Peritoneal Dialysis Prescription and Adequacy Monitoring

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Disclosures

No financial disclosures relevant to this talk

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Some slides previously borrowed/modified from Dr. Christine Sethna

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Overview

- Physiology of the peritoneal membrane
- Clinical factors that impact peritoneal dialysis (PD) prescription in the pediatric population
- Role of dialysis adequacy to monitor the effectiveness of peritoneal dialysis

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Why Peritoneal Dialysis?

Advantages

- Vascular access not required
- Improved fluid balance; less antihypertensive medications
- Fewer dietary restrictions
- Relatively safe and simple
- Allows for regular school attendance
- Better growth
- Better for infants
- Less travel to dialysis unit

Disadvantages

- Risk of infection (peritonitis, exit site and tunnel infections)
- Hernias
- Labor intensive; increased caregiver burden
  - Risk of non-adherence
- Decreased appetite
- Body image disturbance

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Contraindications to PD

ABSOLUTE

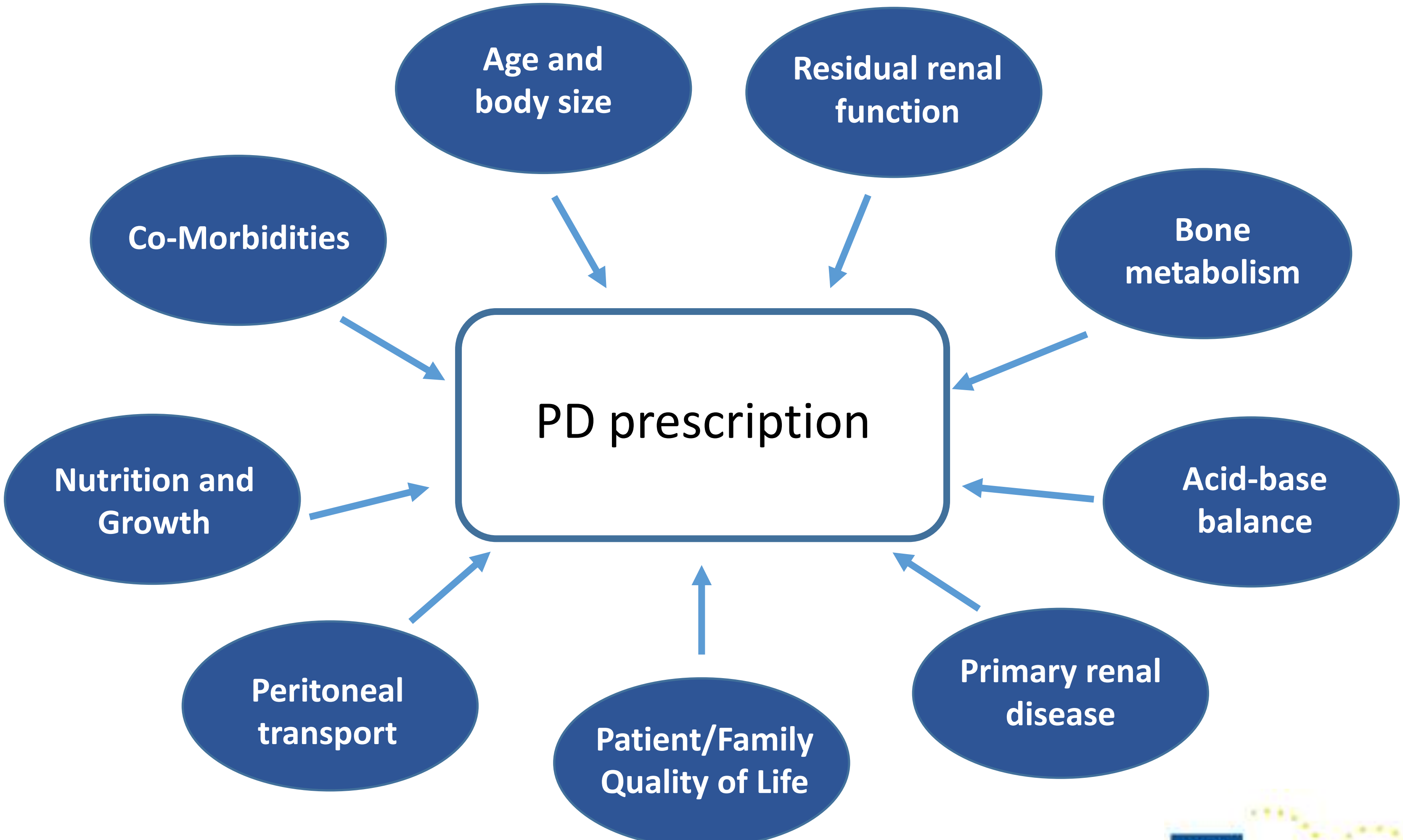
- Omphalocele
- Gastroschisis
- Bladder Exstrophy
- Diaphragmatic hernia
- Obliterated peritoneal cavity
- Peritoneal membrane failure

RELATIVE

- Impending abdominal surgery
- Impending (<6months) living-donor kidney transplantation
- Lack of appropriate caregiver for home therapy; lack of appropriate home environment

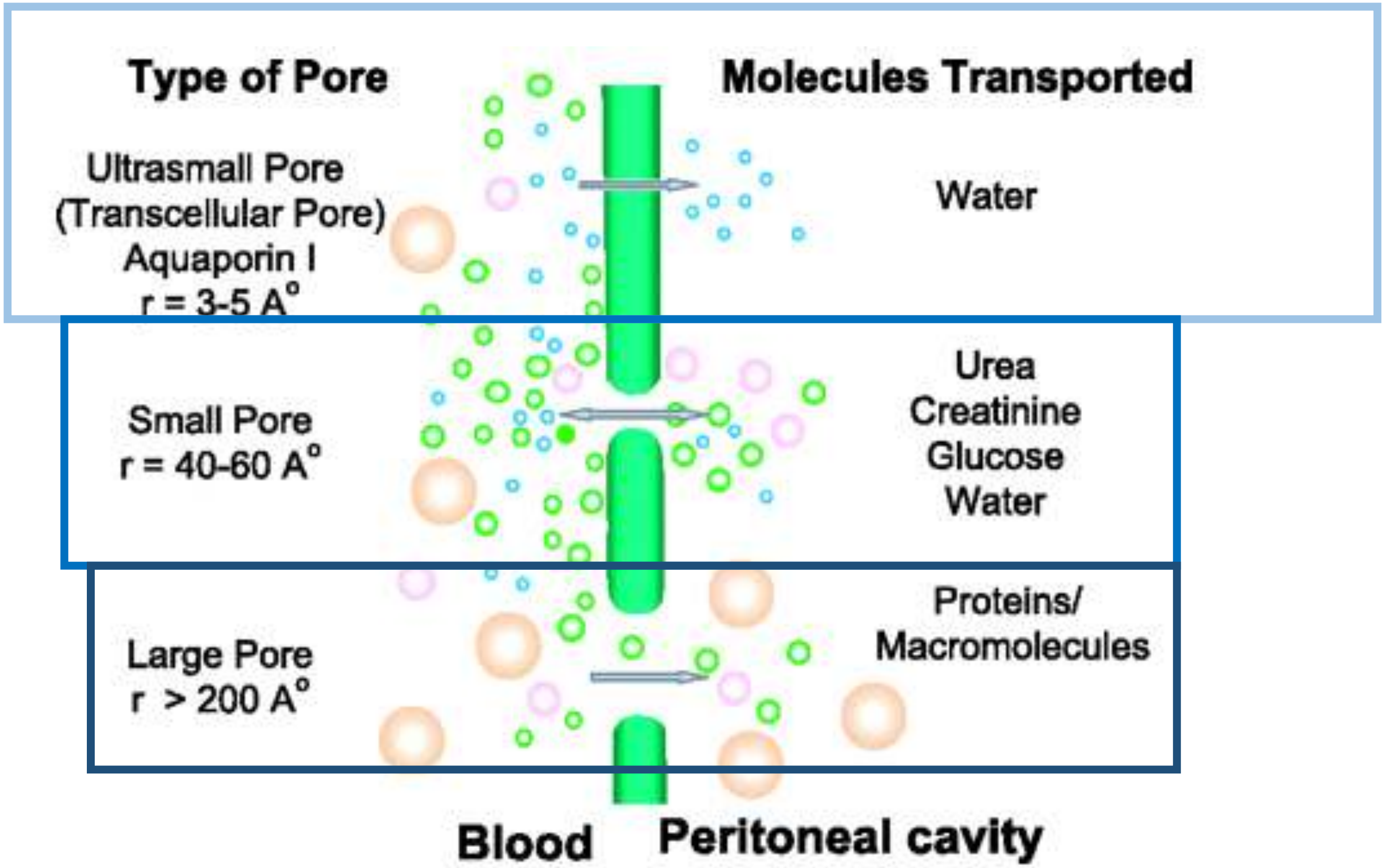
NKF KDOQI Guidelines 2006

PD Prescription



Pediatr Nephrol. 2009 Aug;24(8):1453-64.

Physiology of Peritoneal Membrane



The Journal of the American Board of Family Medicine July 2006, 19 (4) 380-389;

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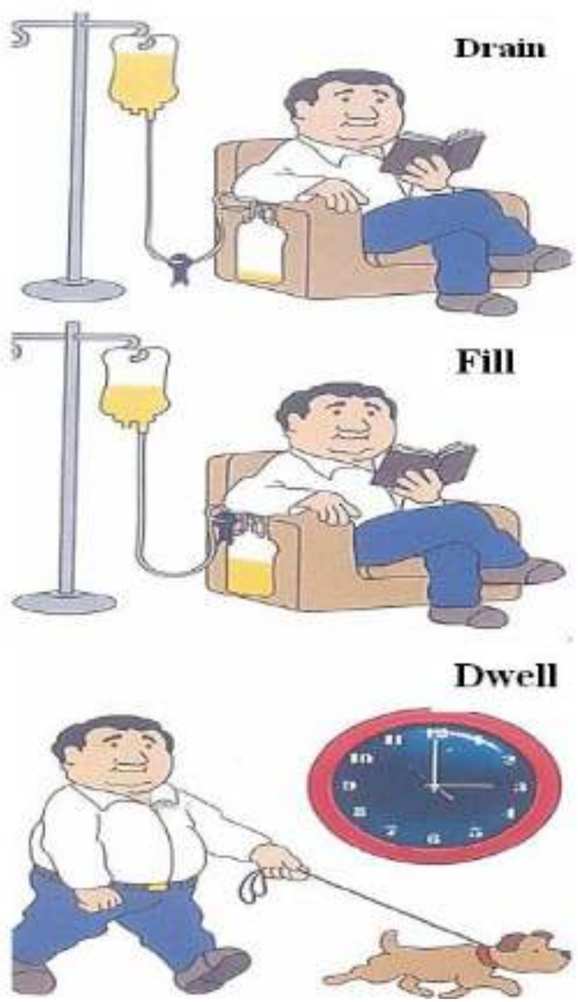
PD Prescription Components

- Modality – CAPD vs APD
- Solution
- Fill volume
- Dwell Time
- Number of Exchanges

Modality – Continuous Ambulatory Peritoneal Dialysis (CAPD)



- Provides continuous solute and fluid removal throughout the day and night
- Daytime exchanges ~5 hours
- Nighttime exchange ~9 hours
- Ease of use
- Low cost of equipment
- Often used in developing countries with limited resources available

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Modality – Automated Peritoneal Dialysis (APD)

- Continuous Cycling (CCPD)
- Nightly Intermittent (NIPD)
- Tidal (TPD)

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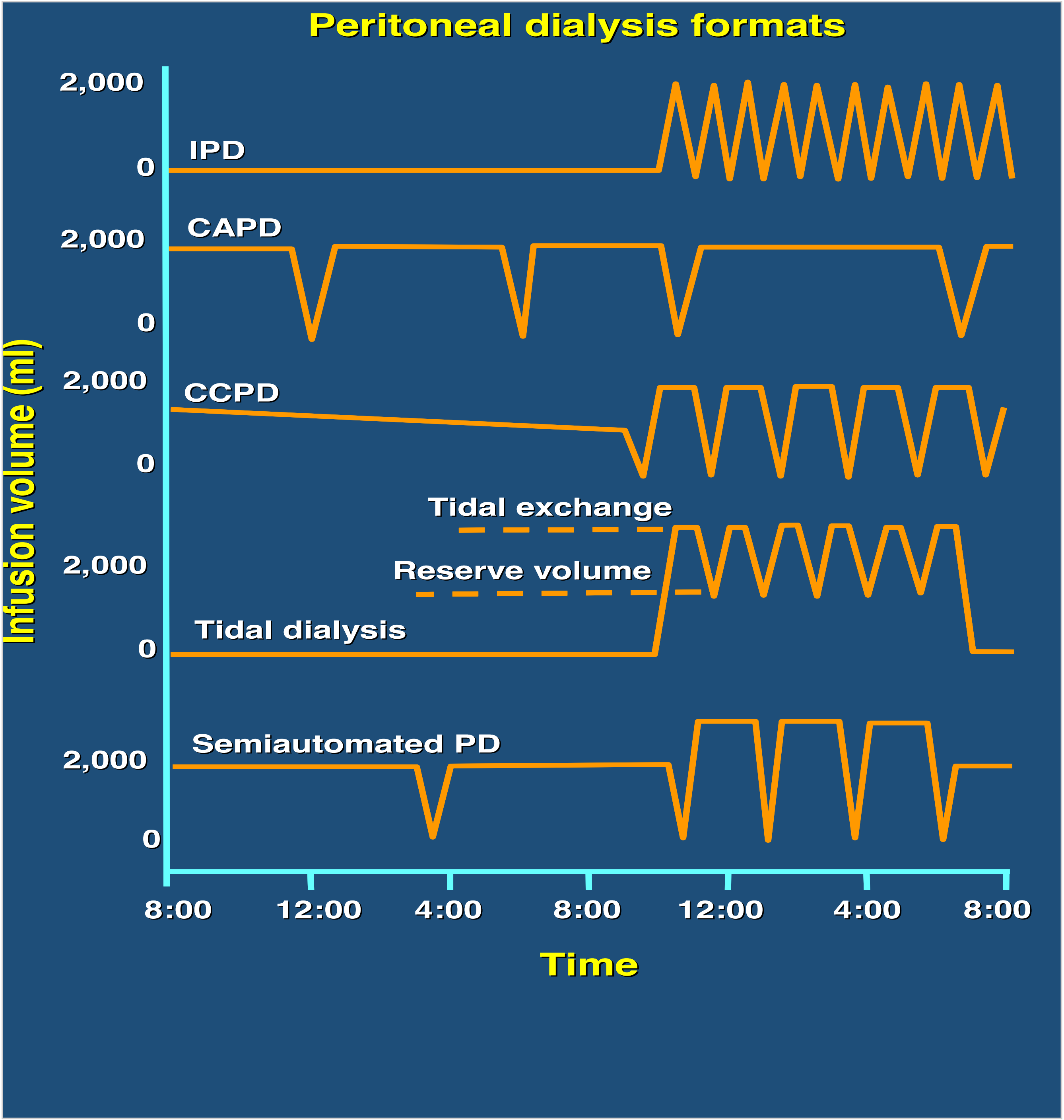
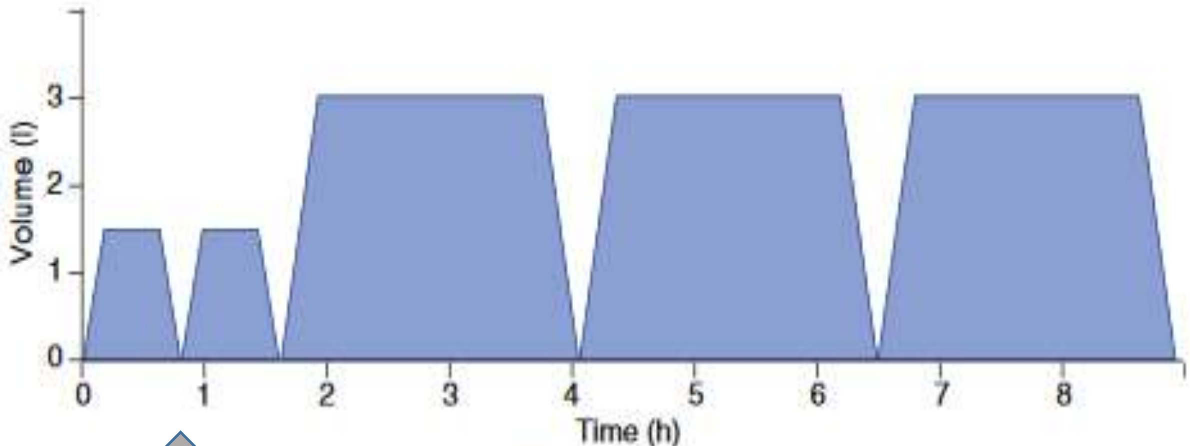


