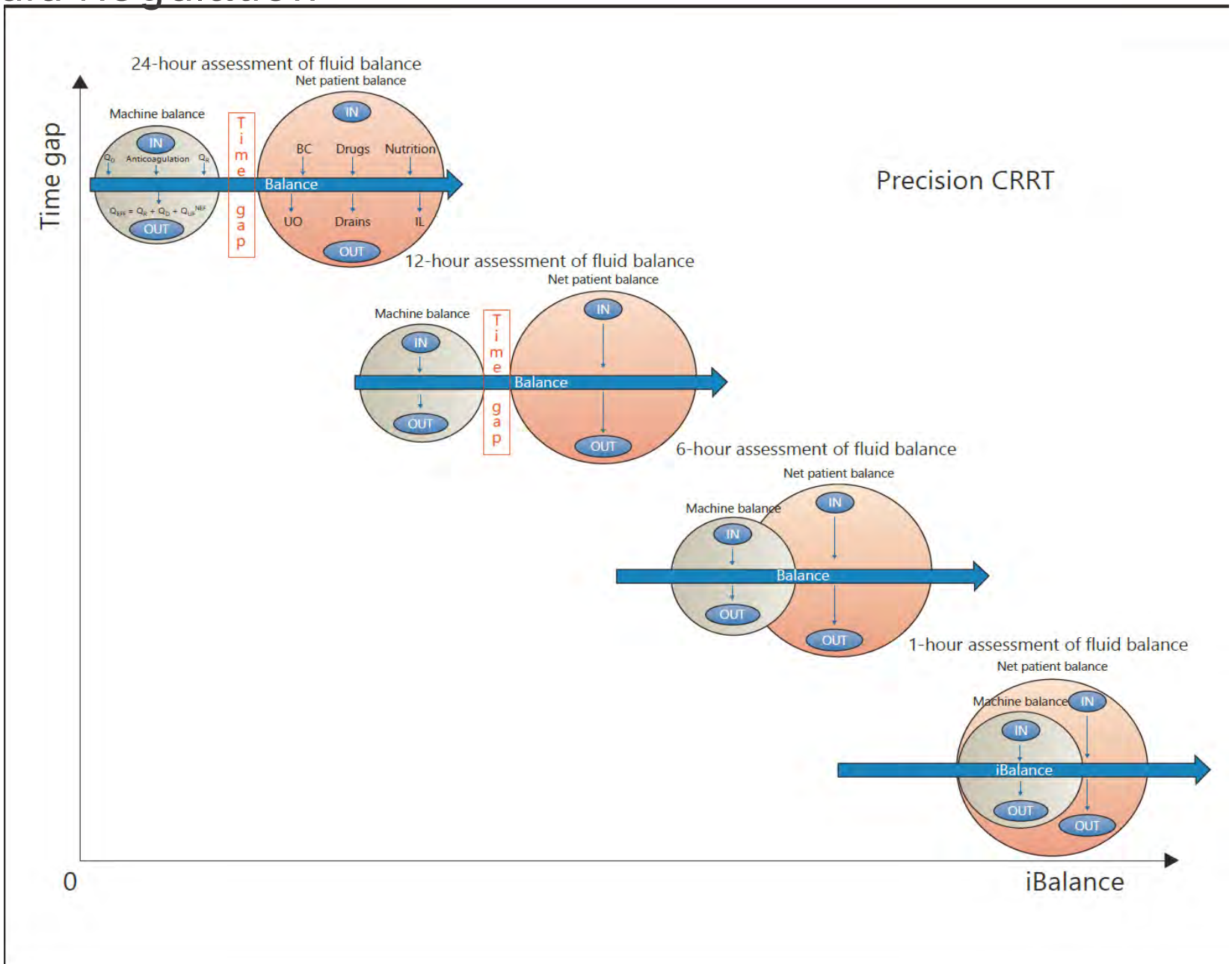
Orders

- Components
- Standardization

Charting

- CRRT Balance
- Patient Balance
- Where and how often is it charted

Approaches to Fluid Balance with CRRT
Fluid Regulation



UCSD MEDICAL CENTER CRRT FLOWSHEET

Case Study 46 yr old woman with MOF

	06	07	11	12	13	14	8hr TOTAL
1A UF OUTPUT	2000	1900					
1B DIALYSATE INFUSED	1000	1000					
1C ACTUAL UF OUT	1000	900					
2 ADDITIONAL OUT	400	200					
3 TOTAL OUT	1400	1100					
4 ALL INTAKE EXCEPT REPL	200	400					
5 HOURLY FLUID BALANCE	-1200	-700					
6 DESIRED OUTCOME	0	0					
7 CALC. REPLACEMENT	1200	700					
8 ACTUAL NET BALANCE	0	0					
ACT'S							

UCSD MEDICAL CENTER CRRT FLOWSHEET

Case Study 46 yr old woman with MOF

Level 3 fluid management

	06	07	11	12	13	14	8hr TOTAL
1A UF OUTPUT	2000	1900	1700	1800	1800	1700	
1B DIALYSATE INFUSED	1000	1000	1000	1000	1000	1000	
1C ACTUAL UF OUT	1000	900	700	800	800	700	
2 ADDITIONAL OUT	400	200	350	400	400	300	
3 TOTAL OUT	1400	1100	1050	1200	1200	1000	
4 ALL INTAKE EXCEPT REPL	200	400	120	145	145	400	
5 HOURLY FLUID BALANCE	-1200	-700	-930	-1055	-1055	-600	
6 DESIRED OUTCOME	0	0	0	-50	-75	+50	
7 CALC. REPLACEMENT	1200	700	930	1005	980	650	
8 ACTUAL NET BALANCE	0	0	0	-50	-75	+50	
ACT'S							
PAWP	16	16	17	18	20	14	

Sliding Scale

UCSD Medical Center CRRT Flowsheet

UCSD Medical Center

CONTINUOUS RENAL REPLACEMENT THERAPY (CRRT) FLOWSHEET

Name
MR#
DOB

RN INITIALS	SIGNATURE	RN INITIALS	SIGNATURE	DATE	Source	Date

Patient Identification

TIME		0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	12 hour total	1900	2000	2100	2200	2300	2400	0100	0200	0300	0400	0500	0600	12 hour total
1A	EFFLUENT (TOTAL OF ALL FLUIDS)																										
1B	PRE ILTER DILUTION SOLUTION (INTERNAL PUMP)																										
1C	DIALYSATE INFUSED																										
1D	PATIENT FLUID REMOVAL (UF)																										
2	ADDITIONAL OUTPUT (URINE, NG, CHEST TUBES, DRAINS)																										
3 (1D+2)	TOTAL OUTPUT																										
4A	ALL INTAKE: IV, PO, etc. EXCEPT REPLACEMENT																										
4B	PRE FILTER DILUATION SOLUTION (EXTERNAL PUMP)																										
4C	= 4A+B																										
5 (3-4C)	HOURLY FLUID BALANCE																										
6-MD ORDER	DESIRED OUTCOME (+ OR -)																										
7 (6-5)	PATIENT FLUID REPLACEMENT GIVEN																										
8 (5+7)	ACTUAL NET FLUID BALANCE																										
	CVP PAWP MAP																										
	ACCURA PRISMA BRAUN																										
	ACCESS ACCESS PRESSURE P A																										
	PREFILTER FILTER PRESSURE PBE																										
	FILTRATE EFFLUENT PRESSURE P D 2																										
	RETURN RETURN PRESSURE P V																										
	BLOOD FLOW / CONNECTIONS CHECK																										
	IONIZED CALCIUM - PERIPHERAL																										
	IONIZED CALCIUM - POST																										
	CITRATE FLOW / CALCIUM CHLORIDE FLOW																										
	RN INITIALS																										

D6037(12-04)

UCSD Medical Center

CONTINUOUS RENAL REPLACEMENT THERAPY (CRRT) FLOWSHEET

Name
MR#
DOB

RN INITIALS	SIGNATURE	RN INITIALS	SIGNATURE	DATE	Source	Date

Patient Identification

TIME		0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	12 hour total
1A	EFFLUENT (TOTAL OF ALL FLUIDS)	2348	2415	2246	2501	2264		2126	2264	2416	2277	2322	2500	
1B	PRE FILTER DILUTION SOLUTION (INTERNAL PUMP)	470	480	458	502	454		424	456	484	446	468	503	
1C	DIALYSATE INFUSED	935	961	921	1000	909		853	907	966	906	932	1001	
1D	PATIENT FLUID REMOVAL (UF)	940	974	919	999	901		849	901	964	925	922	996	
2	ADDITIONAL OUTPUT (URINE, NG, CHEST TUBES, DRAINS)	15	10	15	8	8		0	0	22	9	13	14	
3 (1D+2)	TOTAL OUTPUT	955	984	934	1007	909		849	901	986	934	935	1010	10404
4A	ALL INTAKE: IV, PO, etc. EXCEPT REPLACEMENT	253	318	318	320	220		948	351	428	382	372	570	
4B	PRE FILTER DILUATION SOLUTION (EXTERNAL PUMP)	X	X	X	X	X	X	X	X	X	X	X	X	
4C	= 4A+B TOTAL INTAKE	253	318	318	320	220		948	351	428	382	372	570	4480
5 (3-4C)	HOURLY FLUID BALANCE TOTAL	-702	-666	-616	-687	-689		+99	-550	-558	-552	-563	-440	
6-MD ORDER	DESIRED OUTCOME (+ OR -)	EVEN	EVEN	EVEN	EVEN	-200		EVEN	-150	-200	-200	-200	-200	-1150
7 (6-5)	PATIENT FLUID REPLACEMENT GIVEN	702	666	616	687	889		0	-700	-758	-752	-763	-640	-7173
8 (5+7)	ACTUAL NET FLUID BALANCE	EVEN	EVEN	EVEN	EVEN	-200		EVEN	-150	-200	-200	-200	-200	
	~~CVP PAWP MAP~~ SBP	97	97	98	99	159	CVP 14 BPS 102		CVP 18	CVP 20	CVP 20	CVP 19	CVP 21	
	ACCURA PRISMA BRAUN	PF	PF	PF	Flex Prisma	Prisma Flex		PRISMA FLEX	PRISMA FLEX	PRISMA FLEX	PRISMA FLEX	PRISMA FLEX	PRISMA FLEX	
	ACCESS / ACCESS PRESSURE / PA	0	-2	-6	-3	-7		-5	-2	2	0	-1	-2	
	PREFILTER / FILTER PRESSURE / PBE	98	99	110	110	128	Filter Blood	111	101	104	101	105	102	
	FILTRATE / EFFLUENT PRESSURE / PD2	-114	-114	-120	-133	-156		-10	-17	-11	-7	-3	-14	
	RETURN / RETURN PRESSURE / PV	39	40	42	43	43		39	41	46	42	42	42	
	BLOOD FLOW / CONNECTIONS CHECK	100 ✓	100 ✓	100 ✓	100 ✓	100 ✓		100 ✓	100 ✓	100 ✓	100 ✓	100 ✓	100 ✓	
	IONIZED CALCIUM - PERIPHERAL													
	IONIZED CALCIUM - POST													
	CITRATE FLOW / CALCIUM CHLORIDE FLOW	155 70	155 90	155 90	155 90	155 90		155 90	155 90	155 90	155 90	160 85	160 85	
	RN INITIALS	XH	JGC	JGC	HC	JN		HC	JGC	JN	JN	JN	JN	

TIME		1900	2000	2100	2200	2300	2400	0100	0200	0300	0400	0500	0600	12 hour total
1A	EFFLUENT (TOTAL OF ALL FLUIDS)	2082	2499	2278	2224	2024	2552	2196	2550	2621	2416	2522	2226	
1B	PRE ILTER DILUTION SOLUTION (INTERNAL PUMP)	416	498	457	444	414	496	432	501	487	485	467	467	
1C	DIALYSATE INFUSED	833	1000	908	887	809	999	890	996	975	965	944	902	
1D	PATIENT FLUID REMOVAL (UF)	831	1001	923	883	801	1005	878	1006	967	966	945	907	
2	ADDITIONAL OUTPUT (URINE, NG, CHEST TUBES, DRAINS)	7	5	7	30	40	15	17	5	35	30	15	15	
3 (1D+2)	TOTAL OUTPUT	838	1006	930	913	841	1020	895	1011	1002	996	960	922	11,334
4A	ALL INTAKE: IV, PO, etc. EXCEPT REPLACEMENT	468	373	343	328	328	378	318	340	315	320	320	372	4,203
4B	PRE FILTER DILUATION SOLUTION (EXTERNAL PUMP)	X	X	X	X	X	X	X	X	X	X	X	X	
4C	= 4A+B TOTAL INTAKE	468	373	343	328	328	378	318	340	315	320	320	372	4,203
5 (3-4C)	HOURLY FLUID BALANCE TOTAL	+370	-633	587	585	513	642	577	671	687	676	640	550	
6-MD ORDER	DESIRED OUTCOME (+ OR -)	-200	-200	-200	-200	-200	-200	-200	-200	-200	-200	-200	-200	-2400
7 (6-5)	PATIENT FLUID REPLACEMENT GIVEN	-570	-835	-787	785	713	842	777	-871	887	876	840	750	9531
8 (5+7)	ACTUAL NET FLUID BALANCE	-200	-200	-200	-200	-200	-200	-200	-200	-200	-200	-200	-200	-2400
	~~CVP PAWP MAP~~ SBP	CVP 20	21	23	21	21	21	22	21	23	21	21	22	
	ACCURA PRISMA BRAUN	PRISMA FLEX	FLEX	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	ACCESS / ACCESS PRESSURE / PA	0	-3	-24	-31	-34	-64	-52	-77	-67	-75	-57	-47	
	PREFILTER / FILTER PRESSURE / PBE	102	103	106	114	103	114	114	111	116	113	110	113	
	FILTRATE / EFFLUENT PRESSURE / PD2	-75	-12	-12	-27	-22	-31	-21	-29	-21	-26	-36	-29	
	RETURN / RETURN PRESSURE / PV	47	49	44	44	43	42	51	46	51	50	49	43	
	BLOOD FLOW / CONNECTIONS CHECK	100 ✓	100 ✓	100 ✓	100 ✓	100 ✓	100 ✓	100 ✓	100 ✓	100 ✓	100 ✓	100 ✓	100 ✓	
	IONIZED CALCIUM - PERIPHERAL	1.56				1.32			1.07					
	IONIZED CALCIUM - POST	0.30				0.28			0.26					
	CITRATE FLOW / CALCIUM CHLORIDE FLOW	160 85	160 75	160 75	160 75	160 75	160 75	160 65	160 75	160 70	160 70	160 70	160 70	
	RN INITIALS	JN	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK	