Peritoneal dialysis formats
Infusion volume (ml)
2,000
0
IPD
CAPD
2,000
0
CCPD
2,000
0
Tidal exchange
Reserve volume
2,000
Tidal dialysis
0
Semiautomated PD
2,000
0
8:00
12:00
4:00
8:00
12:00
4:00
8:00
Time

Adapted APD



Water and
small molecules

Sodium and
large molecules
(uremic toxins)

Fischbach et al Kidney International (2016) 89: 761-766

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PD Rx: Modality

Determinants of Modality Choice

- Financial
- Center preference
- Geography
- Lifestyle
- Peritoneal membrane transport characteristics

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PD Rx: Solution

Composition:

- Water
- Osmotic agent
  - Dextrose (1.5%, 2.5%, 4.25%)
  - Icodextrin
  - Amino acids
- Buffer
  - Lactate
  - Bicarbonate

- Electrolytes
  - Sodium 132-134 mEq/L
  - Chloride 96-105 mEq/L
  - Magnesium 0.25-0.5 mEq/L
  - Calcium 2-3.5 mEq/L
  - No potassium
- Additives
  - Heparin
  - Antibiotics

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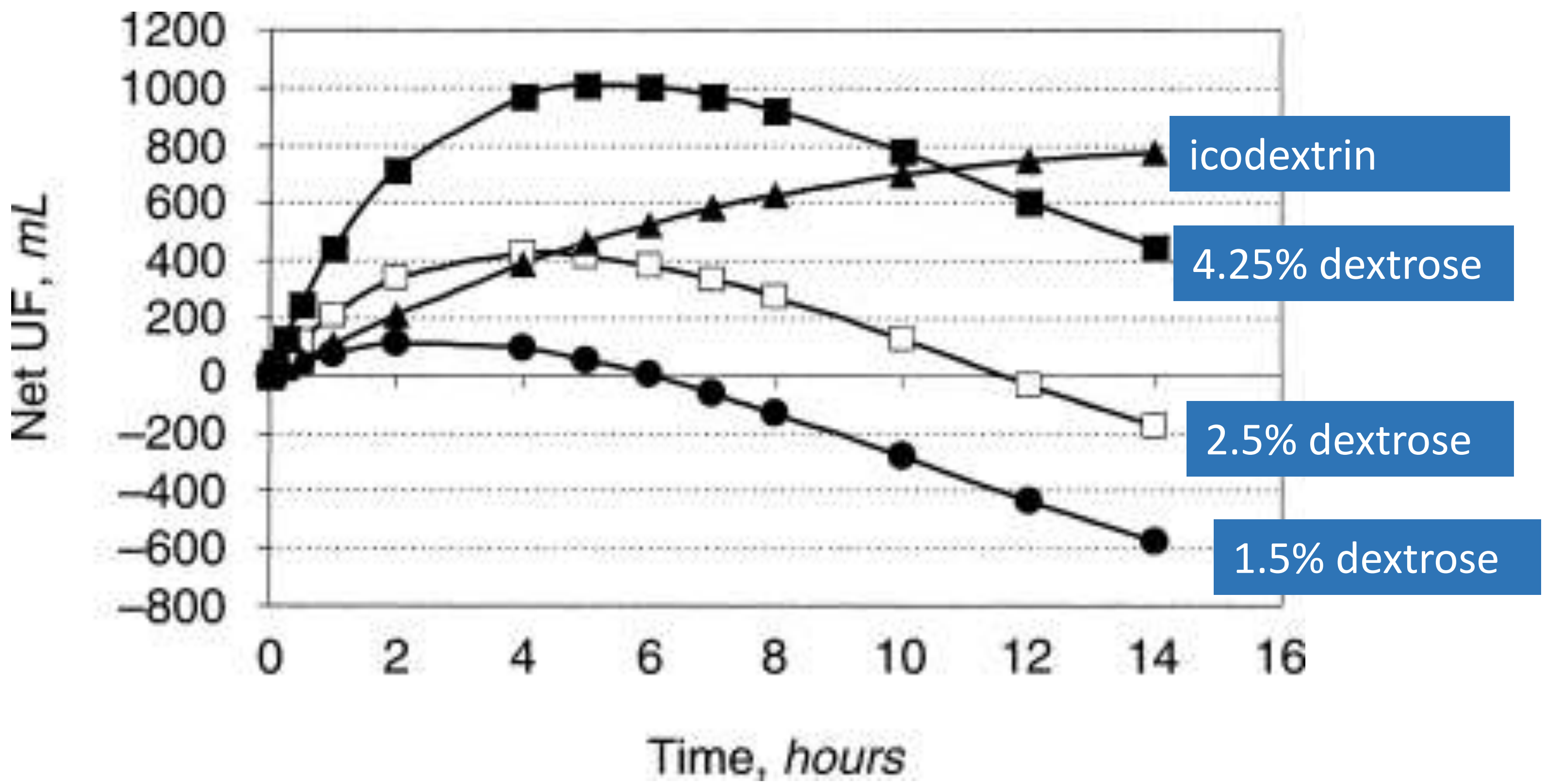
PD Rx: Solution



Kidney International 2002 62, S17-S22DOI: (10.1046/j.1523-1755.62.s81.4.x)

Solutions

Table 1 | Selected peritoneal dialysis solutions currently available in Europe

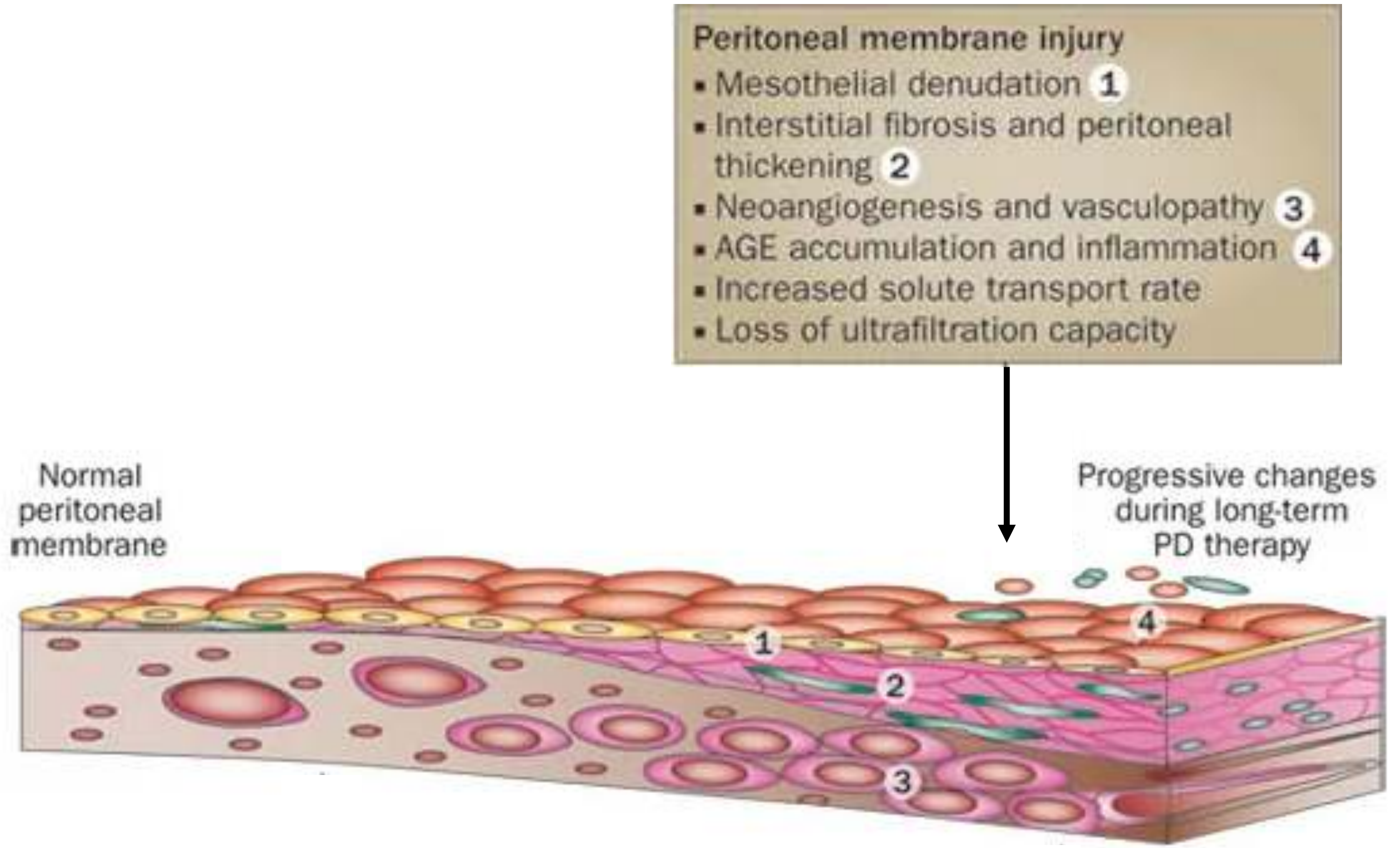
Solution (manufacturer)	pH	Chambers	Buffer	Osmotic agent	GDPs	Advantages	Disadvantages
Dianeal® (Baxter*)	5.2	Single	Lactate	Glucose	High	Easy to manufacture; low cost	Low pH; poor peritoneal membrane biocompatibility; infusion pain; contains lactate
Extraneal® (Baxter*)	5.6	Single	Lactate	Icodextrin	Low	Sustained ultrafiltration; reduced [illegible]	Contains lactate; low pH; single daily use only; hypersensitivity
Nutrineal® (Baxter*)	5.5	Single	Lactate	Amino acids	No	[illegible] nutrition	Contains lactate; low pH; single daily use only
Physioneal® (Baxter*)	7.4	Double	Lactate/ bicarbonate	Glucose	Low	Improved biocompatibility; preserved membrane defense; reduced infusion pain	Local and systemic glucose exposure; reduced peritoneal lactate exposure
Stay-safe® (Fresenius‡)	5.5	[illegible]	Lactate	Glucose	High	Ease of manufacture; low cost	Low pH; poor peritoneal membrane biocompatibility; infusion pain; contains lactate
Balance® (Fresenius‡)	7.0	Double	Lactate	Glucose	Low	Improved biocompatibility; preserved membrane defense; reduced risk of peritonitis?	Higher but not neutral pH; local and systemic glucose exposure; contains lactate
BicaVera® (Fresenius‡)	7.4	Double	Bicarbonate	Glucose	Low	Improved biocompatibility; preserved membrane defense; improved correction of acidosis	Local and systemic glucose exposure
Gambrosol® Trio (Fresenius‡)	6.5	Triple	Lactate	Glucose	Low	Improved biocompatibility; preserved membrane defense	Higher but not neutral pH; local and systemic glucose exposure; contains lactate

*Deerfield, IL, USA. ‡Bad Homburg, Germany. Abbreviation: GDPs, glucose degradation products.

Glucose degradation products

Delflex

Effects of Conventional Solutions



Nature Reviews Nephrology 8:224-233, 2012

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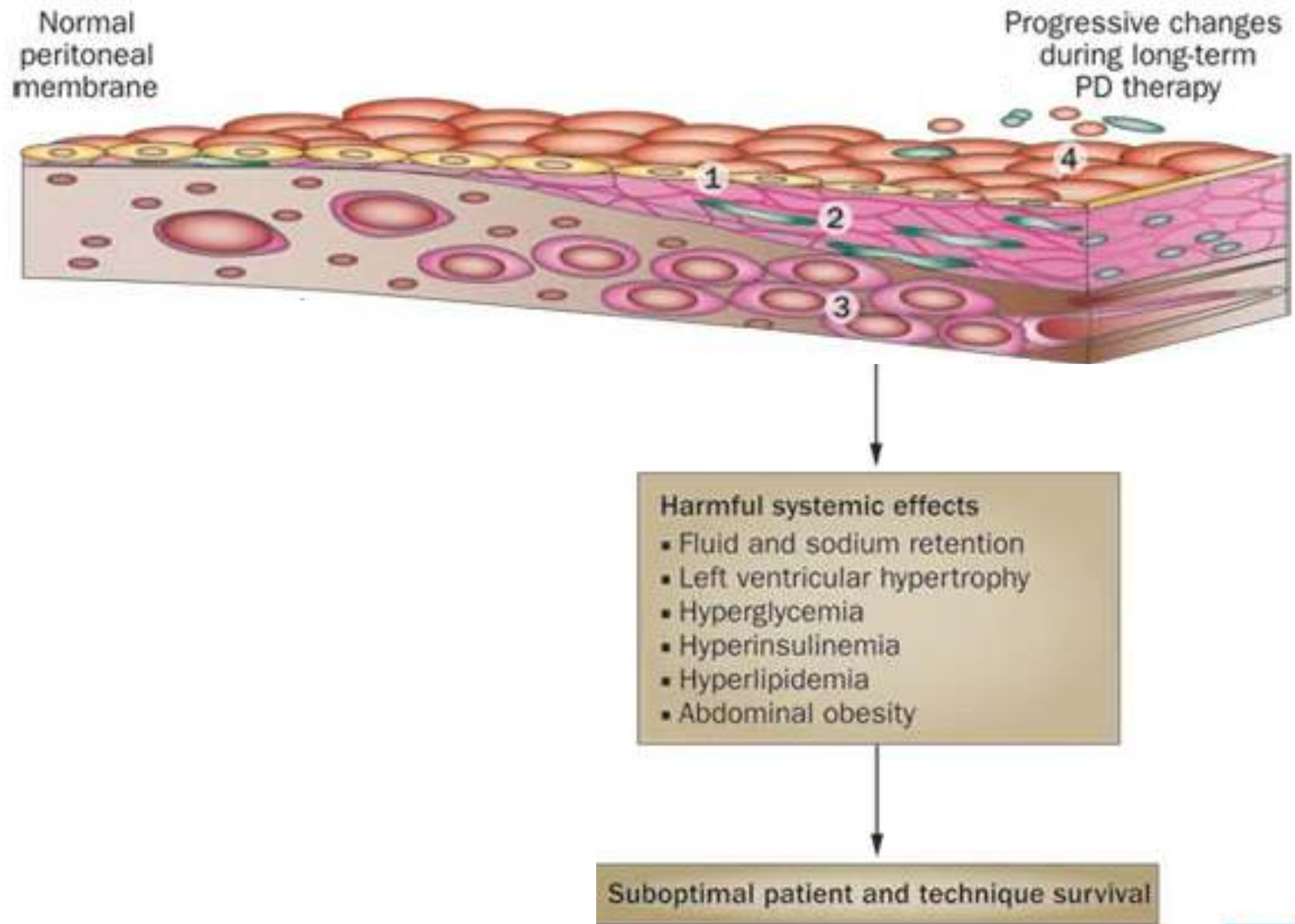
Effects of Conventional Solutions



Nature Reviews Nephrology 8:224-233, 2012

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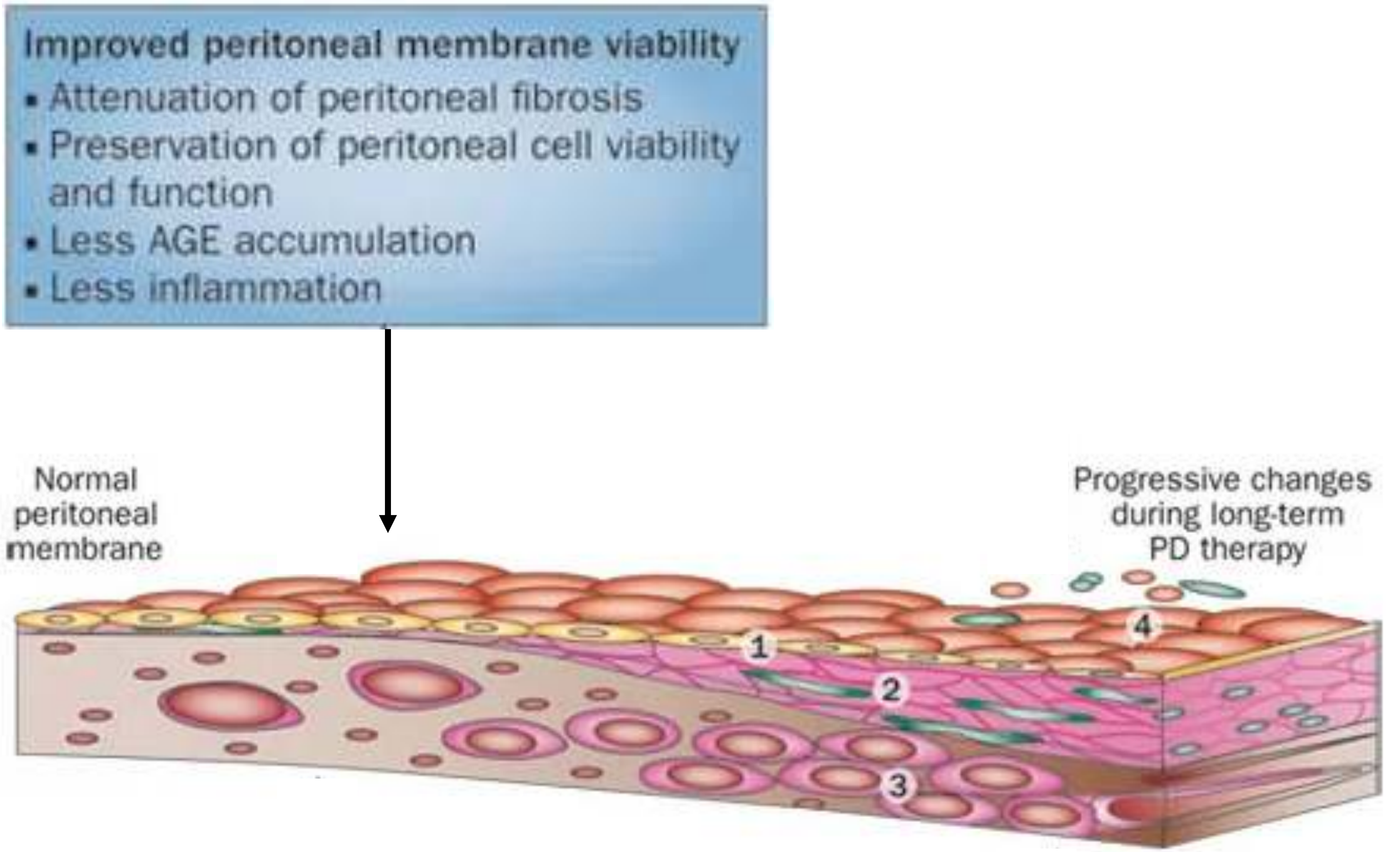
Biocompatible Solutions



Nature Reviews Nephrology 8:224-233, 2012

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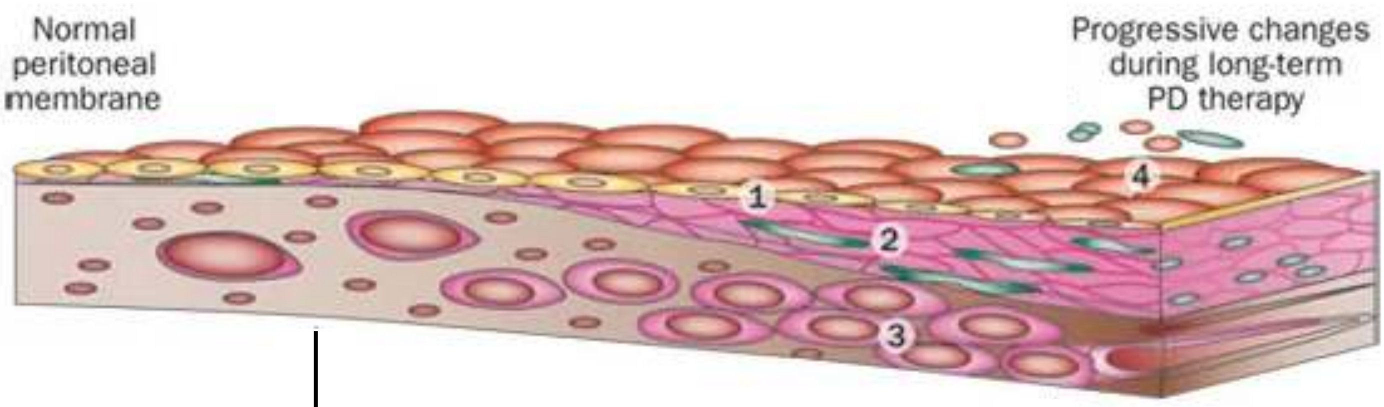
Effects of Biocompatible Solutions



Improved systemic effects
- Improved metabolic control
- Improved body composition
- Improved UF capacity
- Improved fluid status
- Preservation of RRF?
- Reduced peritonitis rate?
- Reduced systemic inflammation?

↓

Improved patient and technique survival?

Nature Reviews Nephrology 8:224-233, 2012

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PD Rx: Solution

Risk factors for loss of residual renal function in children treated with chronic peritoneal dialysis

Il-Soo Ha[1], Hui K. Yap[2], Reyner L. Munarriz[3], Pedro H. Zambrano[4], Joseph T. Flynn[5], Ilmay Bilge[6], Maria Szczepanska[7], Wai-Ming Lai[8], Zenaida L. Antonio[9], Ashima Gulati[10], Nakysa Hooman[11], Koen van Hoeck[12], Lina M.S. Higuita[13], Enrico Verrina[14], Günter Klaus[15], Michel Fischbach[16], Mohammed A. Riyami[17], Emilja Sahpazova[18], Anja Sander[19], Bradley A. Warady[20] and Franz Schaefer[21] for the International Pediatric Peritoneal Dialysis Network (IPPN) Registry[22]

- Icodextrin associated with increased risk of developing oligoanuria HR 2.38 (1.33-4.2) and lower residual urine output (p=0.043)
- Biocompatible fluid associated with greater residual urine output (p=0.028)

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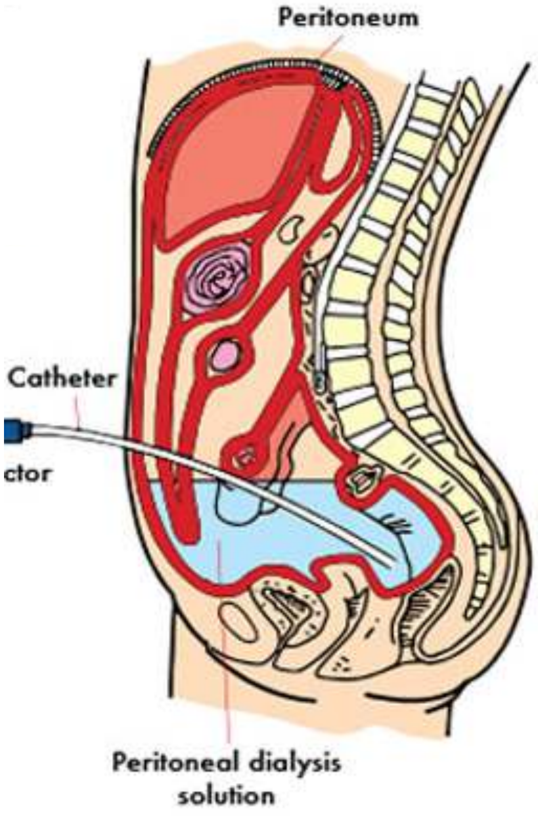
Kidney Int. 2015 Sep; 88(3): 605–613.

PD Rx: Fill Volume

- Peritoneal membrane area is related to body size
- Use body surface area to calculate fill volume (as opposed to weight)
- Fill volume affects peritoneal membrane recruitment and diffusion capacity

↑ Volume = ↑ Clearance



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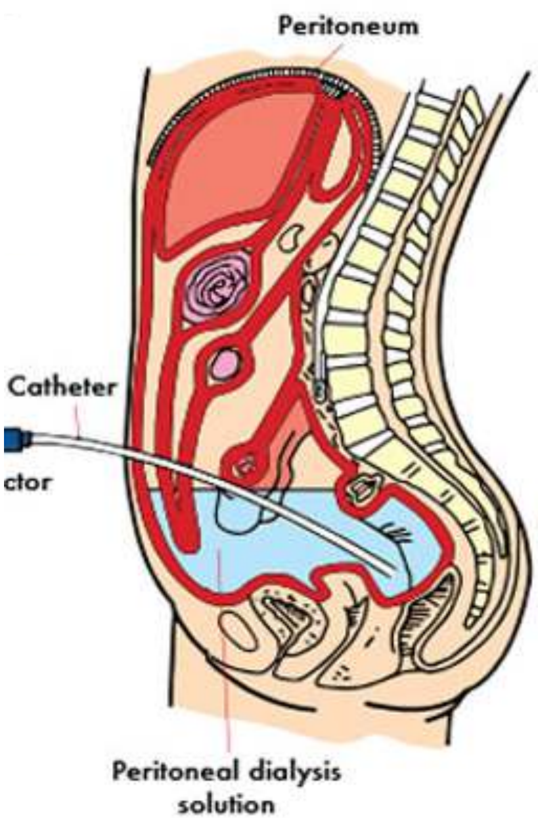
PD Rx: Fill Volume

APD:

- Nocturnal fill volume:
  - >2 years: 1000-1200 mL/m^2
  - < 2 years: 600-800 mL/m^2
- Daytime Fill volume:
  - 50% of nocturnal fill volume



CAPD:

- 600-800 mL/m^2 (day)
- 800-1000 mL/m^2 (night)

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Measuring IPP

Intra-peritoneal pressure maximum 18 cm H_2O

Normal 7-14 cm H_2O

- Empty bladder
- Patient placed completely flat
- Connection made to peritoneal system
- Any fluid in abdominal cavity is drained and defined volume of PD fluid is instilled
- PD line is fixed vertically
- Zero level of column (on graduated scale) is set at center of abdominal cavity, on the medial axillary line
- Connection of line to patient is opened
- Level of column of dialysis fluid in the PD line is read with a scale graduated in cm after height of column stabilizes

Fig. 1 The zero level of the column (*on the graduated scale*) is set at the centre of the abdominal cavity, i.e. medial axillary line

$$\text{Mean IPP} = \frac{\text{IPP insp} + \text{IPP exp}}{2}$$

Pediatr Nephrol (2003) 18:976-980

PD Rx: Excess Volume

Intra-peritoneal pressure maximum 18 cm H_2O
Normal 7-14 cm H_2O

Excess volume:

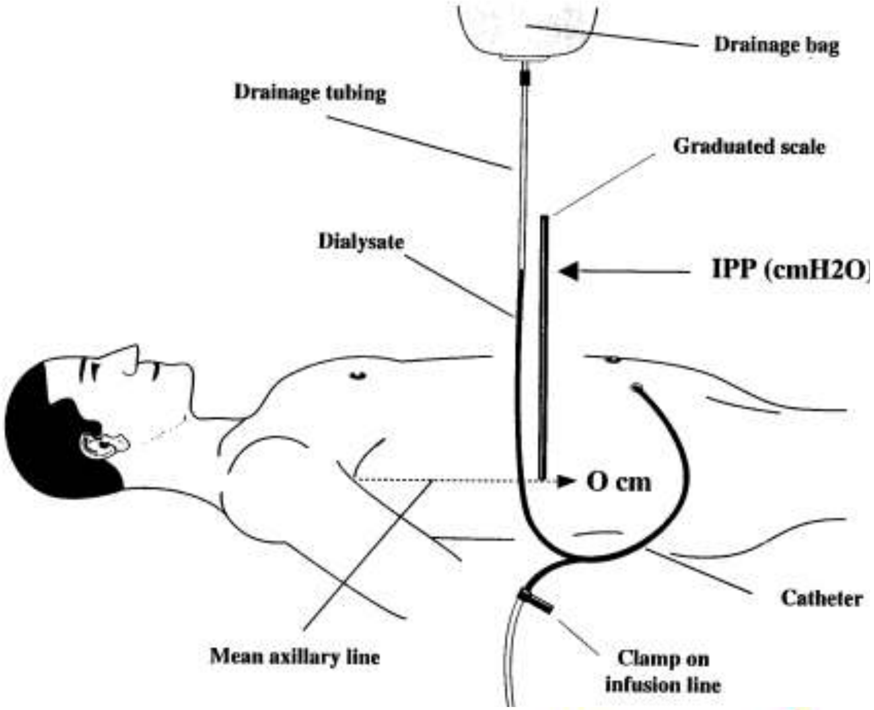
-Loss of UF

-Pain

-Risk of hernia

-Risk of hydrothorax

-Risk of breathing problems



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PD Rx: Dwell Time

Short exchanges

- Clearance of small solutes (urea)
- Better ultrafiltration

Long exchanges

- Clearance of higher molecular weight (creatinine and phosphate)
- Less ultrafiltration

Dwell time should be determined by individual peritoneal membrane transport status

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PD Rx: # Exchanges

APD

- 5-10 exchanges overnight
- 9-12 hours
- Daytime dwell

CAPD

- 3-5 exchanges/day
- 4-5 hour dwell time, with longer overnight dwell

PD Rx cheat sheet

Automated PD

Solution:

1.5%, 2.5% or 4.25% dianeal

Fill volume (nocturnal):

< 2years old = 600-800 mL/m^2

> 2 years old = 1000-1200 mL/m^2

Last fill (daytime):

1/2 the nocturnal fill volume

#exchanges over #hours:

5-10 exchanges overnight over 9-12 hrs

Fill/Drain time: 15 minutes

Dwell time: 40-60 minutes

CAPD

Solution:

1.5%, 2.5% or 4.25% dianeal

Fill volume (daytime):

600-800 mL/m^2

Long overnight dwell(nocturnal):

800-1000 mL/m^2

 # exchanges:

3-5 exchanges/day with dwell time: 4 hours **AND**

1 nocturnal exchange with dwell time: ~9 hours

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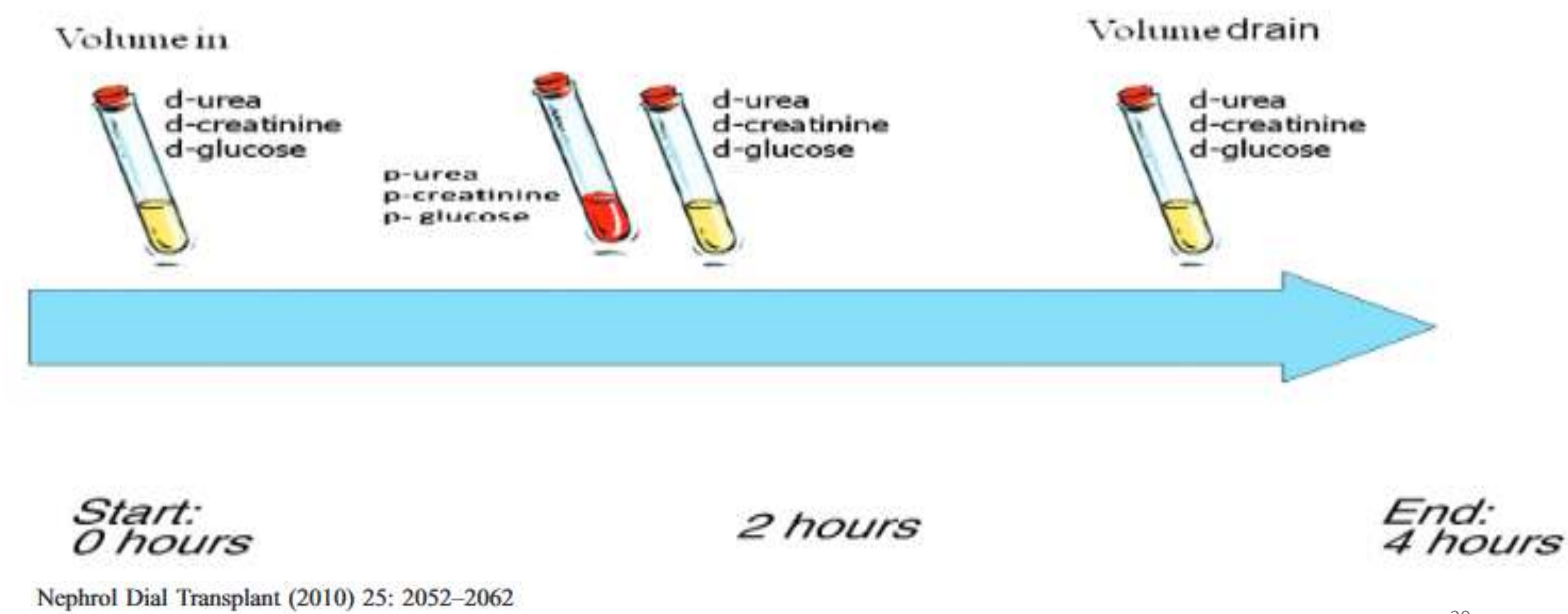
Peritoneal Equilibration Test (PET)