D6037(12-04)

+99

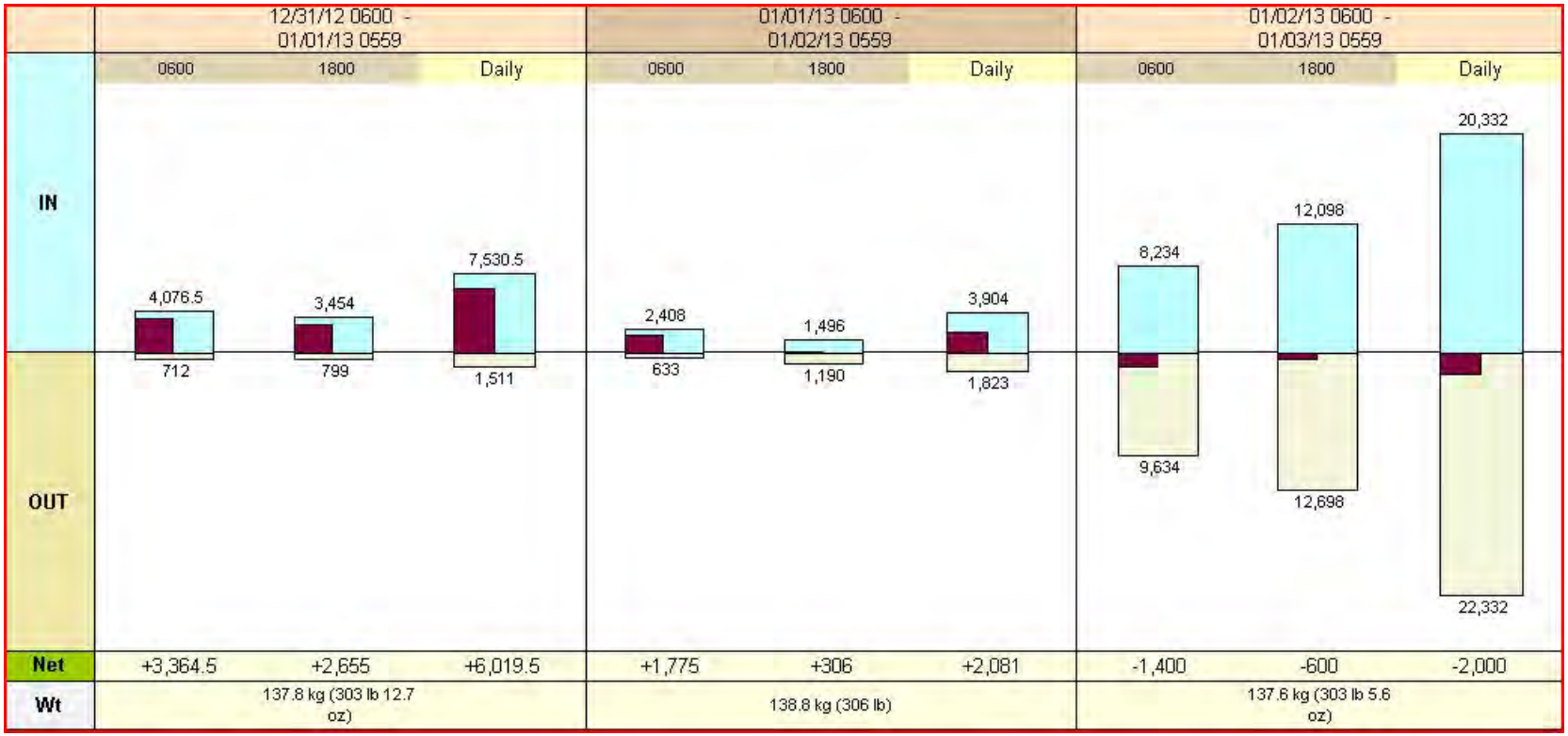
CRRT Flow sheets in EMR

24 Hrs 8 Hrs 4 Hrs 12 Hrs

Date:	02/05 0600 - 02/06 0559																																									
1 Hr:	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-00	00-01	01-02	02-03	03-04	04-05	05-06
Dialysis RN Checks																						
MD Report			No					Yes											No			
Prescription Verified w/ CRRT Ord...			Yes					Yes											Yes			
Treatment Type			CVVHDF					CVVH... *	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF
Status			Off					Contin...	*Continu...	Continu...	Continu...	Continu...	Continu...	Continu...	Continu...	Continu...	Continu...	Off	Restarted	Continu...	Continu...	Continu...
Off Status Reason			OR																			
Machine Type			Prismaflex...					Prismaflex...											Prismaflex...			
Machine Number			4					4											4			
Lines Reversed								No											Yes			
UF Clear								Yes											Yes			
Citrate Tubing Labeled								Yes											Yes			
Deaeration Chamber Level								Yes											Yes			
Blood Lines Warm								Yes											Yes			
Blood Warmer Temp								105.4 (...											104.2 (...			
CRRT Filter Number								7											8			
CRRT Filter Day								1											1			
Treatment																						
Treatment Type			CVVHDF					CVVH... *	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF	CVVHDF
Status			Off					Contin...	*Continu...	Continu...	Continu...	Continu...	Continu...	Continu...	Continu...	Continu...	Continu...	Off	Restarted	Continu...	Continu...	Continu...
Effluent								2387	2448	2686	2546	2636	2658	2857	2652	2832	2427		2700	2638	2594	2882
Dialysate								877	900	1000	944	977	984	986	984	963	892		999	976	964	993
Post Filter Rep.								176	181	199	189	198	198	198	193	197	178		200	194	193	199
Pre Blood Pump								438	458	4088	471	487	485	486	400	487	443		500	487	479	498
Intake																						
Intake								270	204	489	309	319	414	294	301	301	301		301	351	351	351
Output																						
Other Output								125	100	110	190	50	50	300	95	50	50		65	50	50	150
Total Output								1001	1002	1111	1132	1026	1031	1287	1080	1035	984		1066	1028	1028	1142
Goal/ Replace Calc																						
CRRT Goal Parameter								Constant	Constant	Constant	Constant	Constant	Constant	Constant	Constant	Constant	Constant		Constant	Constant	Constant	Constant
Hourly Goal								100	100	100	100	100	100	100	100	100	100		100	100	100	100
Hourly Balance								-722	-798	-622	-923	-707	-917	-993	-779	-734	-883		-765	-677	-677	-791
Calculated Rep Fld								822	898	722	923	807	717	1093	879	834	783		865	777	777	891
Replacement Fld																						
NaCl 0.9%								823 ml			923 ml	807 ml	717 ml				783 ml		865 ml	777 ml	777 ml	891 ml
NaCL 0.45% Dicarb 75meq									898 ml	722 ml				1093 ml	879 ml	834 ml						
Hourly Net Balance																						
Total Intake (2 + Replacement)								1101	1102	1211	1232	1126	1131	1387	1180	1135	1084		1166	1129	1128	1242
Total Output (3A + 3B)								1001	1002	1111	1132	1026	1031	1287	1080	1035	984		1066	1028	1028	1142
Hourly Net Balance (J-K)								100	100	100	100	100	100	100	100	100	100		100	100	100	100
CRRT Filter Labs																						
Ionized Calcium - Peripheral									1.01			1.03								1.1		
Ionized Calcium - Post Filter									+0.28			0.31								0.27		
Ca / Citrate Rates																						
Citrate Volume - ml								140	140	130	130	135	135	135	135	135	135		135	135	135	135
Volume (ml) Calcium Chloride								80 ml	80 ml	85 ml	85 ml	90 ml	90 ml	90 ml	95 ml	95 ml	95 ml		95 ml	95 ml	95 ml	95 ml
BUN/Cr Monitoring																						
BUN - Pre-Filter																				21		
Cr - Pre-Filter																				1.19		
BUN - Post-Filter																				16		
Cr - Post-Filter																				0.85		
BUN - UF																				22		
Cr - UF																				1.2		
Sieving Coefficient (%)																				104.76		
Machine																						
Machine								Prismaflex	Prismaflex	Prismaflex	Prismaflex	Prismaflex	Prismaflex	Prismaflex	Prismaflex	Prismaflex	Prismaflex		Prismaflex	Prismaflex	Prismaflex	Prismaflex
Access Pres								-10	-20	-29	-24	-17	-19	-14	-12	-13	-13		-10	-10	-10	-10
Filter Pres								82	94	92	87	88	88	93	88	102	115		75	83	87	90
Effluent Pres								20	6	-3	-25	-40	-89	-89	-90	-130	-140		-8	-32	-51	-70
Return Pres								33	42	39	33	34	27	33	31	33	32		25	31	37	35
Blood Pump Rate								100	100	100	100	100	100	100	100	100	100		100	100	100	100
I/O Totals																						
Total In							**5760**	**1101**	**1322**	**1211**	**1232**	**1126**	**1131**	**1387**	**1180**	**1135**	**1084**	**71**	**1166**	**1128**	**1128**	**1242**
Cumulative In	1050	1050	1050	1050	1050	6800	6800	7901	9233	10434	11666	12792	13923	15310	16490	17625	18709	18780	19946	21074	22182	23424
Total Out						**5500**		**1001**	**1222**	**1111**	**1132**	**1026**	**1031**	**1287**	**1080**	**1035**	**984**	**50**	**1066**	**1028**	**1028**	**1142**
Cumulative Out	950	950	950	950	950	6450	6450	7451	8673	9784	10916	11942	12973	14260	15340	16375	17359	17409	18475	19503	20531	21673
I/O Net						**4250**		**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**21**	**100**	**100**	**100**	**100**
I/O Cumulative Net	100	100	100	100	100	4350	4350	4450	4550	4650	4750	4850	4950	5050	5150	5250	5350	5371	5471	5571	5671	5771

Date:	02/06 0600 - 02/07 0559																							
1 Hr:	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-00	00-01	01-02	02-03	03-04
Dialysis RN Checks																						
MD Report				No									No	No								
Prescription Verified w/ CRRT Ord...				Yes									Yes	Yes								
Treatment Type	CVVHDF	CVVHDF	CVVHDF	CVVH... *	CVVHDF	CVVHDF	CVVHDF	CVVHDF					CVVHDF	CVVHDF	CVVHDF							
Status	Continu...	Continu...	Continu...	Contin...	*Continu...	Continu...	Continu...	Continu...					Continu...	Restarted	Restarted							
Off Status Reason														Other								
Machine Type				Prismaflex...									Prismaflex...	Prismaflex...								
Machine Number				4									4	4								
Lines Reversed				No									No	No								
UF Clear				Yes									Yes	Yes								
Citrate Tubing Labeled				Yes									Yes	Yes								
Deaeration Chamber Level				Yes									Yes	Yes								
Blood Lines Warm				Yes									Yes	Yes								
Blood Warmer Temp				105.4 (...									104.4 (...	104.5 (...								
CRRT Filter Number				9									9	10								
CRRT Filter Day				1									1	1								
Treatment																						
Treatment Type	CVVHDF	CVVHDF	CVVHDF	CVVH... *	CVVHDF	CVVHDF	CVVHDF	CVVHDF					CVVHDF	CVVHDF	CVVHDF							
Status	Continu...	Continu...	Continu...	Contin...	*Continu...	Continu...	Continu...	Continu...					Continu...	Restarted	Restarted							
Effluent	2836	2846	2239	2801	2576	2538	2700	2462					2689		2700							
Dialysate	978	978	830	995	920	938	1022	900					996		1001							
Post Filter Rep.	197	195	165	195	188	187	199	188					199		198							
Pre Blood Pump	486	488	418	477	472	476	501	463					498		500							
Intake																						
Intake	356	611	511	311	611	301	606	606					306		291							
Output																						
Other Output	45	90	60	45	60	75	40	50					260		50							
Total Output	1020	1075	886	979	1028	1010	1010	983					1256		1051							
Goal/ Replace Calc																						
CRRT Goal Parameter	Constant	Constant	Constant	Constant	Constant	Constant	Constant	Constant					Constant		Constant							
Hourly Goal	100	100	0	0	0	0	0	0					0		0							
Hourly Balance	-664	-464	-375	-668	-417	-709	-412	-377					-950		-760							
Calculated Rep Fld	764	564	375	668	417	709	412	377					950		760							
Replacement Fld																						
NaCl 0.9%	764 ml	564 ml	375 ml	668 ml									950 ml		760 ml							
NaCL 0.45% Dicarb 75meq					417 ml	709 ml	412 ml	377 ml														
Hourly Net Balance																						
Total Intake (2 + Replacement)	1120	1175	886	979	1028	1010	1010	983					1256		1051							
Total Output (3A + 3B)	1020	1075	886	979	1028	1010	1018	983					1256		1051							
Hourly Net Balance (J-K)	100	100	0	0	0	0	0	0					0		0							
CRRT Filter Labs																						
Ionized Calcium - Peripheral			1.11											1.27								
Ionized Calcium - Post Filter			0.31											+0.28								
Ca / Citrate Rates																						
Citrate Volume - ml	140	140	140	140	140	140	140	140					140	0	130							
Volume (ml) Calcium Chloride	95 ml	95 ml	95 ml	95 ml	95 ml	90 ml	90 ml	90 ml					90 ml	0 ml	85 ml							
BUN/Cr Monitoring																						
BUN - Pre-Filter																						
Cr - Pre-Filter																						
BUN - Post-Filter																						
Cr - Post-Filter																						
BUN - UF																						
Cr - UF																						
Sieving Coefficient (%)																						
Machine																						
Machine	Prismaflex	Prismaflex	Prismaflex	Prismaflex	*Prismaflex	Prismaflex	Prismaflex	Prismaflex					Prismaflex	Prismaflex	Prismaflex							
Access Pres	-17	-14	-14	-19*		-19	-15	-19					-14	-24	-54							
Filter Pres	92	91	97	122*		133	138	141					75	83	81							
Effluent Pres	-123	-168	-140	-155*		-153	-166	-201					19	-37	-39							
Return Pres	29	30	28	36*		38	38	38					32	34	30							
Blood Pump Rate	100	100	100	100*		100	100	100					100	100	100							
I/O Totals																						
Total In	**1120**	**1175**	**886**	**979**	**1028**	**1010**	**1018**	**983**	**71**	**126**	**76**	**126**	**1256**	**76**	**1051**							
Cumulative In	24544	25719	26605	27584	28612	29622	30640	31623	31694	31820	31896	32022	33278	33354	34405							
Total Out	**1020**	**1075**	**886**	**979**	**1028**	**1010**	**1018**	**983**	**79**	**85**	**445**	**88**	**1256**	**79**	**1051**							
Cumulative Out	22693	23768	24654	25633	26661	27671	28689	29672	29751	29836	30281	30369	31625	31704	32755							
I/O Net	**100**	**100**	**0**	**0**	**0**	**0**	**0**	**0**	**-8**	**41**	**-369**	**46**	**0**	**-3**	**0**							
I/O Cumulative Net	5851	5951	6951	6951	6951	6951	6951	6951	6943	6984	6615	6661	6661	6658	6658							

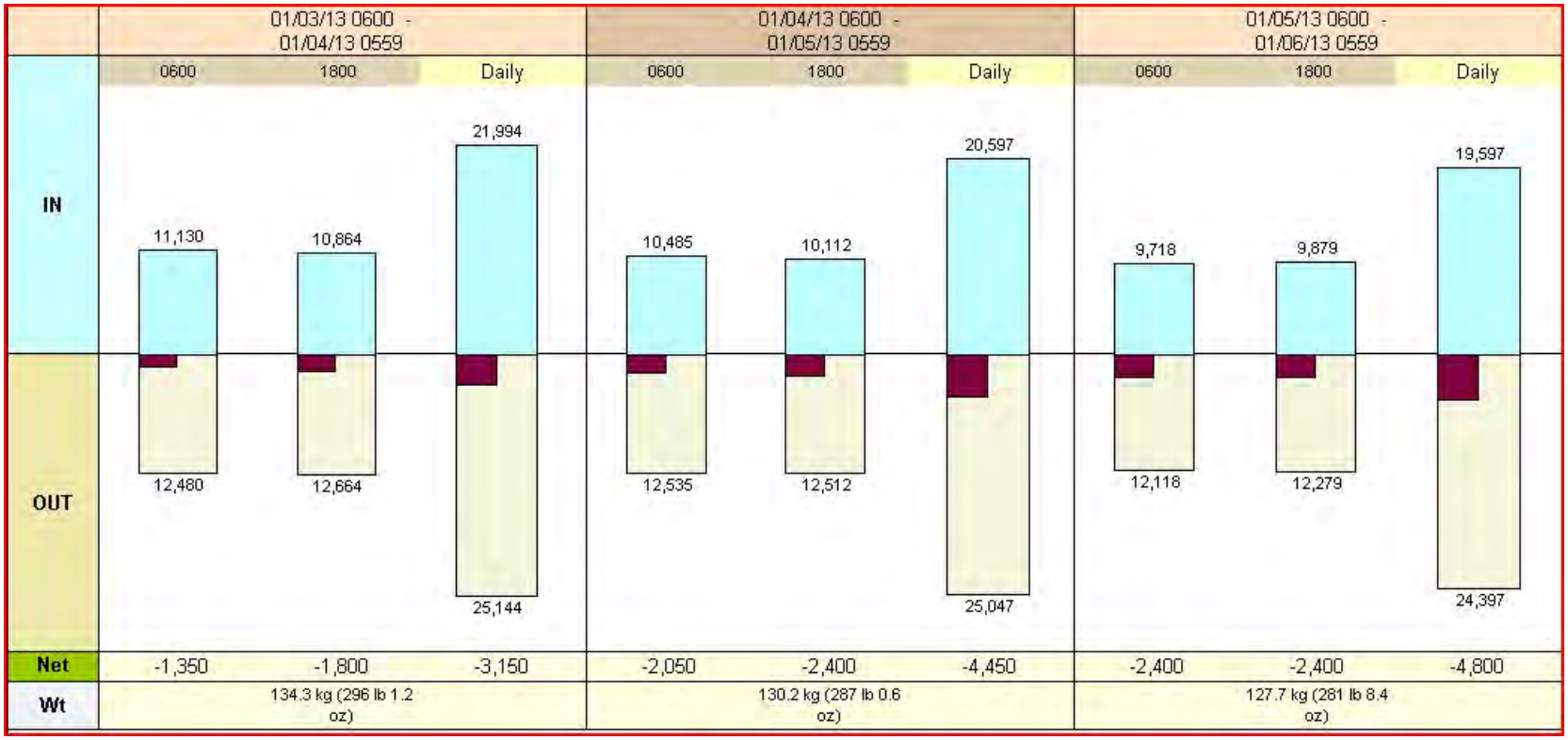
Case Study


12/31/12 0600 - 01/01/13 0559
01/01/13 0600 - 01/02/13 0559
01/02/13 0600 - 01/03/13 0559
0600
1800
Daily
IN
OUT
4,076.5
712
3,454
799
7,530.5
1,511
2,408
633
1,496
1,190
3,904
1,823
8,234
9,634
12,098
12,698
20,332
22,332
Net
+3,364.5
+2,655
+6,019.5
+1,775
+306
+2,081
-1,400
-600
-2,000
Wt
137.8 kg (303 lb 12.7 oz)
138.8 kg (306 lb)
137.6 kg (303 lb 5.6 oz)

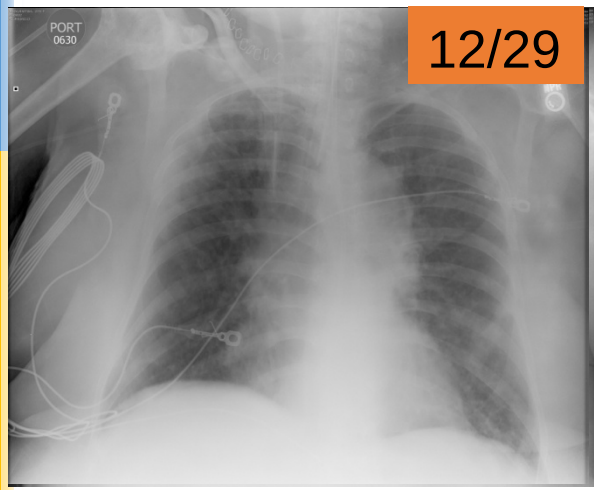
Case Study


Graph (12/29/12 0130 - 2/11/13 0215)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0130
12/29/12
2051
1/6/13
Creatinine

Case Study


01/03/13 0600 - 01/04/13 0559
01/04/13 0600 - 01/05/13 0559
01/05/13 0600 - 01/06/13 0559
0600
1800
Daily
IN
OUT
11,130
10,864
21,994
12,480
12,664
25,144
10,485
10,112
20,597
12,535
12,512
25,047
9,718
9,879
19,597
12,118
12,279
24,397
Net
-1,350
-1,800
-3,150
-2,050
-2,400
-4,450
-2,400
-2,400
-4,800
Wt
134.3 kg (296 lb 1.2 oz)
130.2 kg (287 lb 0.6 oz)
127.7 kg (281 lb 8.4 oz)