- Test of peritoneal membrane transport
- 4 hour dwell, 1,100 mL/m2 BSA, 2.5% Dextrose
- “Short” PET – 2 hours

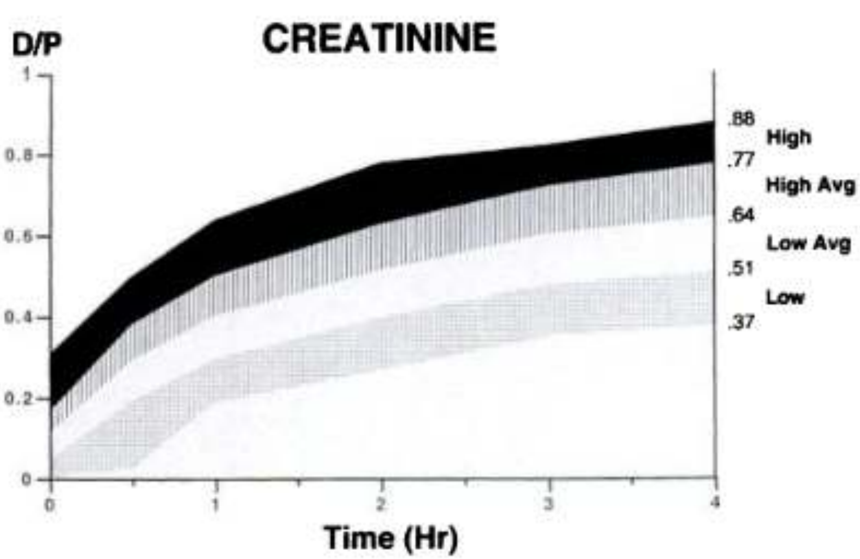


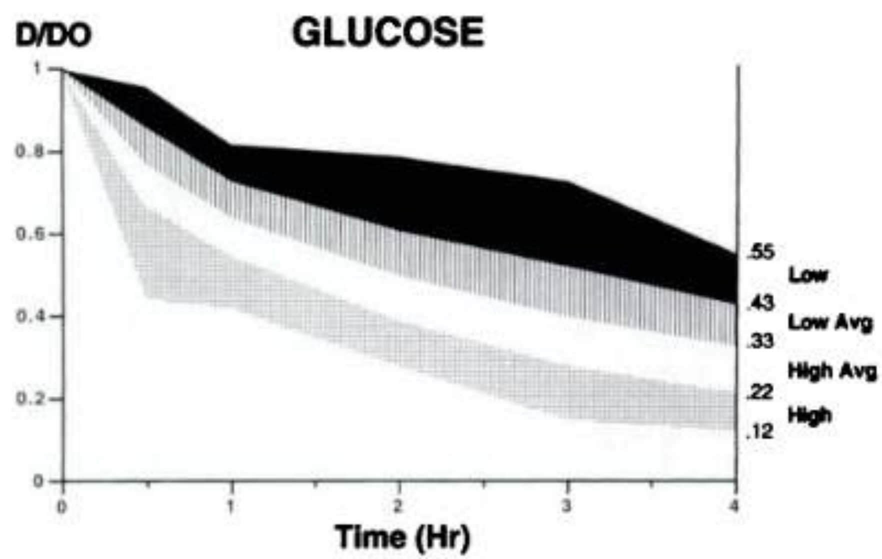
NKF KDOQI Guidelines 2006

PET: Transporter Type

Category of peritoneal transport	D/P urea[a]	D/P creatinine[a]	D/D0 glucose[a]
High	0.91–0.94	0.77–0.88	0.12–0.21
High average	0.82–0.90	0.64–0.76	0.22–0.32
Low average	0.74–0.81	0.51–0.63	0.33–0.42
Low	0.54–0.73	0.37–0.50	0.43–0.55

[a]At a 4 h dwell of an exchange performed with 1,100 ml/m² BSA of a 2.5% dextrose solution





B A Warady, S R Alexander, S Hossli, E Vonesh, D Geary, S Watkins, I B Salusky and E C Kohaut
JASN November 1996, 7 (11) 2385-2391;

PET: Transporter Type

Transporter Type	Characteristics	Prescription
High	-Highly permeable membrane -Rapid solute clearance -Loss of osmotic gradient quickly (poor UF) -Higher protein loss (lower albumin)	-Shorter dwell times -NIPD, or APD with icodextrin daytime fill
High Average	-Efficient membrane -Good solute clearance -Good UF	-Any dialysis regimen
Low Average	-Less efficient membrane -Slower solute cleranace -Good UF	-Any dialysis regimen, but with fewer cycles
Low	-Low membrane permeability -Slow solute clearance -Very good UF -Lower protein loss (higher albumin)	-Larger fill volumes -Longer duration of dwell with less cycles -CAPD or CCPD

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PD Rx: Modeled Approach

Kinetic Modeling Software Based Programs

- PD-Adequest 2.0 (Baxter)
  - Validated in children
- Patient Online (Fresenius)

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PD Rx: Adjustment

Inadequate Clearance

- Introduce daytime dwell
- Increase fill volume
- Lengthen exchange time
- Increase number of exchanges
- Increase solution tonicity

Inadequate Ultrafiltration

- Increase solution tonicity
- Icodextrin
- Shorten exchange time

PD Adequacy

Delivered dose of dialysis is "adequate":

- Optimal growth
- Blood pressure control
- Optimal nutritional status
- Avoidance of hypovolemia and sodium depletion
- Adequate psychomotor development

NKF KDOQI Guidelines 2006

Adequacy: Measures of Clearance

- Solute Clearance Measures:
  - Weekly Kt/V_{urea}
  - Weekly Creatinine Clearance
- Current guidelines and consensus statements favor use of Kt/V_{urea} as the ‘standard’ measure to follow

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Kt/V_{urea}

- "K" is representative of CLEARANCE of UREA

    -Kd = clearance of dialysis delivered

    -Kr = clearance of 'residual' renal function

- "t" is the time over which dialysis is delivered

    -In PD calculations, "t" is normally considered 24 hours/day (calculation is based on full day of dialysate/urine output, then scaled to 1 week)

- "V"$_{urea}$ is the volume of distribution for Urea in the patient, which is the patient's TBW

Total Kt/V_{urea} = dialysis + renal clearance

Weekly Peritoneal Dialysis Kt/V

$$\frac{\text{24 Hr D/P urea} \times \text{24-hr drained volume} \times 7}{V}$$

Weekly Renal Kt/V

$$\frac{\text{mL/min Urea clearance} \times \text{1440 min/day} \times 7}{\text{1000 mL} \times V}$$

Daily Renal Urea Clearance

$$\frac{\text{Volume of 24-hr urine in mL} \times \text{Urine Urea Nitrogen Conc.}}{\text{1440 min/day} \times \text{BUN Concentration}}$$

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Total Body Water Calculation

$$\text{Males: TBW} = 0.010 \cdot (\text{height} \cdot \text{weight})^{0.68} - 0.37 \cdot \text{weight}$$

$$\text{Females: TBW} = 0.14 \cdot (\text{height} \cdot \text{weight})^{0.64} - 0.35 \cdot \text{weight}$$

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Table 17. Male Total Body Water (L) Nomograms

Height (cm) across; Weight (kg) down.

Weight (kg)	50	54	58	62	66	70	74	78	82	86	90	94	98	102	106	110	114
2	1.6	1.7	1.8	1.9													
3	1.9	2.1	2.2	2.4													
4	2.2	2.4	2.6	2.8	3.0												
5	2.4	2.7	2.9	3.1	3.3												
6	2.6	2.9	3.1	3.4	3.6	3.9	4.1										
7	2.8	3.1	3.4	3.6	3.9	4.2	4.4	4.7	4.9								
8	2.9	3.2	3.5	3.9	4.1	4.4	4.7	5.0	5.3	5.5	5.8						
9				4.0	4.4	4.7	5.0	5.3	5.6	5.9	6.2	6.5	6.7				
10				4.2	4.6	4.9	5.2	5.6	5.9	6.2	6.5	6.8	7.1	7.4	7.7		
11				4.4	4.8	5.1	5.5	5.8	6.2	6.5	6.8	7.1	7.5	7.8	8.1	8.4	8.7
12				4.5	4.9	5.3	5.7	6.0	6.4	6.8	7.1	7.5	7.8	8.1	8.5	8.8	9.1
13								6.3	6.6	7.0	7.4	7.8	8.1	8.5	8.8	9.2	9.5
14								6.5	6.9	7.3	7.7	8.0	8.4	8.8	9.2	9.5	9.9
15								6.7	7.1	7.5	7.9	8.3	8.7	9.1	9.5	9.9	10.2
16								6.8	7.3	7.7	8.1	8.6	9.0	9.4	9.8	10.2	10.6
17											8.4	8.8	9.2	9.7	10.1	10.5	10.9
18											8.6	9.0	9.5	9.9	10.4	10.8	11.2
19											8.8	9.3	9.7	10.2	10.6	11.1	11.5
20											9.0	9.4	9.9	10.4	10.9	11.3	11.8

Table 17 (cont'd). Male Total Body Water (L) Nomograms

Height (cm) across; Weight (kg) down.

Weight (kg)	106	110	114	118	122	126	130	134	138	142	146	150	154	158	162	166	170	174	178	182	186	190
20	10.9	11.3	11.8	12.3	12.7	13.2	13.6	14.0	14.5	14.9	15.3	15.7										
22	11.4	11.9	12.4	12.8	13.3	13.8	14.3	14.7	15.2	15.7	16.1	16.5										
24	11.8	12.3	12.9	13.4	13.8	14.4	14.8	15.4	15.9	16.4	16.8	17.3	17.8	18.3	18.7							
26	12.2	12.8	13.3	13.9	14.4	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5							
28	12.6	13.2	13.8	14.4	14.9	15.5	16.0	16.6	17.1	17.7	18.2	18.7	19.3	19.8	20.3	20.8	21.3					
30	13.0	13.6	14.2	14.8	15.4	16.0	16.6	17.1	17.7	18.3	18.8	19.4	19.9	20.5	21.0	21.6	22.1					
32	13.3	14.0	14.6	15.2	15.8	16.5	17.1	17.7	18.3	18.8	19.4	20.0	20.6	21.2	21.7	22.3	22.9	23.4	24.0			
34	13.6	14.3	15.0	15.6	16.3	16.9	17.5	18.2	18.8	19.4	20.0	20.6	21.2	21.8	22.4	23.0	23.6	24.2	24.7			
36	13.9	14.6	15.3	16.0	16.7	17.3	18.0	18.7	19.3	19.9	20.6	21.2	21.8	22.4	23.1	23.7	24.3	24.9	25.5	26.1	26.6	
38	14.2	14.9	15.7	16.4	17.1	17.8	18.4	19.1	19.8	20.4	21.1	21.8	22.4	23.0	23.7	24.3	24.9	25.6	26.2	26.8	27.4	
40			16.0	16.7	17.4	18.1	18.8	19.6	20.2	20.9	21.6	22.3	23.0	23.6	24.3	24.9	25.6	26.2	26.9	27.6	28.1	28.8
42			16.3	17.0	17.8	18.5	19.2	20.0	20.7	21.4	22.1	22.8	23.5	24.2	24.9	25.5	26.2	26.9	27.5	28.2	28.8	29.5
44			16.6	17.3	18.1	18.9	19.6	20.4	21.1	21.8	22.6	23.3	24.0	24.7	25.4	26.1	26.8	27.5	28.2	28.8	29.5	30.2
46			16.8	17.6	18.4	19.2	20.0	20.8	21.5	22.3	23.0	23.8	24.5	25.2	26.0	26.7	27.4	28.1	28.8	29.5	30.2	30.9
48			17.1	17.9	18.7	19.5	20.3	21.1	21.9	22.7	23.5	24.2	25.0	25.7	26.5	27.2	27.9	28.7	29.4	30.1	30.8	31.5
50			17.3	18.2	19.0	19.8	20.7	21.5	22.3	23.1	23.9	24.7	25.4	26.2	27.0	27.7	28.5	29.2	30.0	30.7	31.5	32.2
52						20.1	21.0	21.8	22.6	23.5	24.3	25.1	25.9	26.7	27.5	28.2	29.0	29.8	30.6	31.3	32.1	32.8
54						20.4	21.3	22.1	23.0	23.8	24.7	25.5	26.3	27.1	27.9	28.7	29.5	30.3	31.1	31.9	32.7	33.4
56						20.7	21.6	22.5	23.3	24.2	25.0	25.9	26.7	27.6	28.4	29.2	30.0	30.8	31.7	32.4	33.2	34.0
58						20.9	21.8	22.8	23.7	24.5	25.4	26.3	27.1	28.0	28.8	29.7	30.5	31.4	32.2	33.0	33.8	34.6
60						21.2	22.1	23.1	24.0	24.9	25.8	26.7	27.5	28.4	29.3	30.1	31.0	31.8	32.7	33.5	34.4	35.2
62						21.4	22.4	23.3	24.3	25.2	26.1	27.0	27.9	28.8	29.7	30.6	31.5	32.3	33.2	34.0	34.9	35.7
64						21.7	22.6	23.6	24.6	25.5	26.4	27.4	28.3	29.2	30.1	31.0	31.9	32.8	33.7	34.5	35.4	36.3
66									24.8	25.8	26.8	27.7	28.6	29.6	30.5	31.4	32.3	33.2	34.1	35.0	35.9	36.8
68									25.1	26.1	27.1	28.0	29.0	30.0	30.9	31.8	32.8	33.7	34.6	35.6	36.4	37.3
70									25.4	26.4	27.4	28.4	29.3	30.3	31.3	32.2	33.2	34.1	35.1	36.0	36.9	37.8
72									25.6	26.6	27.7	28.7	29.7	30.7	31.6	32.6	33.6	34.5	35.5	36.4	37.4	38.3
74									25.9	26.9	27.9	29.0	30.0	31.0	32.0	33.0	34.0	34.9	35.9	36.9	37.8	38.8
76									26.1	27.2	28.2	29.3	30.3	31.3	32.3	33.3	34.4	35.3	36.3	37.3	38.3	39.3
78									26.3	27.4	28.5	29.5	30.6	31.6	32.7	33.7	34.7	35.7	36.7	37.7	38.7	39.7
80									26.5	27.6	28.7	29.8	30.9	31.9	33.0	34.1	35.1	36.1	37.1	38.2	39.2	40.2

NKF KDOQI Guidelines 2006

Table 18. Female Total Body Water (L) Nomograms

Height (cm)

Weight (kg)	50	54	58	62	66	70	74	78	82	86	90	94	98	102	106	110	114
2	2.0	2.1	2.2	2.4													
3	2.4	2.6	2.8	2.9													
4	2.8	3.0	3.2	3.4	3.6												
5	3.1	3.3	3.5	3.8	4.0												
6	3.3	3.6	3.8	4.1	4.3	4.6	4.8										
7	3.5	3.8	4.1	4.4	4.8	4.9	5.2	5.5	5.7								
8	3.7	4.0	4.3	4.6	4.9	5.2	5.5	5.8	6.1	6.4	6.6						
9				4.9	5.2	5.5	5.8	6.1	6.4	6.7	7.0	7.3	7.6				
10				5.1	5.4	5.8	6.1	6.4	6.8	7.1	7.4	7.7	8.0	8.3	8.6		
11				5.3	5.6	6.0	6.4	6.7	7.1	7.4	7.7	8.1	8.4	8.7	9.0	9.3	9.6
12				5.4	5.8	6.2	6.6	7.0	7.3	7.7	8.0	8.4	8.7	9.1	9.4	9.7	10.0
13								7.2	7.6	8.0	8.3	8.7	9.1	9.4	9.8	10.1	10.4
14								7.4	7.8	8.2	8.6	9.0	9.4	9.7	10.1	10.5	10.8
15								7.6	8.0	8.5	8.9	9.3	9.7	10.0	10.4	10.8	11.2
16								7.8	8.3	8.7	9.1	9.5	9.9	10.3	10.7	11.1	11.5
17											9.3	9.8	10.2	10.6	11.0	11.4	11.8
18											9.6	10.0	10.5	10.9	11.3	11.7	12.2
19											9.8	10.2	10.7	11.1	11.6	12.0	12.5
20											10.0	10.4	10.9	11.4	11.8	12.3	12.7

Table 18 (cont'd). Female Total Body Water (L) Nomograms

Height (cm)

Weight (kg)	106	110	114	118	122	126	130	134	138	142	146	150	154	158	162	166	170	174	178	182	186	190
20	11.8	12.3	12.7	13.2	13.6	14.0	14.5	14.9	15.3	15.7	16.1	16.5										
22	12.3	12.8	13.3	13.7	14.2	14.7	15.1	15.6	16.0	16.4	16.9	17.3										
24	12.8	13.3	13.8	14.3	14.8	15.2	15.7	16.2	16.7	17.1	17.6	18.0	18.5	18.9	19.4							
26	13.2	13.7	14.2	14.8	15.3	15.8	16.3	16.8	17.3	17.8	18.3	18.7	19.2	19.7	20.1							
28	13.6	14.1	14.7	15.2	15.8	16.3	16.8	17.3	17.9	18.4	18.9	19.4	19.9	20.4	20.9	21.3	21.8					
30	13.9	14.5	15.1	15.7	16.2	16.8	17.3	17.9	18.4	18.9	19.5	20.0	20.5	21.0	21.5	22.0	22.5					
32	14.3	14.9	15.5	16.1	16.6	17.2	17.8	18.4	18.9	19.5	20.0	20.6	21.1	21.7	22.2	22.7	23.2	23.7	24.3			
34	14.6	15.2	15.8	16.4	17.0	17.7	18.2	18.8	19.4	20.0	20.6	21.1	21.7	22.3	22.8	23.4	23.9	24.4	25.0			
36	14.8	15.5	16.2	16.8	17.4	18.1	18.7	19.3	19.9	20.5	21.1	21.7	22.3	22.8	23.4	24.0	24.5	25.1	25.6	26.2	26.7	
38	15.1	15.8	16.5	17.1	17.8	18.4	19.1	19.7	20.3	21.0	21.6	22.2	22.8	23.4	24.0	24.6	25.1	25.7	26.3	26.9	27.4	
40			16.8	17.4	18.1	18.8	19.5	20.1	20.7	21.4	22.0	22.7	23.3	23.9	24.5	25.1	25.7	26.3	26.9	27.5	28.1	28.6
42			17.0	17.7	18.4	19.1	19.8	20.5	21.1	21.8	22.5	23.1	23.8	24.4	25.0	25.7	26.3	26.9	27.5	28.1	28.7	29.3
44			17.3	18.0	18.7	19.5	20.2	20.9	21.5	22.2	22.9	23.6	24.2	24.9	25.5	26.2	26.8	27.4	28.1	28.7	29.3	29.9
46			17.5	18.3	19.0	19.8	20.5	21.2	21.9	22.6	23.3	24.0	24.7	25.3	26.0	26.7	27.3	28.0	28.6	29.3	29.9	30.5
48			17.8	18.5	19.3	20.0	20.8	21.5	22.3	23.0	23.7	24.4	25.1	25.8	26.5	27.2	27.8	28.5	29.2	29.8	30.5	31.1
50			18.0	18.8	19.6	20.3	21.1	21.8	22.6	23.3	24.1	24.8	25.5	26.2	26.9	27.6	28.3	29.0	29.7	30.4	31.0	31.7
52						20.6	21.4	22.1	22.9	23.7	24.4	25.2	25.9	26.6	27.4	28.1	28.8	29.5	30.2	30.9	31.6	32.2
54						20.8	21.6	22.4	23.2	24.0	24.8	25.5	26.3	27.0	27.8	28.5	29.2	29.9	30.7	31.4	32.1	32.8
56						21.1	21.9	22.7	23.5	24.3	25.1	25.9	26.6	27.4	28.2	28.9	29.7	30.4	31.1	31.9	32.6	33.3
58						21.3	22.1	23.0	23.8	24.6	25.4	26.2	27.0	27.8	28.5	29.3	30.1	30.8	31.6	32.3	33.1	33.8
60						21.5	22.4	23.2	24.1	24.9	25.7	26.5	27.3	28.1	28.9	29.7	30.5	31.3	32.0	32.8	33.5	34.3
62						21.7	22.6	23.4	24.3	25.2	26.0	26.8	27.7	28.5	29.3	30.1	30.9	31.7	32.4	33.2	34.0	34.8
64						21.9	22.8	23.7	24.6	25.4	26.3	27.1	28.0	28.8	29.6	30.4	31.3	32.1	32.9	33.6	34.4	35.2
66									24.8	25.7	26.5	27.4	28.3	29.1	30.0	30.8	31.6	32.4	33.2	34.1	34.9	35.7
68									25.0	25.9	26.8	27.7	28.6	29.4	30.3	31.1	32.0	32.8	33.6	34.5	35.3	36.1
70									25.2	26.1	27.0	27.9	28.8	29.7	30.6	31.5	32.3	33.2	34.0	34.9	35.7	36.5
72									25.4	26.4	27.3	28.2	29.1	30.0	30.9	31.8	32.7	33.5	34.4	35.2	36.1	36.9
74									25.6	26.6	27.5	28.4	29.4	30.3	31.2	32.1	33.0	33.9	34.7	35.6	36.5	37.3
76									25.8	26.8	27.7	28.7	29.6	30.6	31.5	32.4	33.3	34.2	35.1	36.0	36.8	37.7
78									26.0	27.0	27.9	28.9	29.9	30.8	31.7	32.7	33.6	34.5	35.4	36.3	37.2	38.1
80									26.2	27.2	28.1	29.1	30.1	31.1	32.0	33.0	33.9	34.8	35.7	36.7	37.6	38.5

NKF KDOQI Guidelines 2006

KDOQI

The minimal "delivered" dose of total (peritoneal and kidney) small-solute clearance should be a Kt/V_{urea} of at least 1.8/week

Duke Children's

Residual Kidney Function

- Should be measured when UOP > 100 mL/day
- Defined as urine Kt/V_{urea} > 0.1/week
- If the patient has RKF and residual kidney clearance is being considered as part of the patient's total weekly solute clearance goal, a 24 hour urine collection for urine volume and solute clearance determinations should be obtained at a minimum of every 3 months

NKF KDOQI Guidelines 2006

Duke Children's

Residual Kidney Function

- May have a significant impact on patient outcome
- Efforts should be made to preserve RKF
  - Minimize nephrotoxic insults
  - Promptly treat UTIs
  - Diuretics to maximize salt and water excretion
  - Use of ACE/ARBs

NKF KDOQI Guidelines 2006

Duke Children's

Ultrafiltration Adequacy: Euvolemia

Causes of Fluid Overload

- Inappropriate solution selection
- Inappropriate prescription for membrane transport status
- Non-adherence to PD or diet
- Peritoneal membrane dysfunction
- Loss of residual renal function
- Poor blood glucose control

Management

- The pediatric patient's clinical status should be reviewed at least monthly, and delivery of prescribed solute clearance should render the patient free of signs and symptoms of uremia
- Measure Kt/V one month after starting dialysis, when clinically needed and *at least* every 6 months
- PD effluent UF should be reviewed every month

Summary

- PD prescription must be individualized and optimized, and continually re-assessed
- While recommended minimal "delivered" dose of solute clearance should be a Kt/V_{urea} 1.8/week, adequacy is also determined by clinical outcomes of the patient
  - BP control, fluid management, growth, nutrition, bone disease, development

Useful Resources

- Optimal Care of the Infant, Child and Adolescent on Dialysis: 2014 Update. *Am J Kidney Dis 2014; 64(1):128-142*
- Care of the Pediatric Patient on Chronic Dialysis. *Adv Chronic Kidney Dis 2017; 24(6): 388-397*
- Pediatric Dialysis, 2nd Edition. Warady, Schaefer, Alexander.
  - Chapter 11 Technical Aspects of Prescription of Peritoneal Dialysis in Children, p 169-203
- Handbook of Dialysis, 5th Edition. Daugirdas, Blake and Ing.
  - Chapter 25 Adequacy of Peritoneal Dialysis p464-482
  - Chapter 26 Volume Status and Fluid Overload in Peritoneal Dialysis p483-489
  - Chapter 37 Dialysis in Infants and Childrren p693-712
- KDOQI Clinical Practice Guidelines and Clinical Practice Recommendations for 2006 Updates. Hemodialysis Adequacy, Peritoneal Dialysis Adequacy and Vascular Access. *Am J Kidney Dis 2006; 28(suppl 1): S1*

Peritoneal Dialysis Simulator

www.Openpediatrics.org

Harvard University

Screenshots of the various components of the peritoneal dialysis simulator. (A) The knowledge guide. (B) The tactics. (C) The case studies. (D) Learner-controlled feedback.

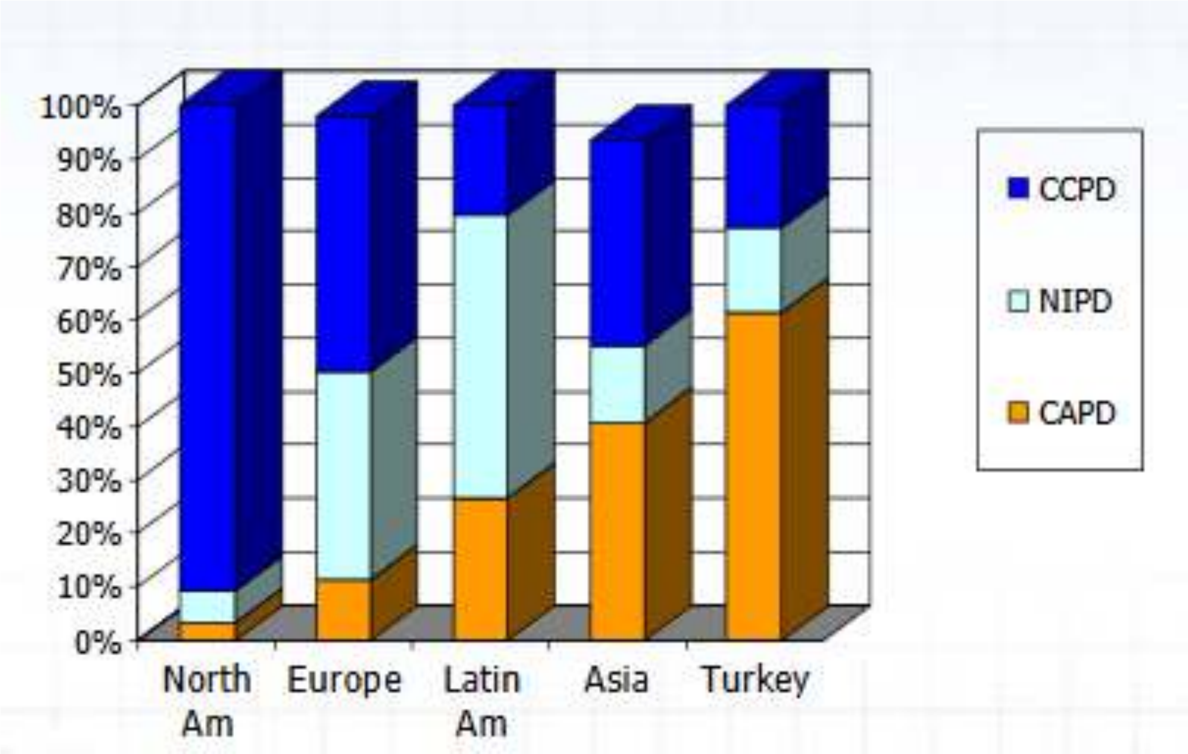
CJASN June 2018, 13 (6) 900-906;

???Questions???

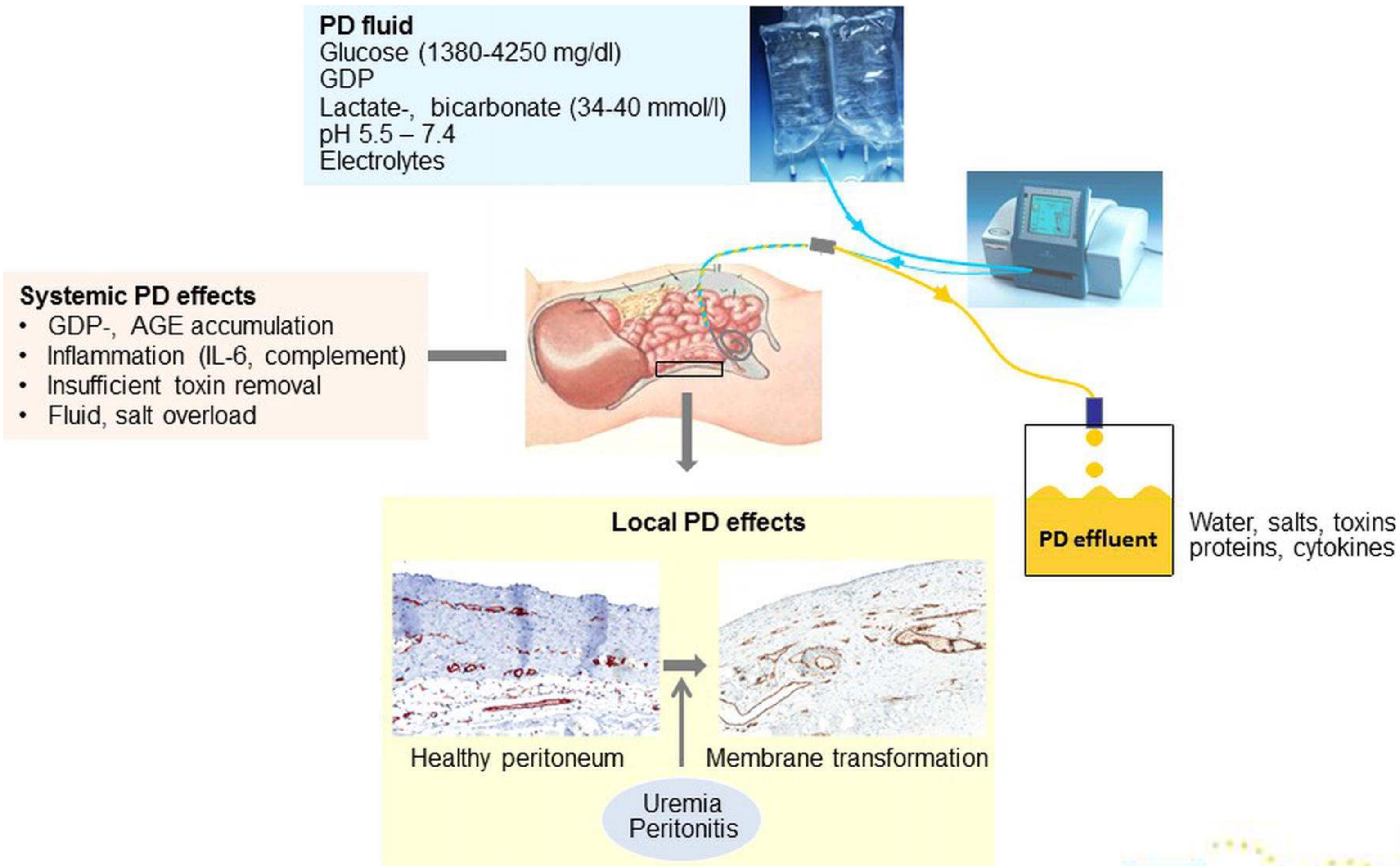
Thank you!