Case Study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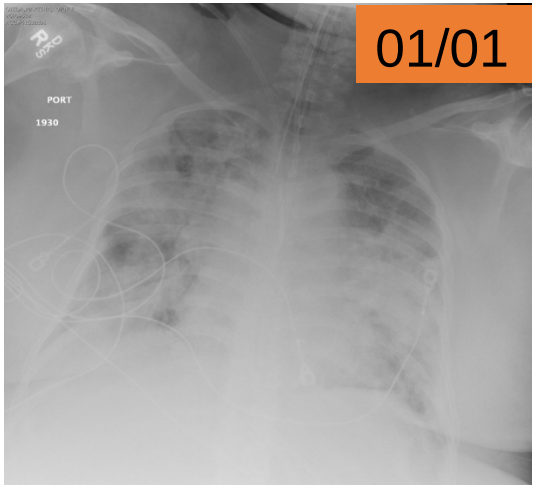
0630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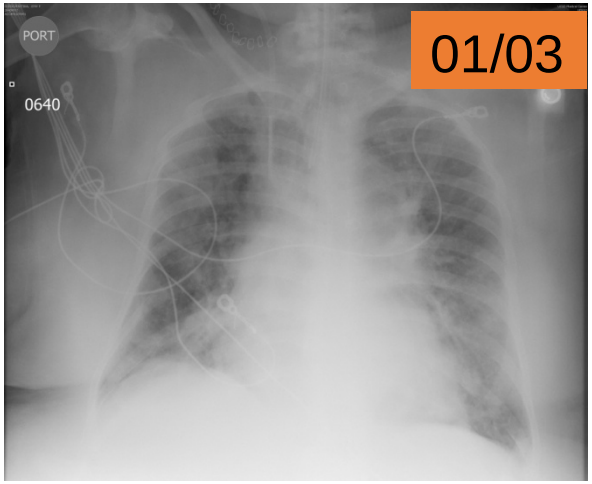
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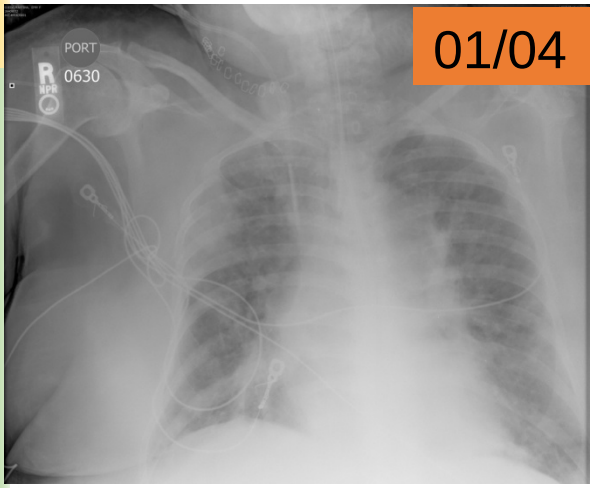
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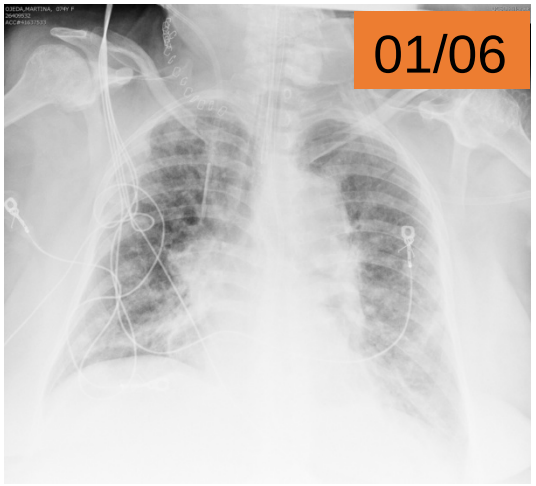
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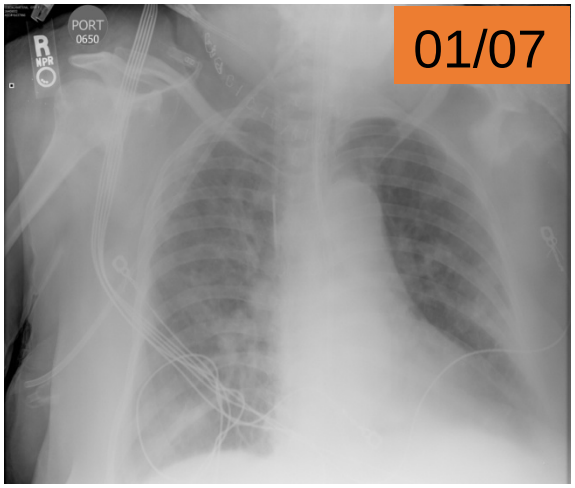
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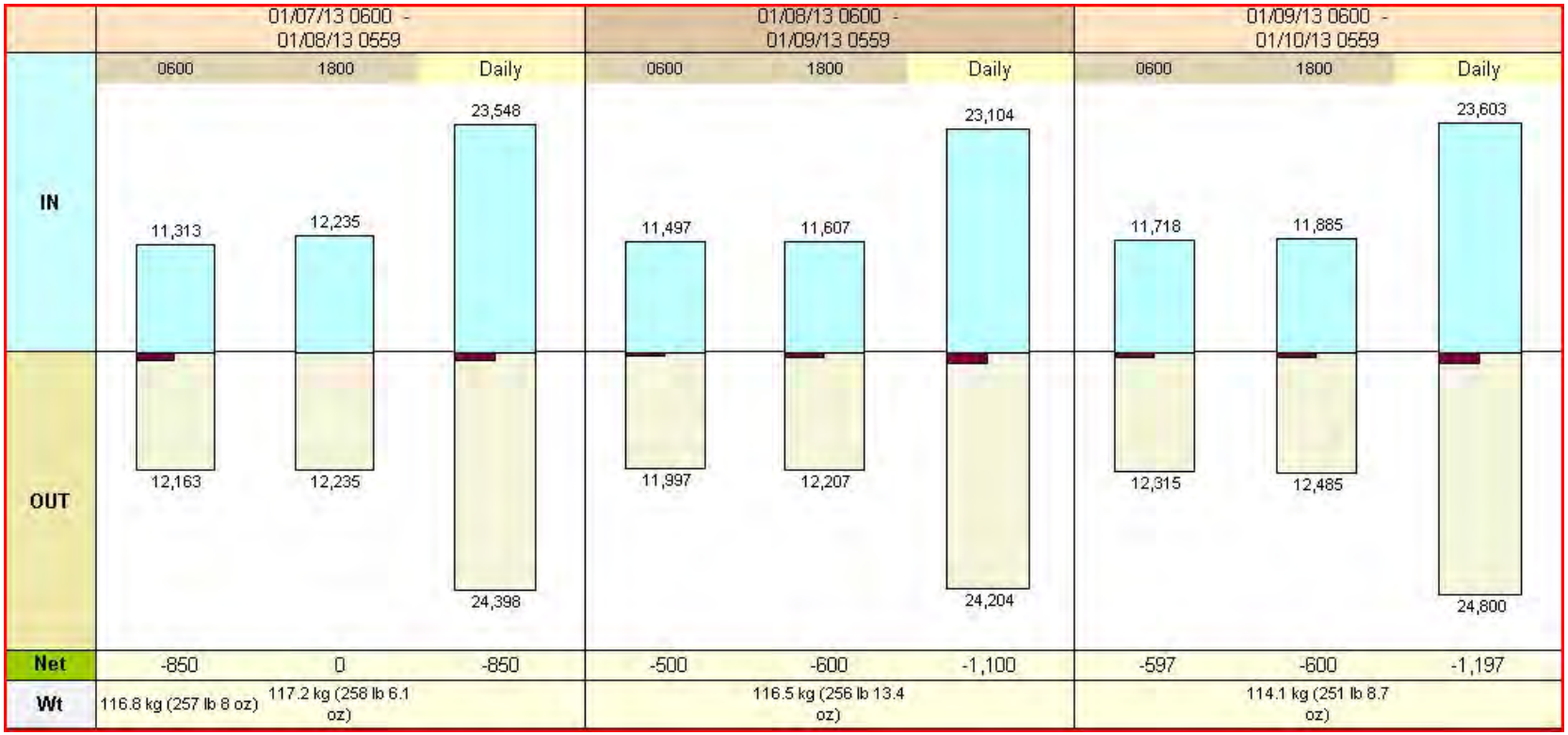
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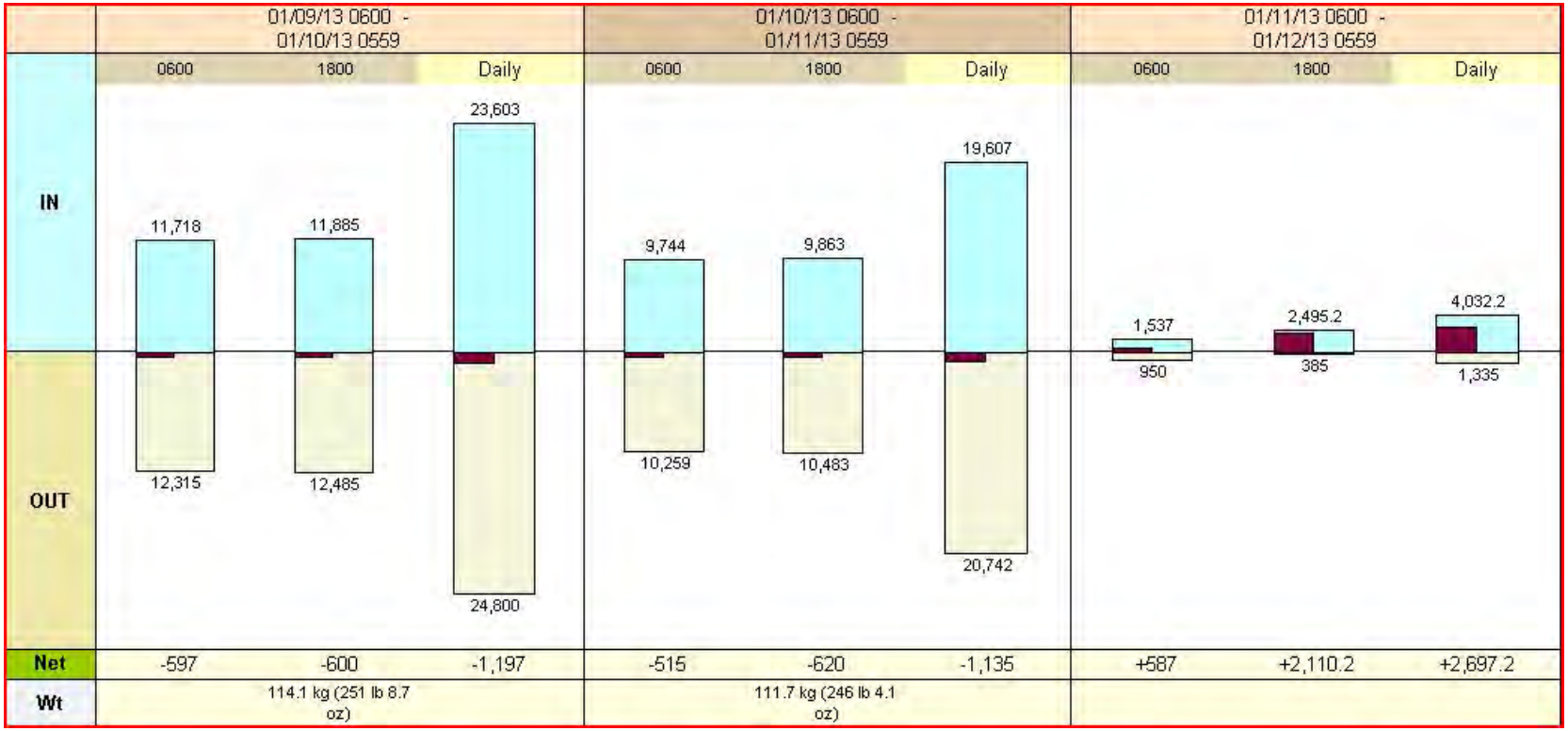
01/09/13 0600 - 01/10/13 0559
0600
1800
Daily
IN
OUT
11,313
12,235
23,548
12,163
12,235
24,398
11,497
11,607
23,104
11,997
12,207
24,204
11,718
11,885
23,603
12,315
12,485
24,800
Net
-850
0
-850
-500
-600
-1,100
-597
-600
-1,197
Wt
116.8 kg (257 lb 8 oz)
117.2 kg (258 lb 6.1 oz)
116.5 kg (256 lb 13.4 oz)
114.1 kg (251 lb 8.7 oz)

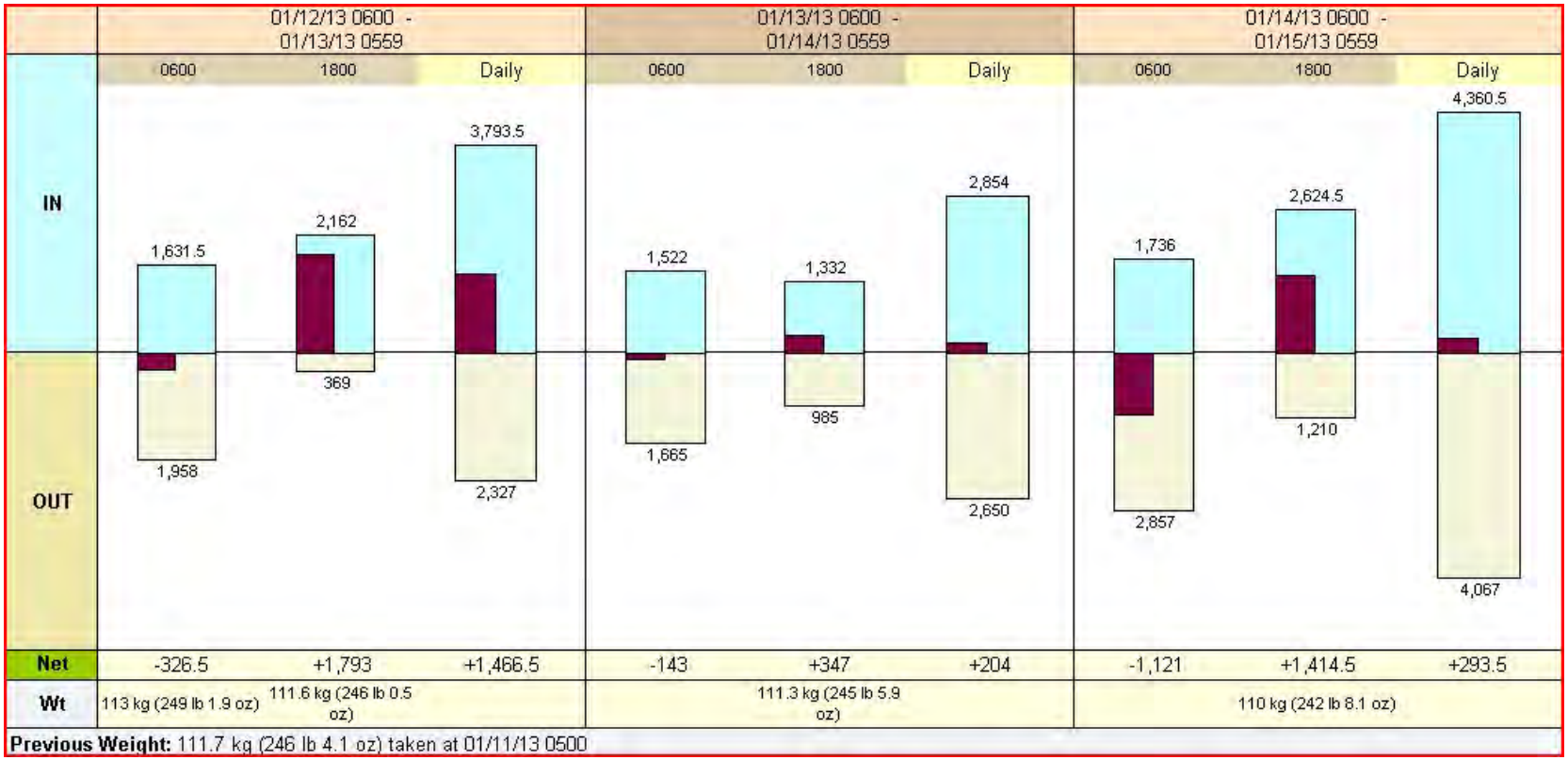
Case Study


01/09/13 0600 - 01/10/13 0559
01/10/13 0600 - 01/11/13 0559
01/11/13 0600 - 01/12/13 0559
0600
1800
Daily
IN
OUT
11,718
11,885
23,603
12,315
12,485
24,800
9,744
9,863
19,607
10,259
10,483
20,742
1,537
2,495.2
4,032.2
950
385
1,335
Net
-597
-600
-1,197
-515
-620
-1,135
+587
+2,110.2
+2,697.2
Wt
114.1 kg (251 lb 8.7 oz)
111.7 kg (246 lb 4.1 oz)

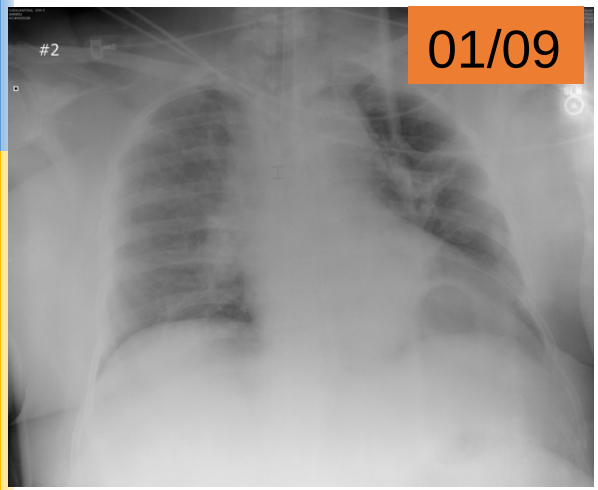
Case Study


Graph (12/29/12 0130 - 2/11/13 0215)
Creatinine
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0130
12/29/12
2051
1/6/13
1612
1/15/13
1133
1/24/13
0654
2/2/13

Case Study


01/12/13 0600 - 01/13/13 0559
01/13/13 0600 - 01/14/13 0559
01/14/13 0600 - 01/15/13 0559
0600
1800
Daily
IN
OUT
1,631.5
1,958
2,162
369
3,793.5
2,327
1,522
1,665
1,332
985
2,854
2,650
1,736
2,857
2,624.5
1,210
4,360.5
4,067
Net
-326.5
+1,793
+1,466.5
-143
+347
+204
-1,121
+1,414.5
+293.5
Wt
113 kg (249 lb 1.9 oz)
111.6 kg (246 lb 0.5 oz)
111.3 kg (245 lb 5.9 oz)
110 kg (242 lb 8.1 oz)
Previous Weight: 111.7 kg (246 lb 4.1 oz) taken at 01/11/13 0500

Case Study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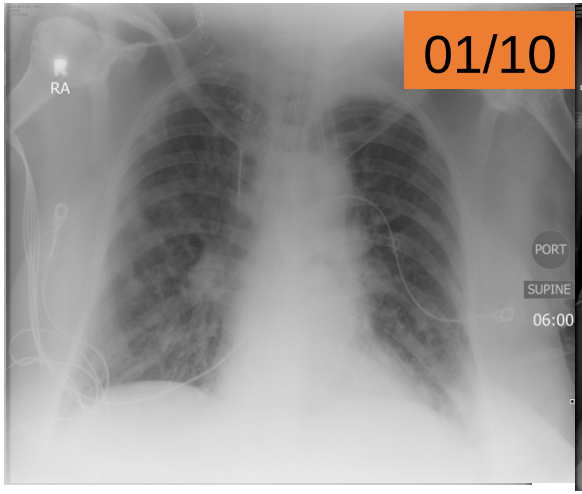
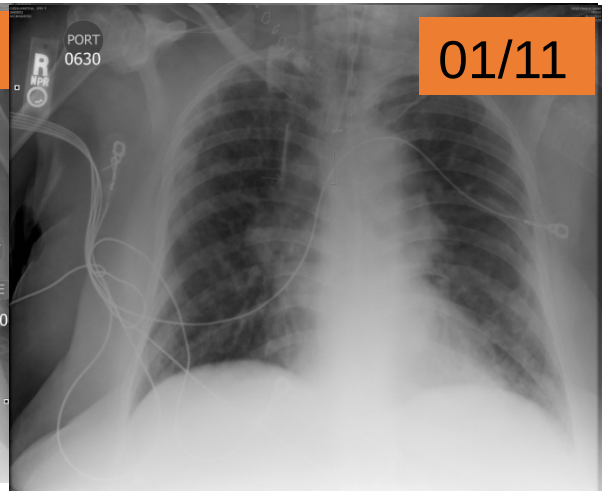
#2


01/10
RA
PORT
SUPINE
06:00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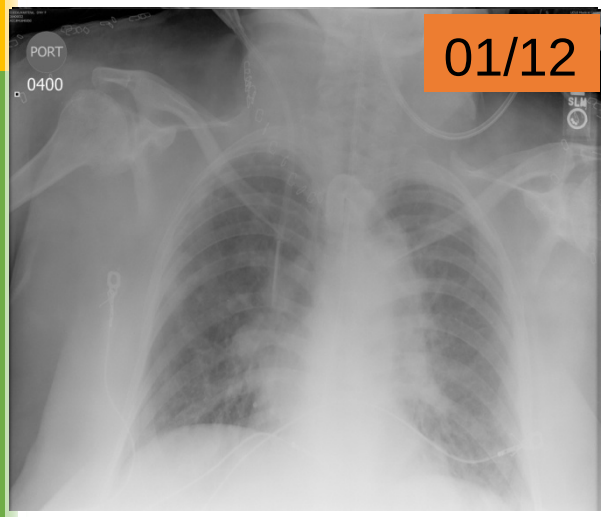
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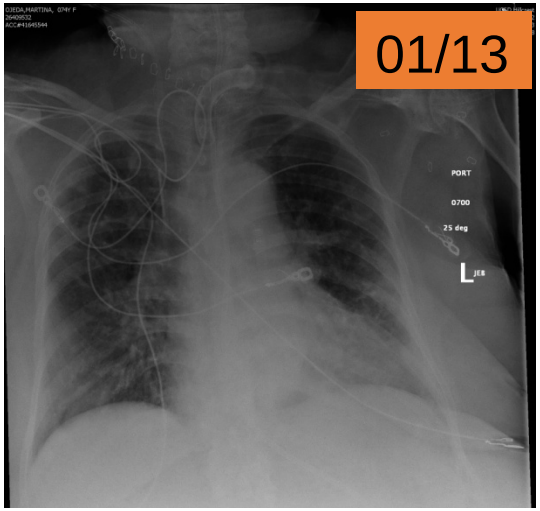
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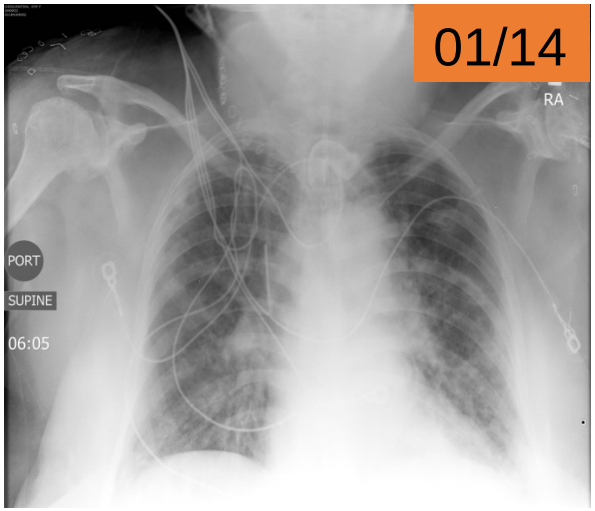
0700
25 deg


01/14
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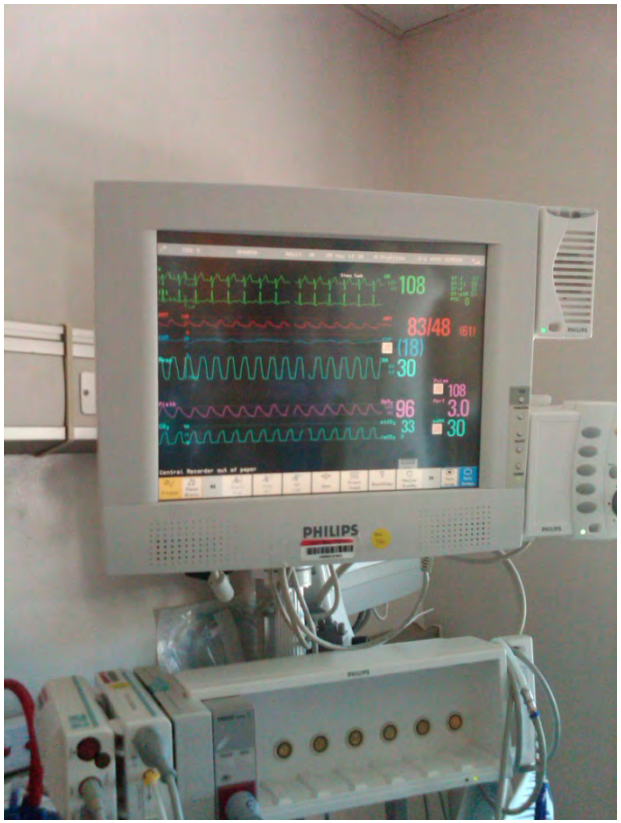
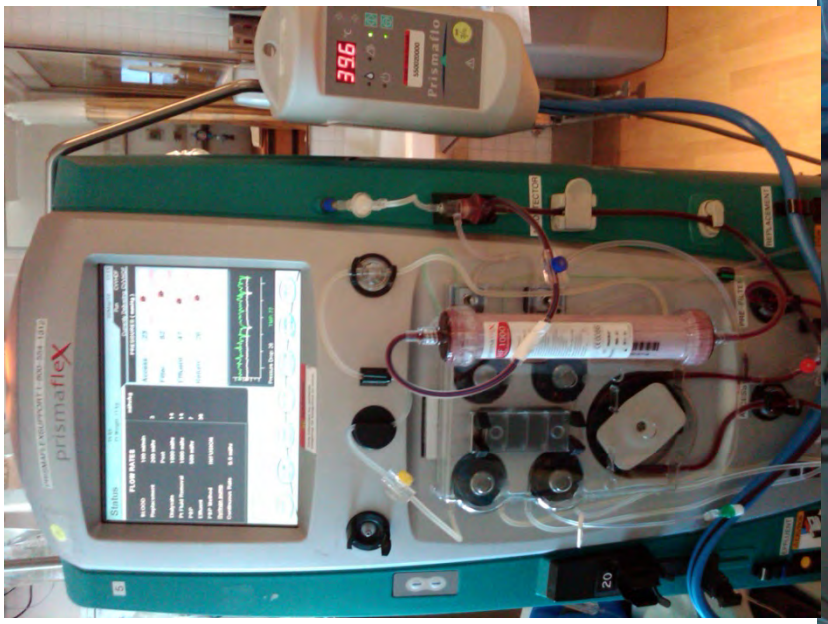
Achieving Fluid Balance with CRRT

- Targeted Fluid management
  - Hemodynamic parameters
  - TBW and compartmental distribution parameters

SVV to Guide Fluid Management in CRRT



SVV to Guide Fluid Management in CRRT



Practical Issues with Fluid Management for CRRT

- Maintaining the Circuit
- Enabling solute clearances and achieving homeostasis
- Volume control and balance with fluid regulation
- Monitoring for and preventing complications

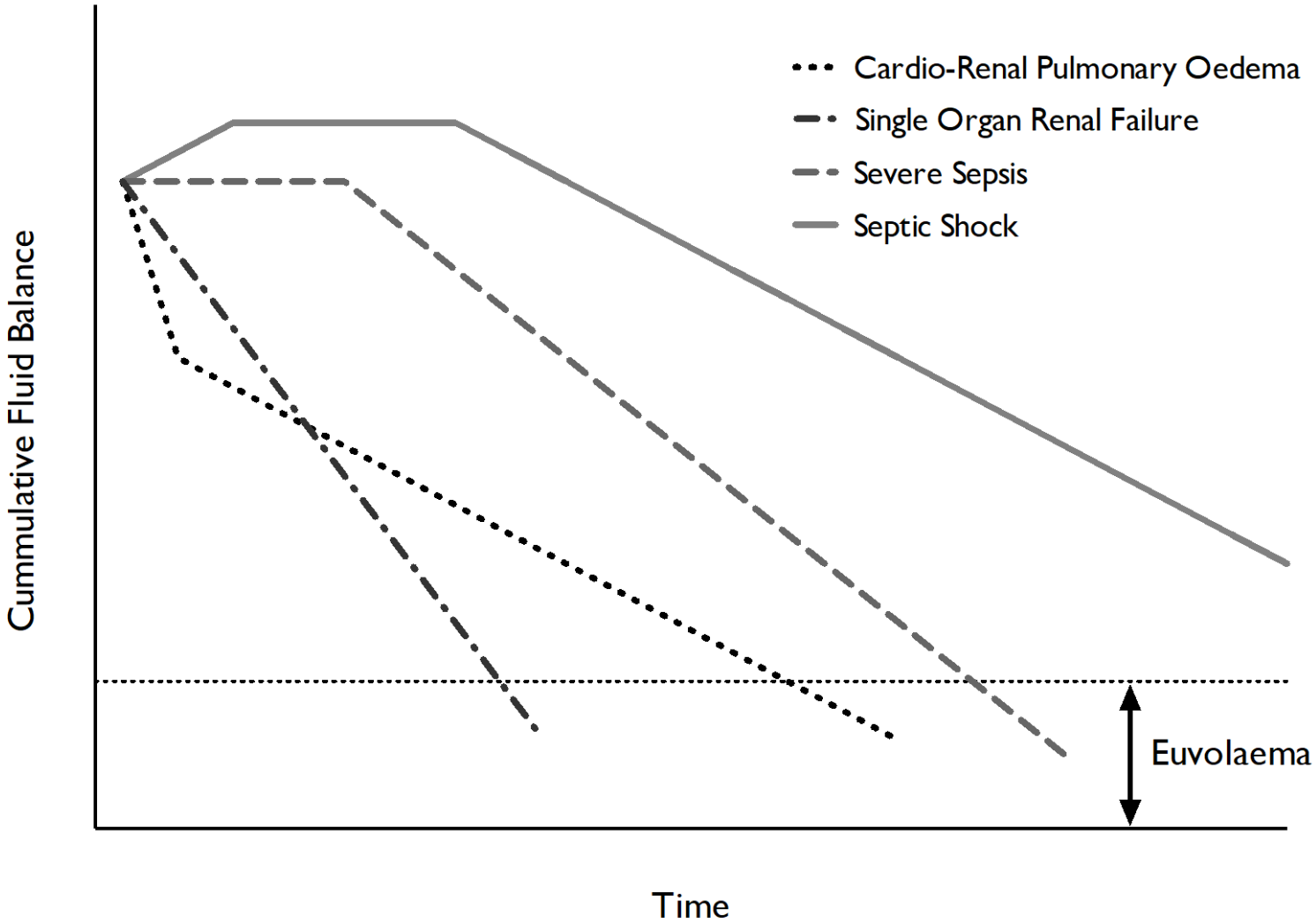
CRRT Fluid Management Preventing Complications

- Prescription
  - **Modality**
  - **Blood flow rate**
  - **Filtration fraction**
  - **Fluid Balance Goal**
  - **Quantity to be Removed**
  - **Fluid removal rate**
  - **Substitution fluid**
  - ***Pre-dilution (Rate/hr))***
  - ***Post-Dilution (Rate/hr)***
  - **Dialysate rate**
  - **Fluid composition**
  - ***Substitution***
  - ***Dialysate***
  - **Warmer Temperature**
  - **External Pumps**
  - **In Circuit**

- Parameter
  - Inappropriate Goal
  - Amount of fluid removed
  - Rate of fluid removal

- Complication
  - Volume depletion
  - Fluid Overload
  - Hypotension
  - Hemodynamic instability

Differing clinical circumstances demand different rates of fluid removal



Rosner MH, Ostermann M, Murugan R, Prowle JR, Ronco C, Kellum JA, Mythen MG, Shaw AD, Group AXI, (2014) Indications and management of mechanical fluid removal in critical illness.
British journal of anaesthesia 113: 764-771

CRRT: communication is crucial

Doctor

- Inserts line
- Prescribes anticoagulant
- Prescribes modality, dose and fluid removal

Nurse

- Sets up & provides therapy
- Adjusts settings to achieve goals
- Measures and adjusts anticoagulant
- Makes chart entries
- Monitors for complications and responds appropriately

Fluid Management with CRRT What can we do?