Duke Children's

PD Rx: Modality



Effect of PD



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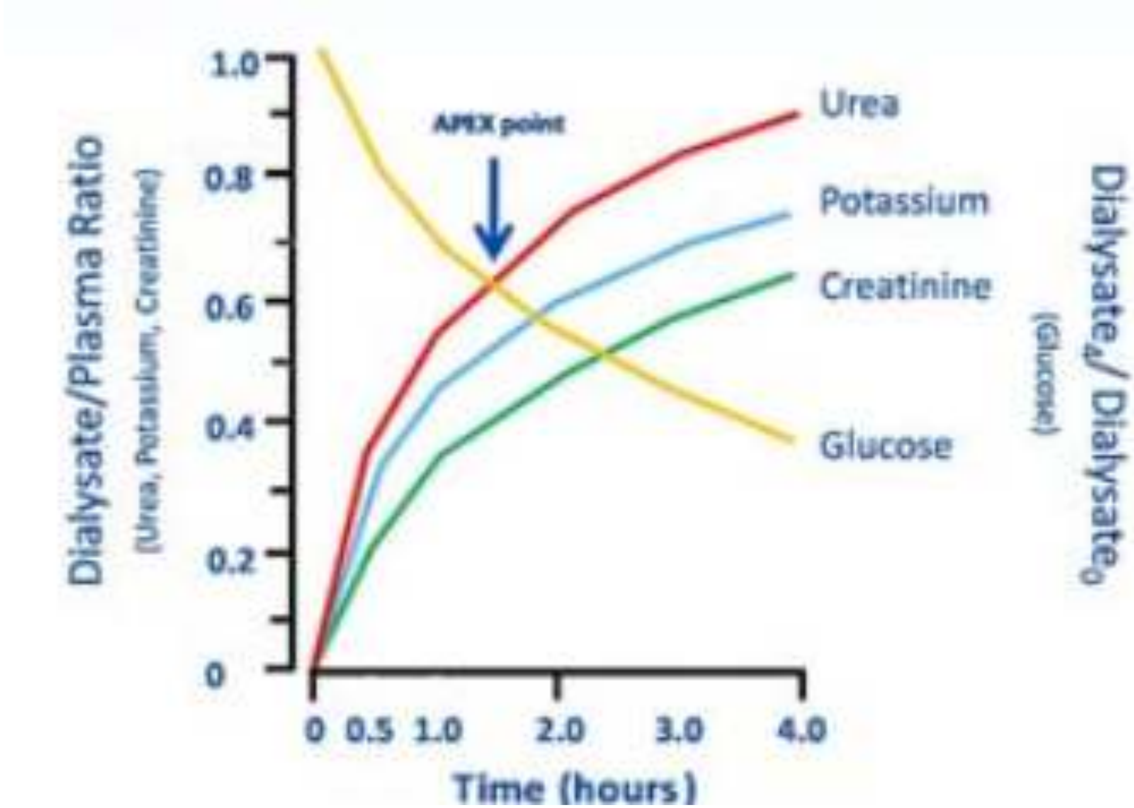
PD Rx: Dwell Time

Accelerated Peritoneal Examination
APEX time indicates optimal dwell time for UF



Duke Children's

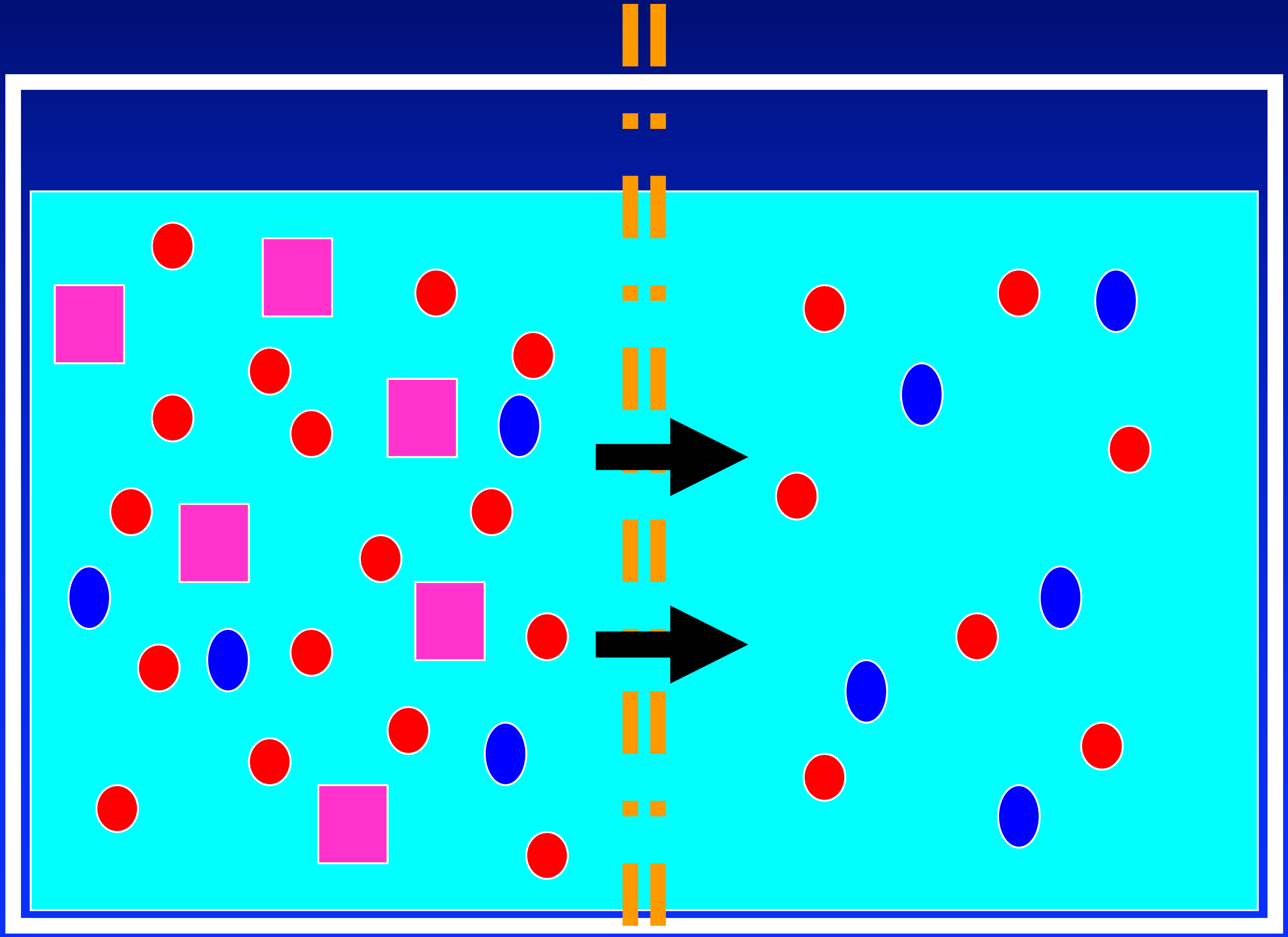
Physiology of Blood Purification: Dialysis & Apheresis

Jordan M. Symons, MD
University of Washington School of Medicine
Seattle Children's Hospital

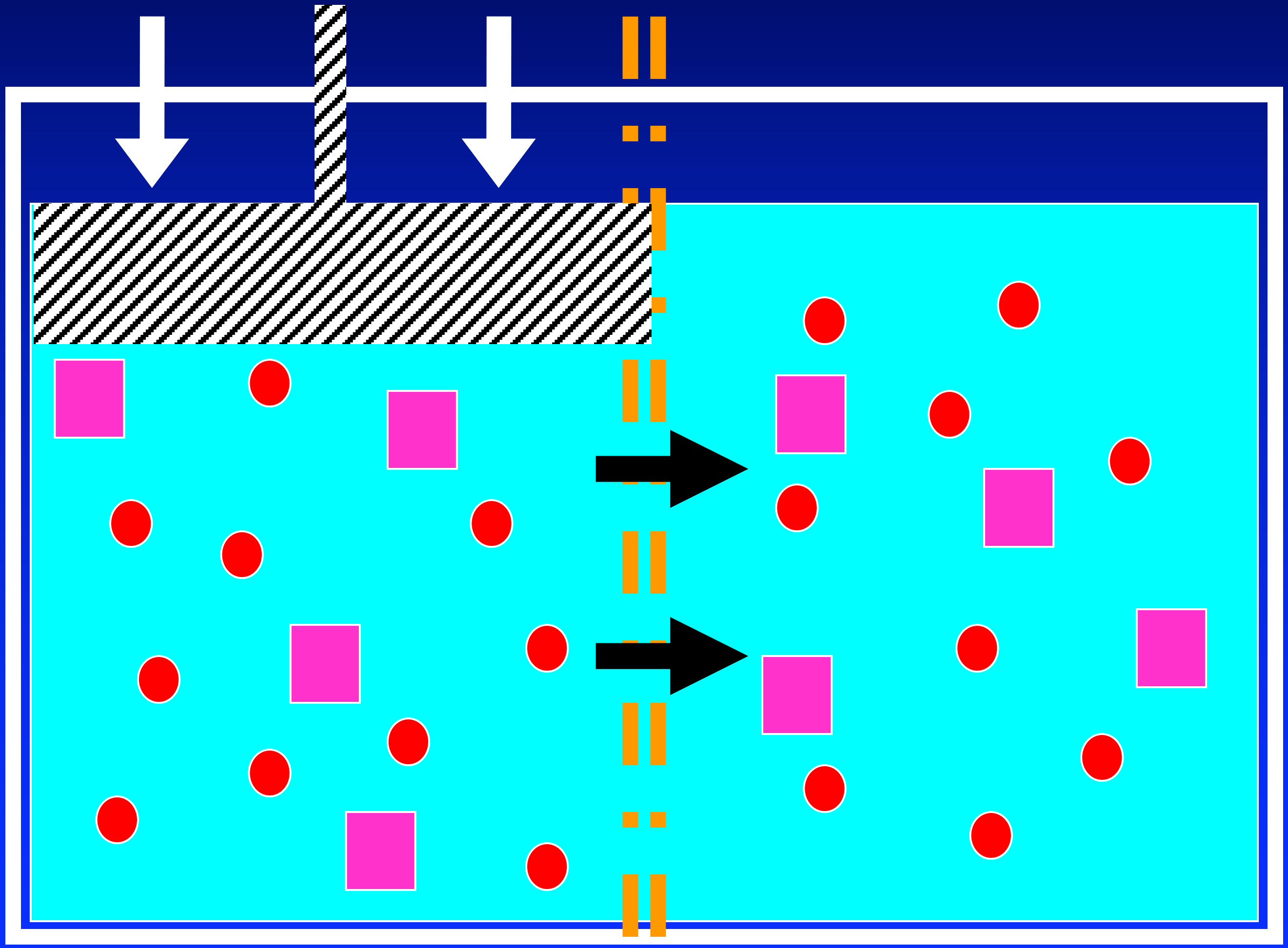
Outline

- Physical principles of mass transfer
- Hemodialysis and CRRT
  - Properties of dialyzers
  - Concepts that underlie the HD procedure
- Peritoneal Dialysis
  - Peritoneal membrane physiology
  - Concepts that underlie the PD procedure
- Apheresis – basic principles of blood separation

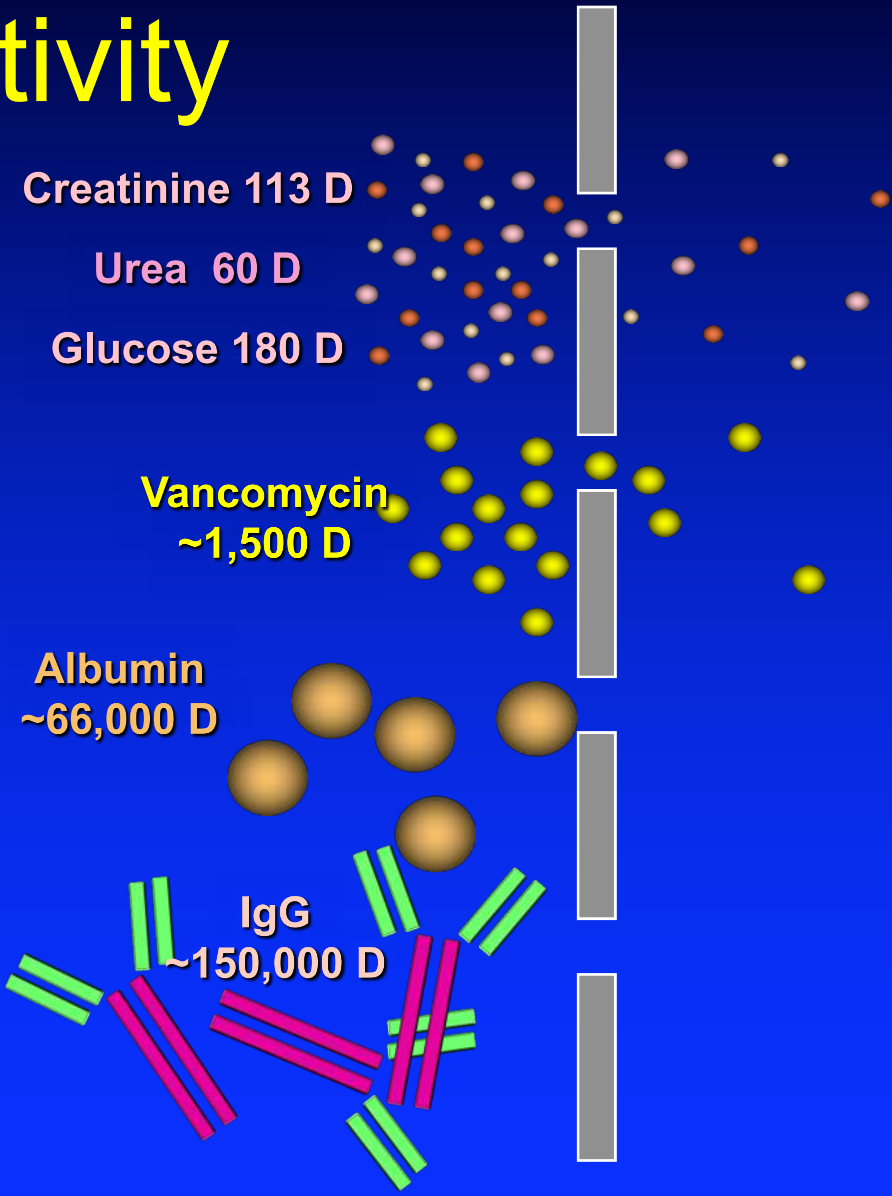
Diffusion



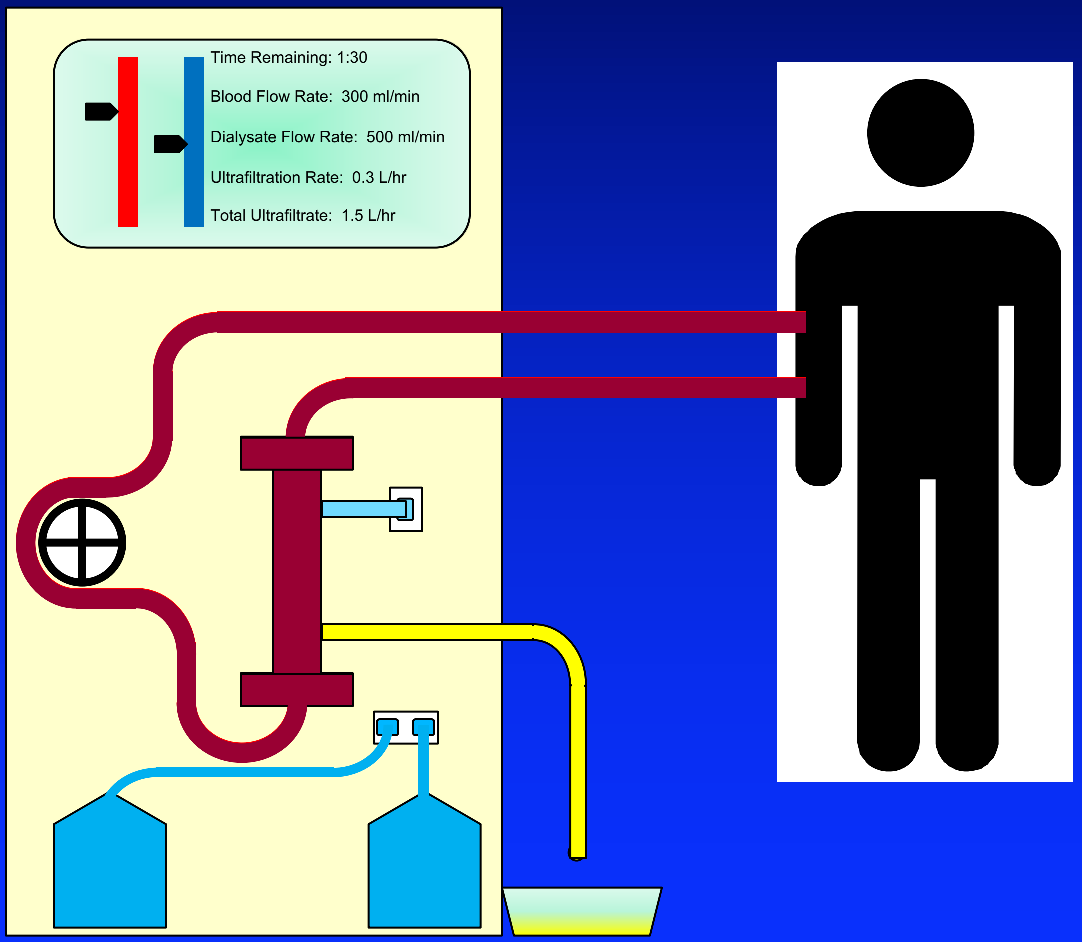
Convection



Effect of Pore Size on Membrane Selectivity



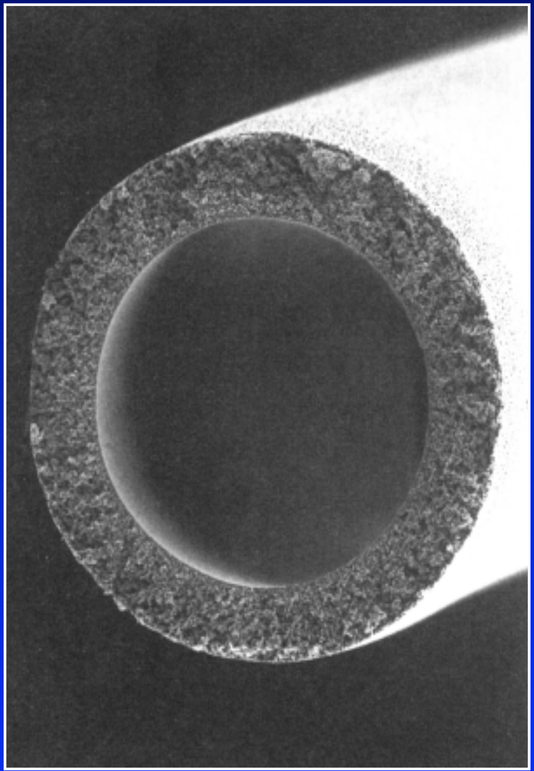
Intermittent Hemodialysis (IHD)