Need	Strategy
Utilize dialysis for fluid regulation instead of fluid removal only	CRRT can continuously adjust fluid balance in critically ill patients
Late utilization when fluid redistribution into large compartments has already occurred	Initiate RRT at earlier time points to prevent fluid accumulation
Develop guidelines based on demonstrated best practices	Protocol based standardization of approach
Recognize importance of fluid retention on outcome	Implement calculators to track fluid accumulation and fluid overload

Achieving Fluid balance: The role of CRRT Summary

Current Knowledge

- Fluid therapy is common in patients at risk for AKI
- Prolonged fluid resuscitation leads to edema of kidney and other organs and can contribute to AKI
- Fluid overload > 10% body weight is associated with increased morbidity and mortality

Intervention Strategies

- An early transition to a fluid restrictive strategy may be beneficial in patients with AKI
- Fluid removal in patients with or at risk for AKI should be implemented with appropriate monitoring
- CRRT allows continuous fluid regulation to support patients

Areas for Research

- Is fluid accumulation a mediator of adverse outcomes from AKI
- Role of endothelial glycocalyx
- Biomarkers/ novel fluid assessment tools to allow safer fluid management
- At what level of volume retention should therapy be started?
- Can dialysis provide a safety net in pts with compromised renal function

Extra slides

Overview

- CRRT Fluid composition and electrolyte and acid base Mx
- Fluid Overload and its treatment with CRRT
- Precision CRRT and individualization of treatment
- Monitoring and complications during CRRT
- Quality metrics and benchmarking

Maximum Ultrafiltration Rate (in L/hr) Achieved at 20% (30%) Filtration Fraction in Post-Dilution CVVH

	QB = 150 mL/min	QB = 200 mL/min
Hct = 0.30	1.3 (1.9)	1.7(2.5)
Hct = 0.40	1.1 (1.6)	1.4 (2.2)

Blood flow requirements for CRRT to maintain filtration fraction at 25%

FF(%) = (UFR x 100) / Qp

Qp = BFR x (1-Hct)

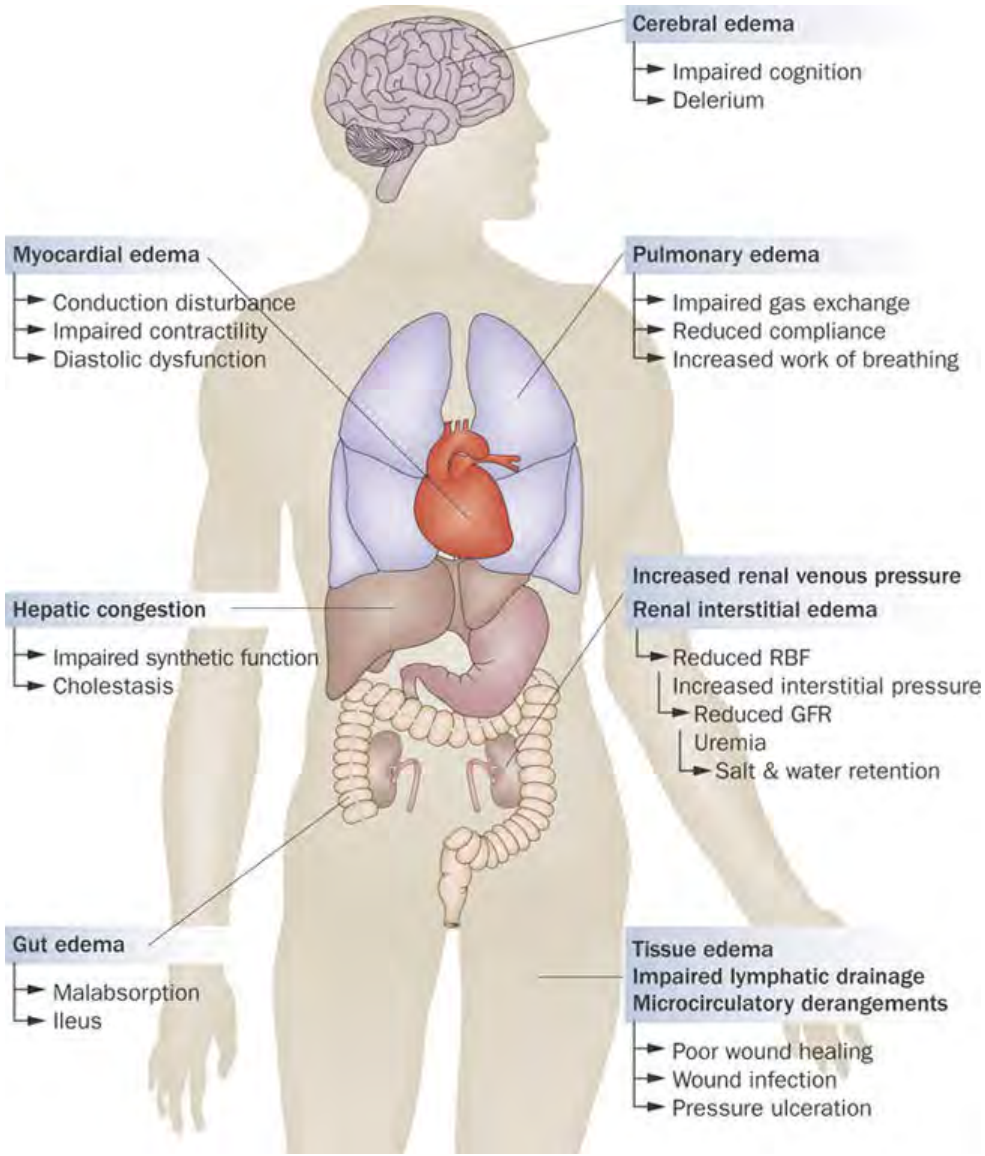
When BFR = 100ml/min, Hct=0.3 Qp=70ml/min

If FF >30%, promote filter clotting

If FF=30%, BFR of 100 ml/min, UF = 21ml/min

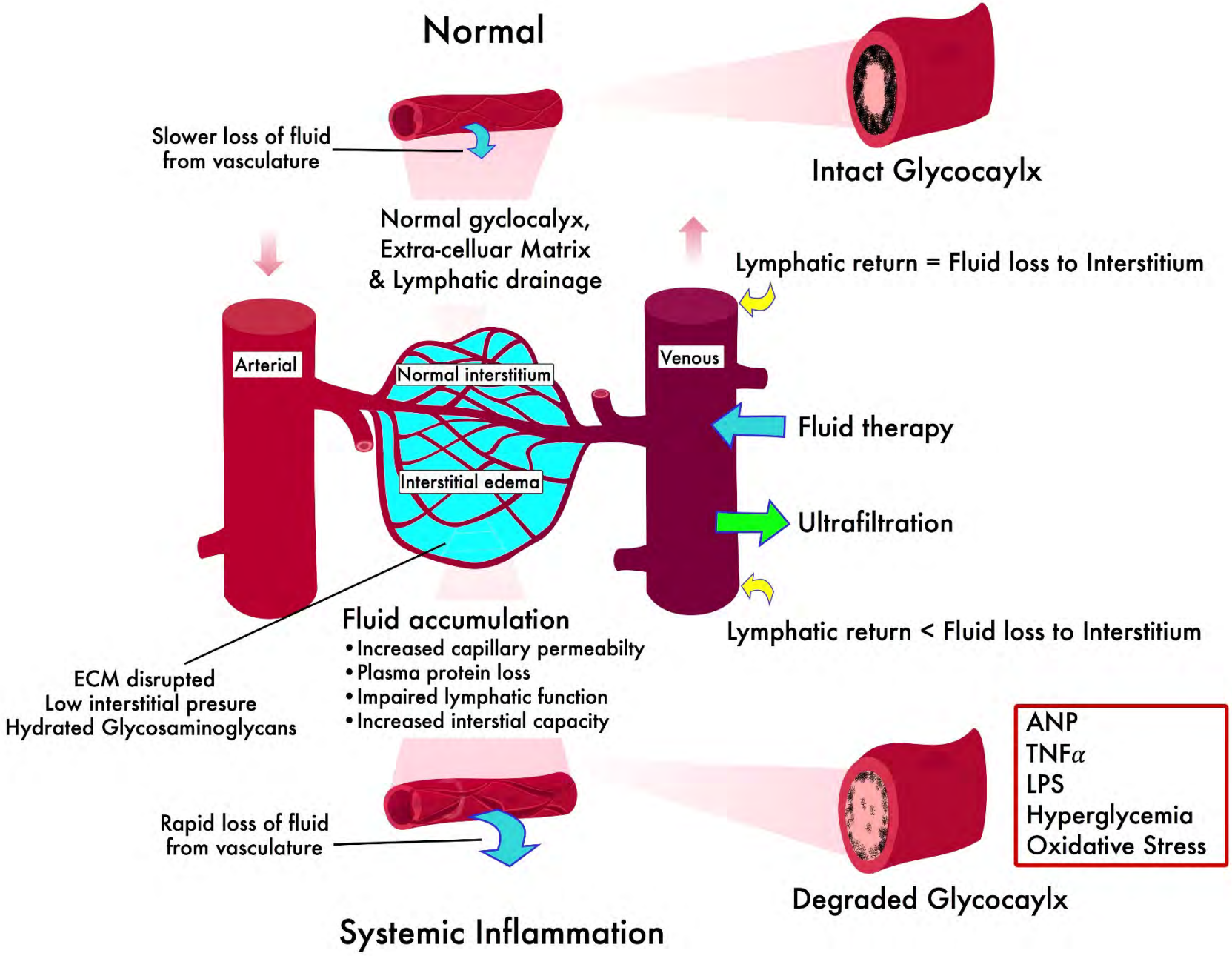
Ultrafiltration rate (mls/hr)	Minimum Qb/min
1500	100
2000	130
2500	155
3000	200
4000	265

Pathological effects of fluid overload in organ systems



Prowle *et al* Fluid balance and acute kidney injury. *Nat Rev Nephrol,* 6**:** 107-115, 2010

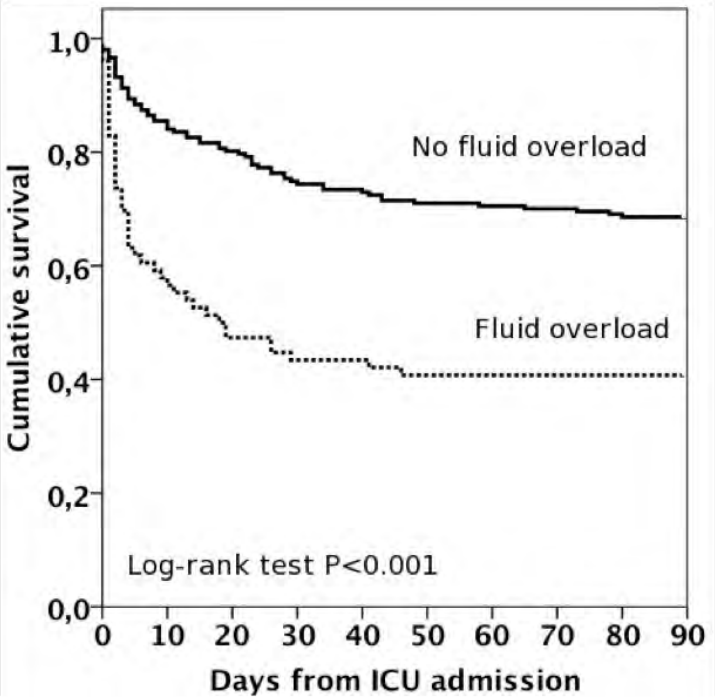
Fluid Overload. O'Connor ME, Prowle JR.
Crit Care Clin. 2015 Oct;31(4):803-21



Fluid overload is associated with an increased risk for 90-day mortality in critically ill patients with renal replacement therapy: data from the prospective FINNAKI study

Vaara *et al. Critical Care* 2012, **16**:R197
http://ccforum.com/content/16/5/R197