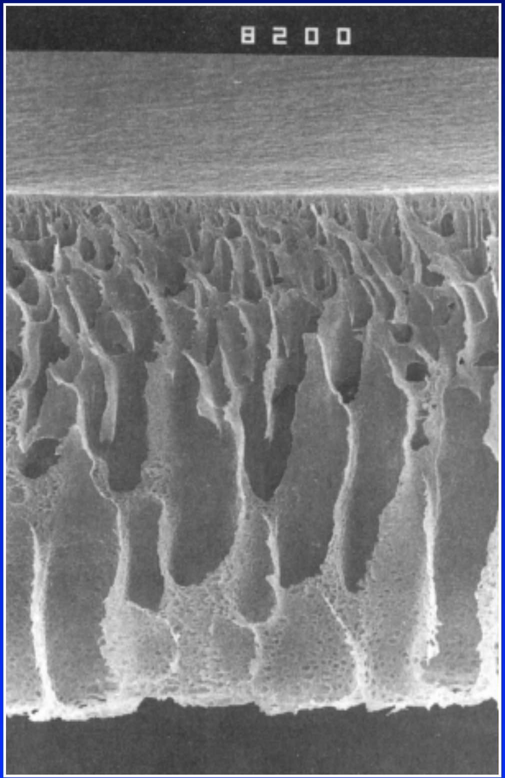
- Blood perfuses extracorporeal circuit
- Dialysate passes on opposite side of membrane
- High efficiency system
- Particle removal mostly by diffusion
- Fluid removal by ultrafiltration (hydrostatic pressure across dialyzer membrane)

Hollow Fiber Dialyzers

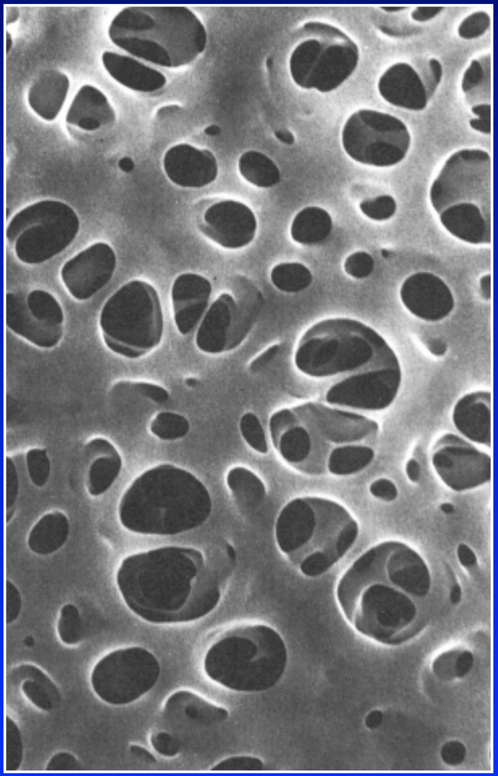
Dialysis/Hemofiltration Membranes



Capillary



Cross Section



Blood Side

Permeability Surface Area Product: K_0A

- K_0A is a property of the *dialyzer*
- Describes maximum ability of dialyzer to clear a given substance

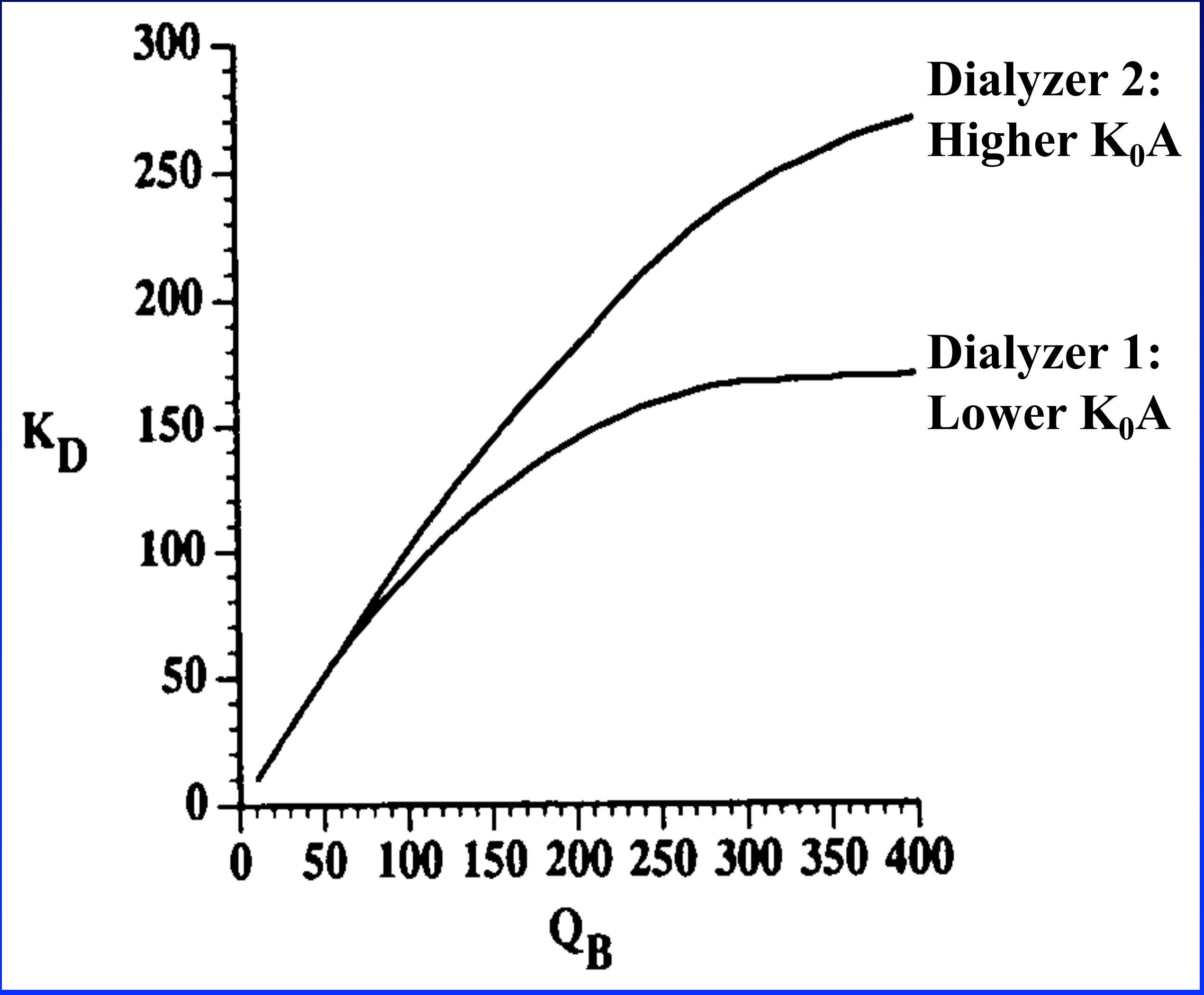
K_0A = permeability (K_0) * surface area (A)

Clearance (K_D)

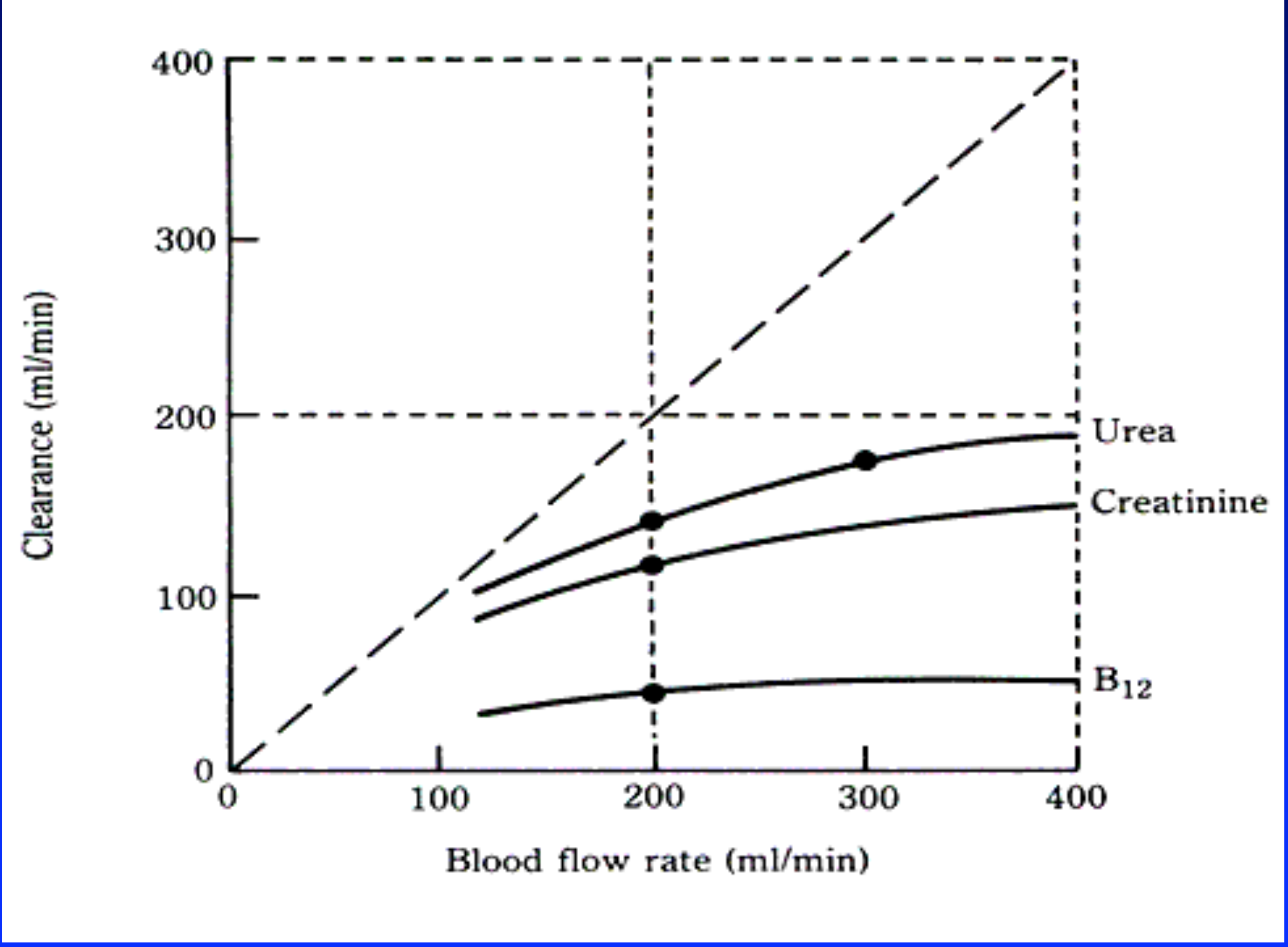
- Clearance (K_D) describes ability of a dialyzer to remove a substance from the blood
- Changes with the dialysis prescription