Suvi T Vaara[1*], Anna-Maija Korhonen[1], Kirsi-Maija Kaukonen[1], Sara Nisula[1], Outi Inkinen[2], Sanna Hoppu[3], Jouko J Laurila[4], Leena Mildh[1], Matti Reinikainen[5], Vesa Lund[6], Ilkka Parviainen[7] and Ville Pettilä[1,8], for The FINNAKI study group



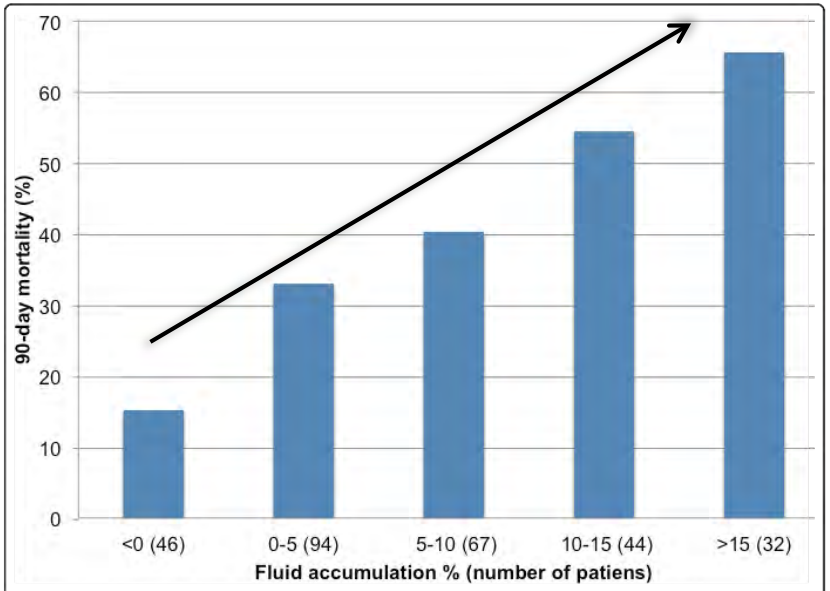
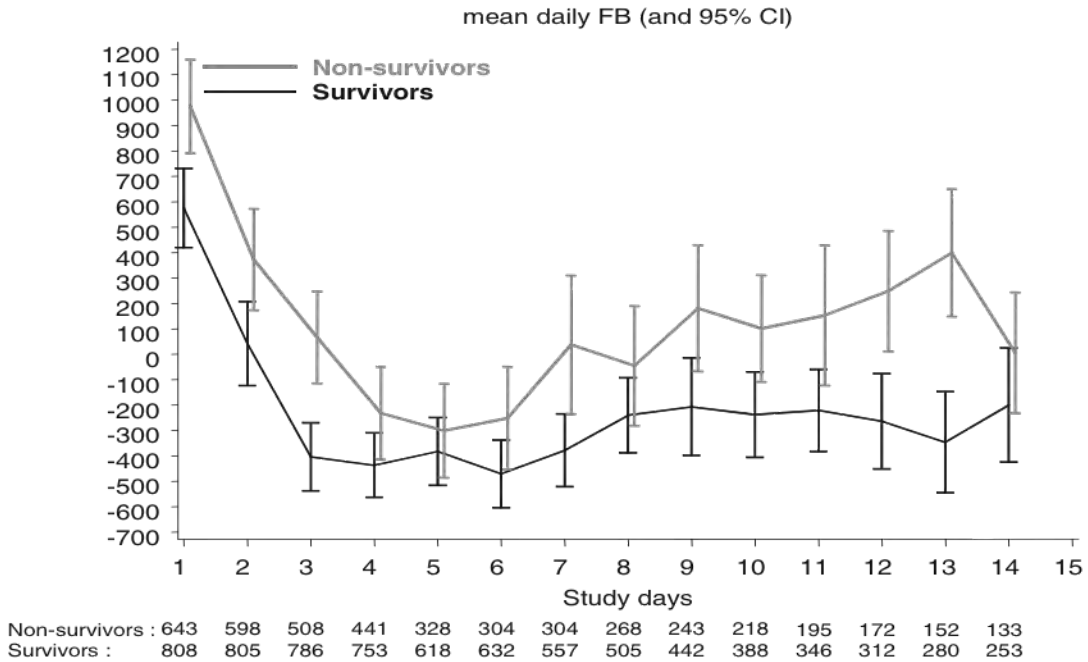
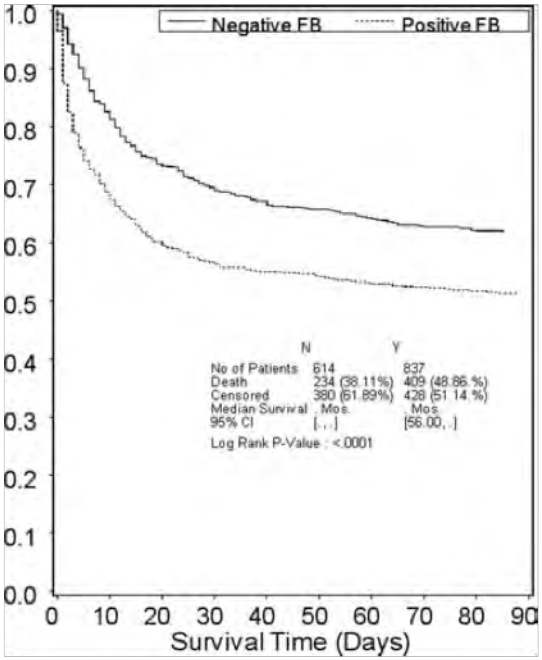


Figure 3 Ninety-day mortality according to the percentage of fluid accumulation prior to renal replacement therapy initiation.
*Comparison across groups $P < 0.001$.

Resolution of Fluid Overload with RRT and Survival



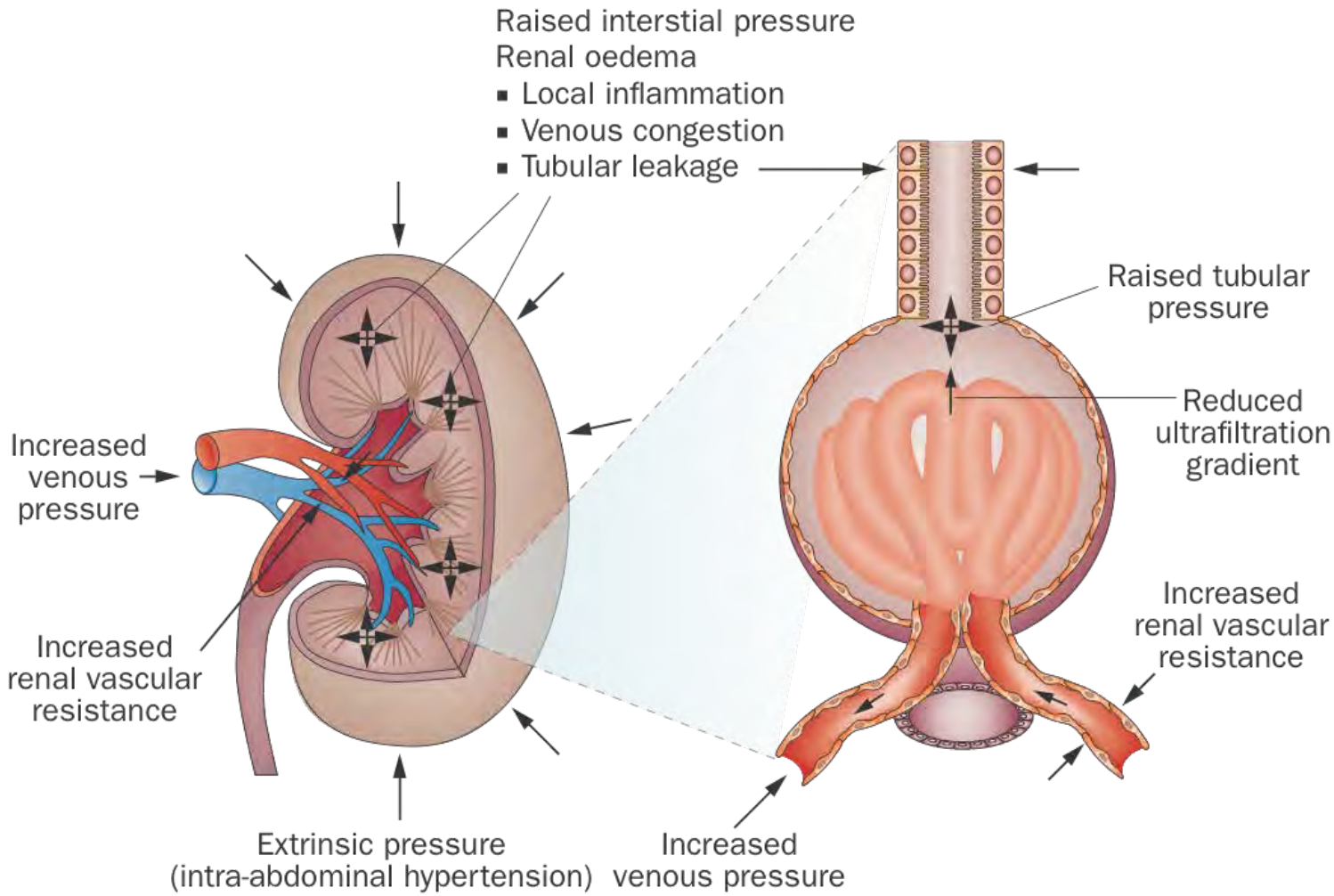


An observational study fluid balance and patient outcomes in the randomized evaluation of normal vs. augmented level of replacement therapy trial*

The RENAL Replacement Therapy Study Investigators

Crit Care Med 2012 Vol. 40, No. 6

Fluid overload and interstitial oedema may contribute to the maintenance of AKI



Prowle, Kirwan, Bellomo *Nat Rev Nephrol* 2013

Questions

- To what extent is fluid overload a marker of illness severity (measure of unknown confounders) and to what extent an avoidable cause of iatrogenic morbidity and mortality?
- Does fluid overload itself contribute to the initiation or persistence of AKI?
  - Can we treat this?
- Does the avoidance or treatment of fluid overload with RRT (or diuretics) improve outcomes?
  - If so when?

VOLUME 2 | ISSUE 1 | MARCH 2012
http://www.kidney-international.org

Section 5: Dialysis Interventions for Treatment of AKI

5.1.1: Initiate RRT emergently when life-threatening changes in fluid, electrolyte, and acid-base balance exist. (*Not Graded*)

5.1.2: Consider the broader clinical context, the presence of conditions that can be modified with RRT, and trends of laboratory tests—rather than single BUN and creatinine thresholds alone—when making the decision to start RRT. (*Not Graded*)

5.2.1: Discontinue RRT when it is no longer required, either because intrinsic kidney function has recovered to the point that it is adequate to meet patient needs, or because RRT is no longer consistent with the goals of care. (*Not Graded*)

5.2.2: We suggest not using diuretics to enhance kidney function recovery, or to reduce the duration or frequency of RRT. (*2B*)

5.8.2: Provide RRT to achieve the goals of electrolyte, acid-base, solute, and fluid balance that will meet the patient's needs. (*Not Graded*)

5.8.3: We recommend delivering a Kt/V of 3.9 per week when using intermittent or extended RRT in AKI. (*1A*)

5.8.4: We recommend delivering an effluent volume of 20–25 ml/kg/h for CRRT in AKI *(1A)*. This will usually require a higher prescription of effluent volume. (*Not Graded*)

Systematic approach to fluid management in critical illness

- Resuscitate appropriately early
- Avoid need for removal as much as possible by then appropriately limiting intake
- Ultrafiltration as a component in an active fluid management strategy

Goals in mechanical fluid removal

- Resolve fluid overload and its adverse effects on organ function
- Allow necessary interventions
  - Nutrition
  - Drugs
- Prevent overt hypovolaemia
  - Secondary ischaemic injury
  - Adverse neuroendocrine responses
- Avoid complications of RRT

Quantification of fluid overload

- Clinical Examination
- Serial Weights
- Cumulative Fluid Balance

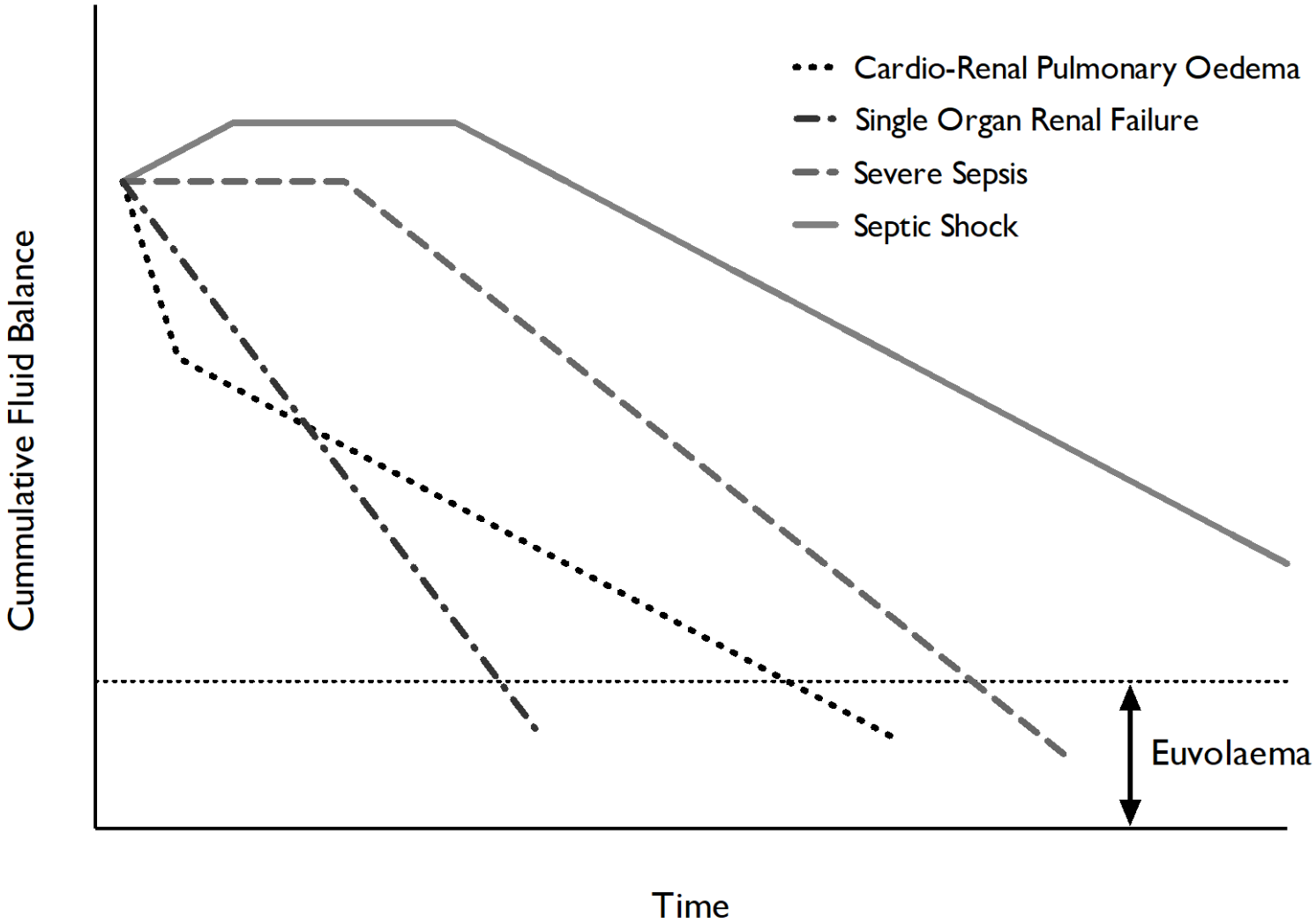
- Chest X-ray
- Oxygenation indices
- Lung Ultrasound
- Intra-abdominal pressure

- Echocardiography
- Bioimpedance body composition analysis

Decisions in prescribing ultrafiltration

- Goal (Long term)
  - Extent of fluid overload
  - “Euvolaemia”
- Tolerance of fluid removal (Short term)
  - Rate of removal
  - Rate of vascular refilling
  - Ability of circulation to tolerate transient reduction in intravascular volume

Differing clinical circumstances demand different rates of fluid removal



Rosner MH, Ostermann M, Murugan R, Prowle JR, Ronco C, Kellum JA, Mythen MG, Shaw AD, Group AXI, (2014) Indications and management of mechanical fluid removal in critical illness.
British journal of anaesthesia 113: 764-771

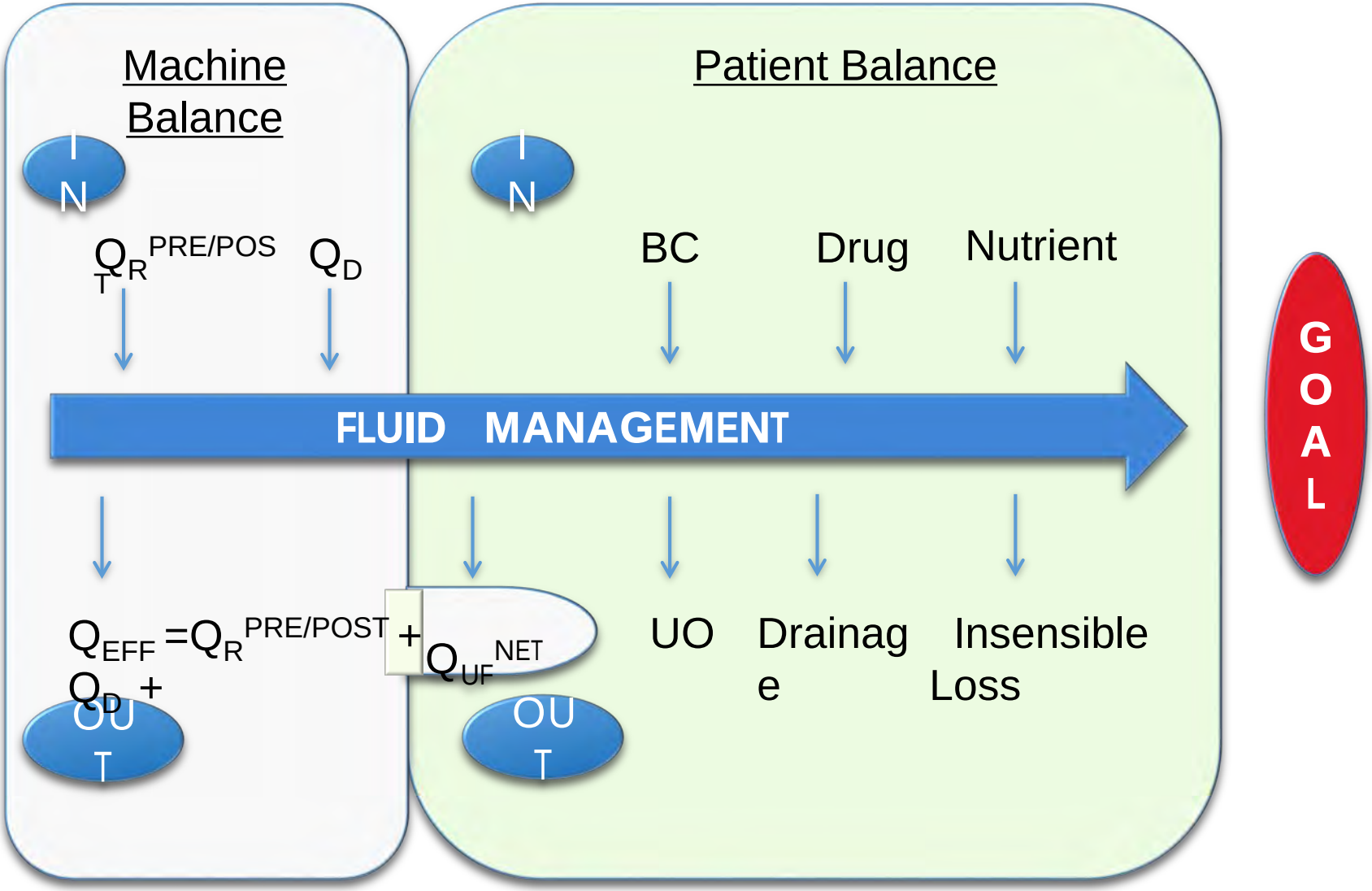
Approaches to Fluid Balance with CRRT Fluid Regulation

Table 3. Techniques for fluid balance in CRRT

Variable	Common	Alternate
Intake	Variable	Variable
Non-CRRT output	Variable	Variable
Ultrafiltration rate	Variable to achieve fluid balance	Fixed to achieve target effluent volume
Substitution fluid rate	Fixed = or < UFR	Varies to achieve negative, zero, or positive fluid balance
Fluid balance	Achieved by varying UF rate	Fluid balance is achieved by adjusting amount of substitution fluid
Key difference	Output is varied to accommodate changes in intake and fluid balance goals	Output is fixed to achieve desired solute clearance and allow flexibility in accommodating varying intake
Advantages		
Patient factors	Similar to strategy for fluid removal in intermittent dialysis	Keeps solute clearance constant. Allows for variation in intake. Individualizes prescription
CRRT factors	Fluid balance calculations can be deferred to longer intervals (e.g., every 8–12 hours)	Therapy parameters dissociate clearance requirements from fluid balance. Reduces interactions with CRRT pump to adjust UF rates. Simplifies regimen for caregiver. First step to utilizing CRRT for fluid regulation
Disadvantages		
Patient factors	Assumes patient in static state. Mimics ESRD prescription. Intake may fluctuate. Fluid boluses not accounted for. Over- or undershoot common. Solute clearances fluctuate, particularly if dependent on convection	Requires hourly calculations for amount of replacement fluid to be given. Potential for fluid imbalances if a balance sheet is not used
CRRT factors	Requires frequent interactions with CRRT pump to adjust UF rates. Underutilizes CRRT for fluid removal only	May require use of an external pump to achieve fluid regulation

Mehta, Kidney Int 2005

Approaches to Fluid Balance with CRRT Fluid Regulation



CRRT : Operating Characteristics

Fluid removal vs Fluid regulation

	Fluid removal	Fluid regulation
UF Rate	To meet anticipated needs	Greater than anticipated needs
Fluid Manangement	Adjust UFR	Adjust amount of replacement fluid
Fluid Balance	Zero or negative balance	Positive, negative or zero balance
Volume removed	Based on physician estimate	Driven by patient characteristics
Application	Easy, similar to IHD	Requires specific tools and training

Principles of Fluid Management in CRRT

Ultrafiltrate

- UF is used to remove fluid and UF rate can be controlled
- UF removes fluid with composition close to plasma water
- Solutes removed to varying degrees depending upon membrane characteristic

Replacement

- Replacement fluid may be used to replace varying amounts of the fluid removed
- Composition of the replacement fluid can be varied

CRRT Fluid Balance

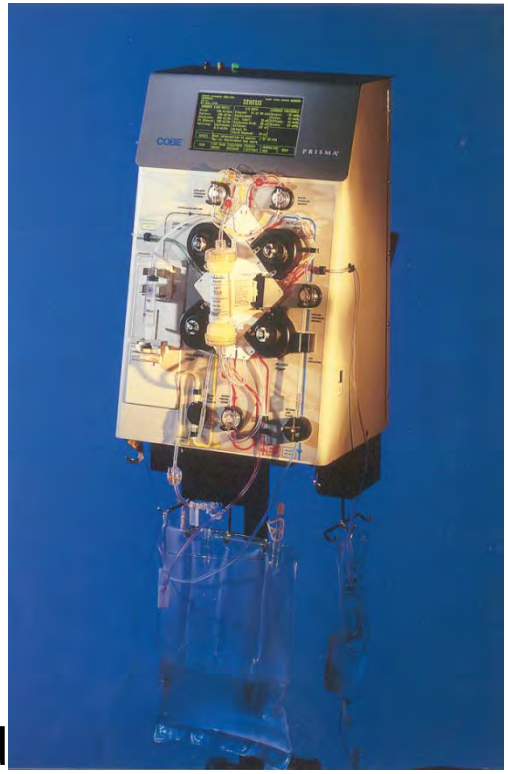
- Fluid balance for the CRRT device is computed as the difference between UF removed and replacement fluid given for any given period of time.

Patient Fluid Balance

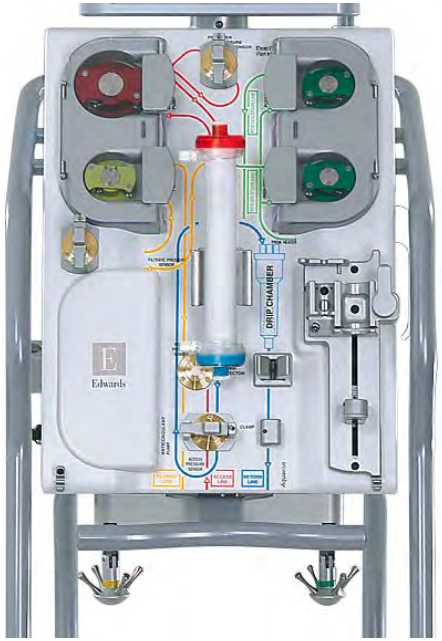
- Depends on the difference between all intakes and outputs including CRRT for any given period of time.

Principles For Fluid Management With Continuous Dialysis

- Fluid is removed by ultrafiltration governed by transmembrane pressure
- Volume of fluid removed is precisely regulated by *Gravimetric* scales outside machine (Prisma, Prismaflex, Aquarius, B. Braun) or *Volumetric* balancing chamber inside machine (NxStage)
- Rate of fluid removal dictated by prescription and operational characteristics
- Maximum fluid removal rate per hour dictated by machine limits (2-12 L/hr)
- Fluid replacement is required



Fluid Control Units on CRRT Machines



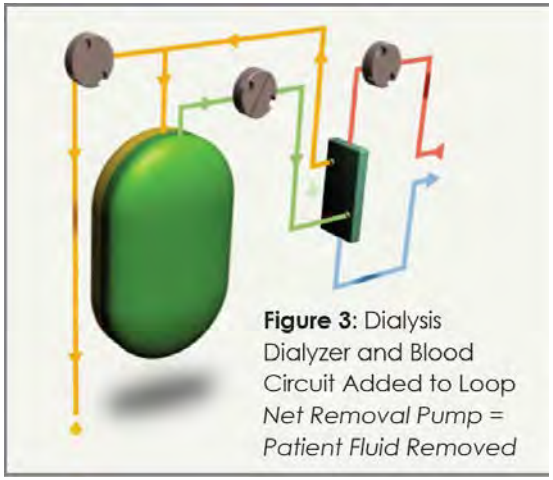


Figure 3: Dialysis Dialyzer and Blood Circuit Added to Loop
Net Removal Pump = Patient Fluid Removed