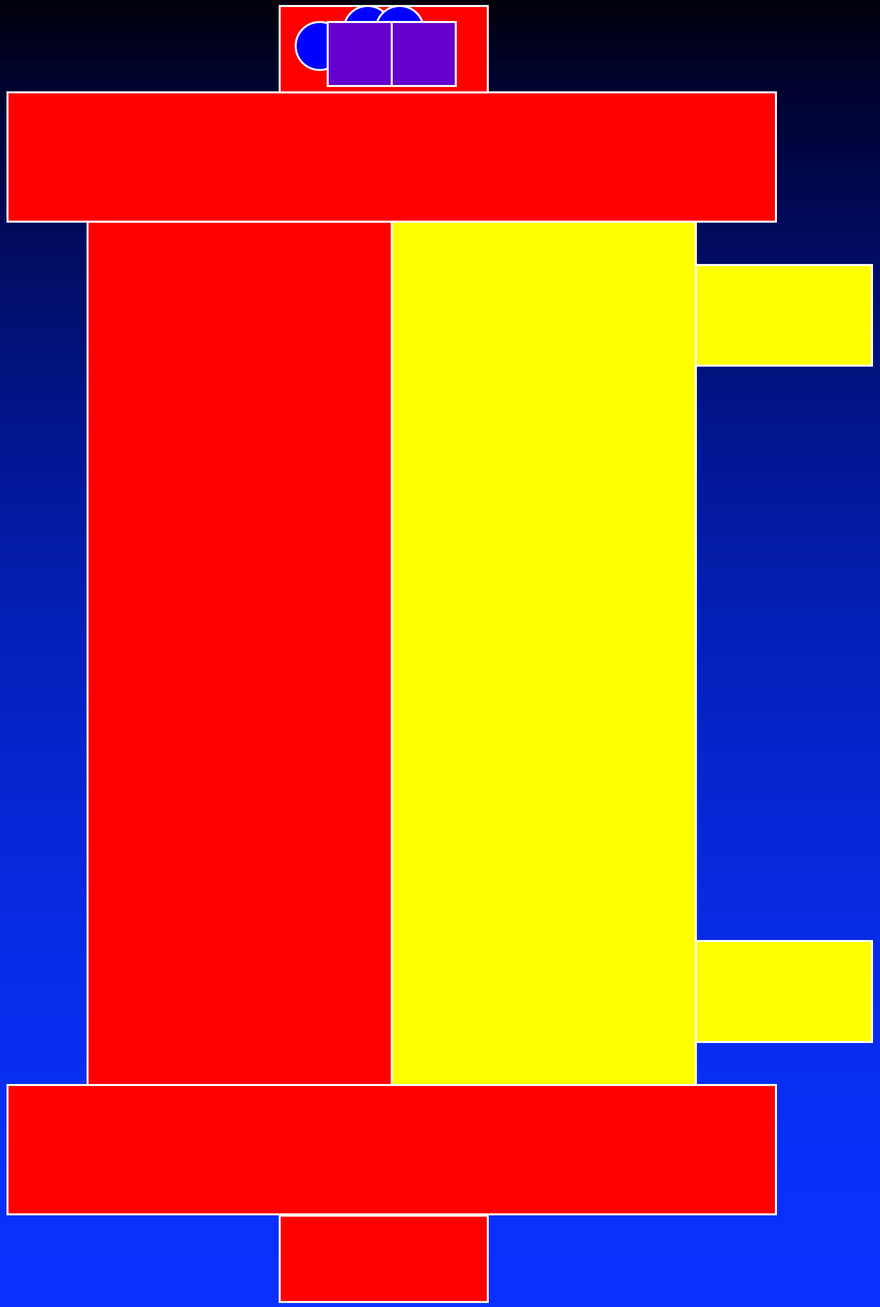
$$K_D = fx\,\{K_0A,\ Q_B,\ Q_D\}$$

Blood Flow and K_0A: Effect on Clearance



Blood Flow and Molecular Weight: Effect on Clearance





Small Molecules

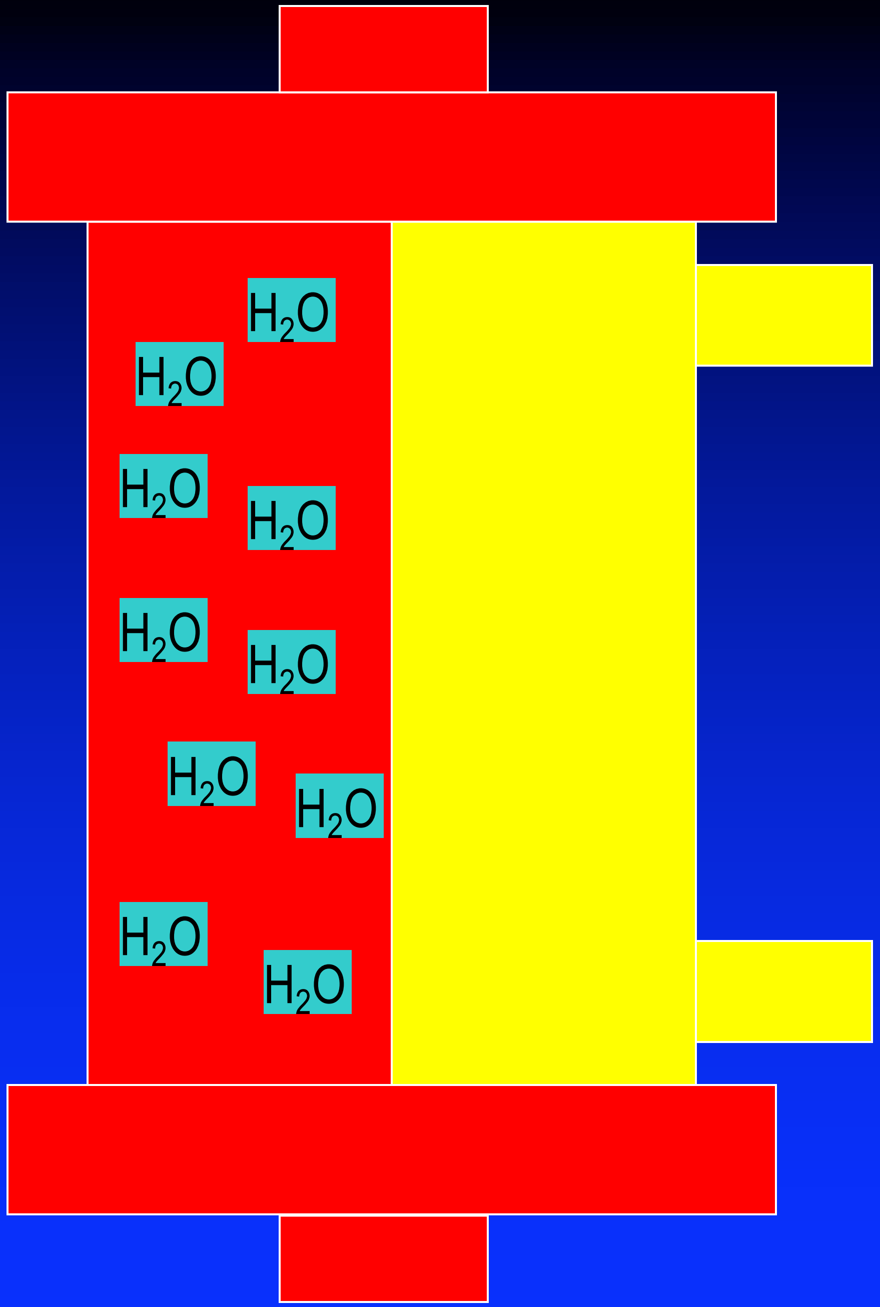
- Diffuse easily
- Higher Kd at given Qb, Qd

Larger Molecules

- Diffuse slowly
- Lower Kd at given Qb, Qd

Ultrafiltration (UF)

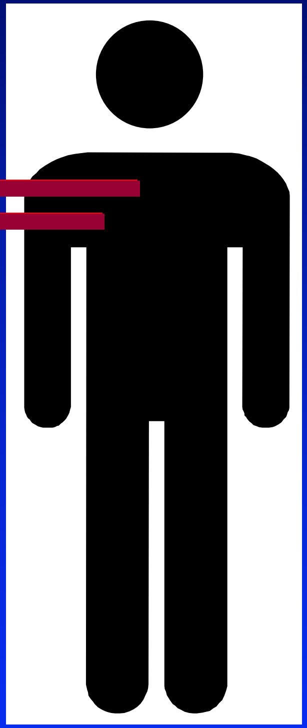
- Removal of water due to effects of pressure
- Solutes removed by convection at the same time
- UF capability of a dialyzer described by the UF coefficient (K_{uf}) – ml/h/mmHg



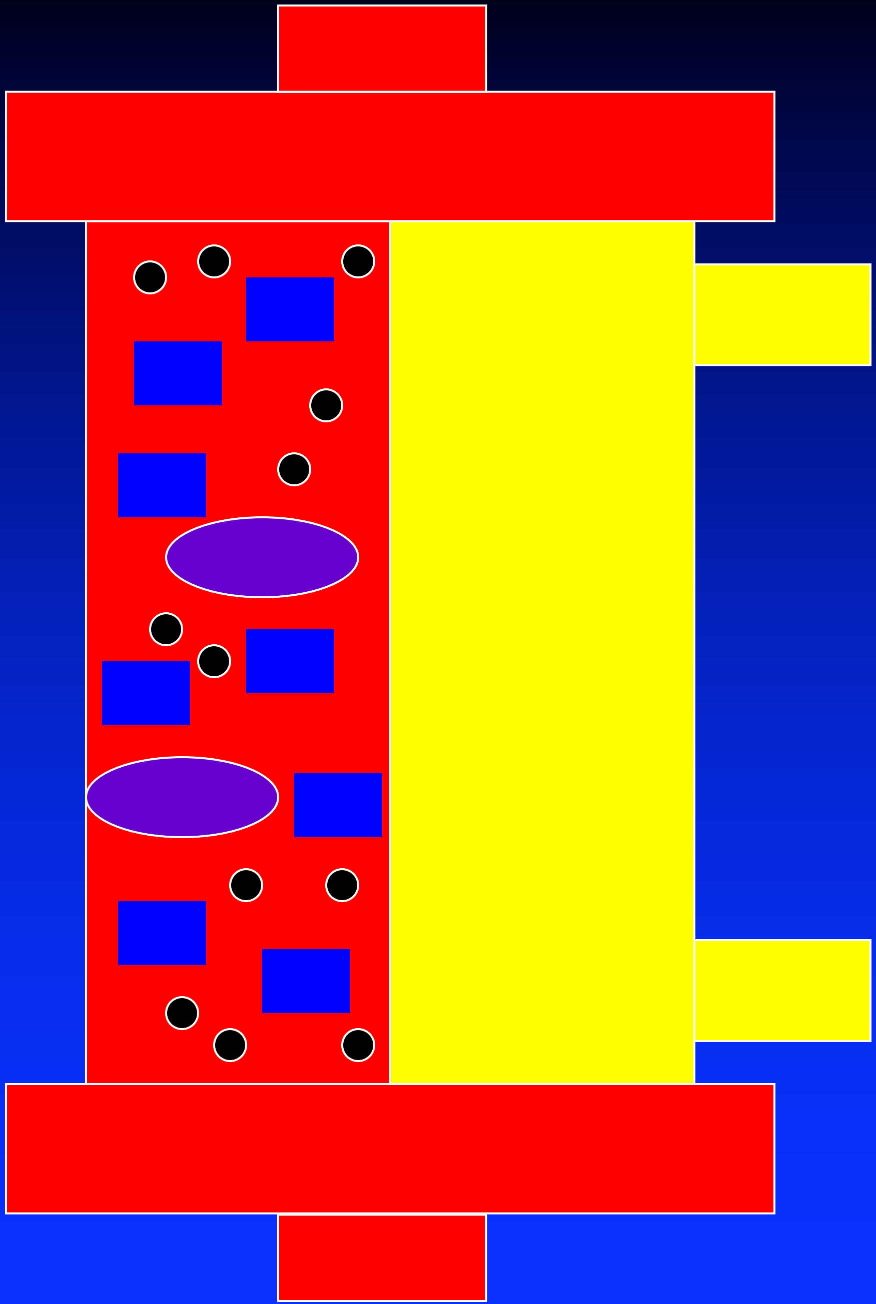
Ultrafiltration

- Hydrostatic pressure across membrane
- More water removal with ↑pressure, ↑K_{uf}

Continuous Renal Replacement Therapy (CRRT)



- Extracorporeal circuit similar to IHD
- Runs continuously
- Particle removal may be by diffusion, convection or a combination
- Fluid removal by ultrafiltration
- Clearance can be approximated by the total effluent rate

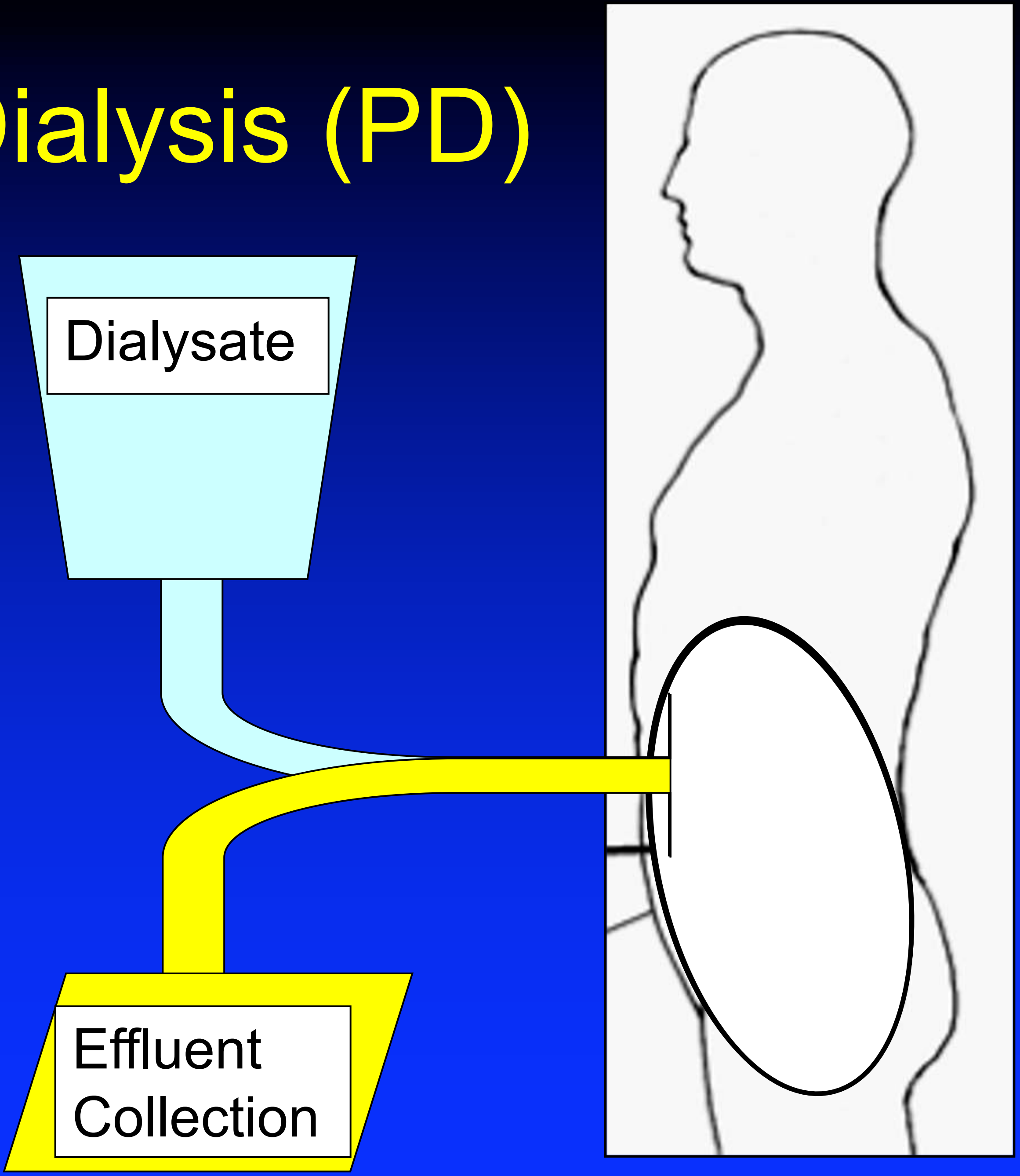


Convection

- Small and large molecules move equally
- Limit is cut-off size of membrane
- Significant solute loss over time in CRRT

Peritoneal Dialysis (PD)

- Sterile dialysate introduced into peritoneal cavity through a catheter
- Dialysate exchanged at intervals
- Particle removal by diffusion
- Fluid removal by ultrafiltration (osmotic gradient using dextrose)



HD and PD: Physiological Differences

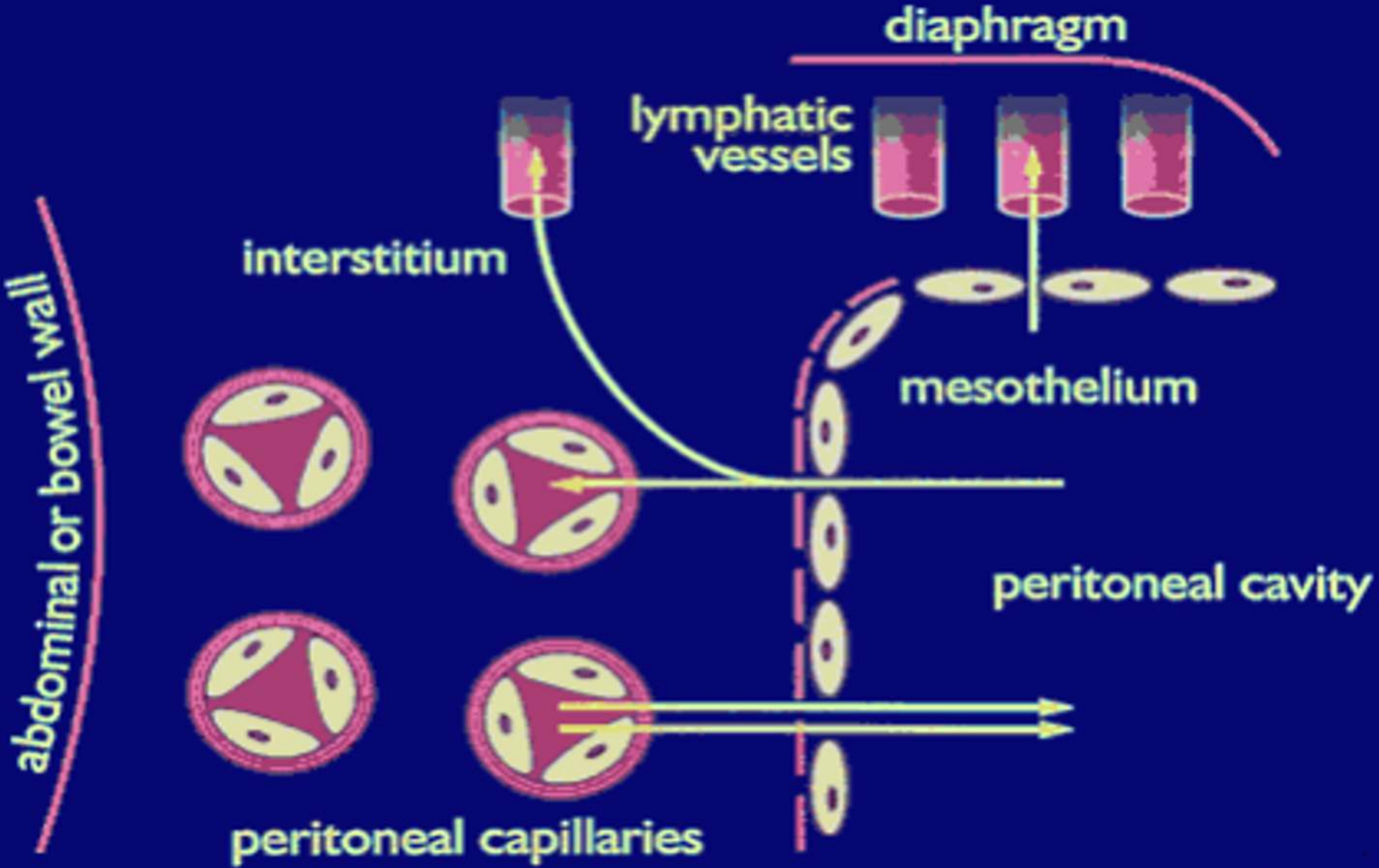
Hemodialysis

- Artificial membrane
- Higher blood flow
- Continuous dialysate flow
- Can use hydrostatic pressures for UF

Peritoneal Dialysis

- Natural membrane
- Capillary blood flow in peritoneum
- “Stationary” dialysate in most forms of PD
- Different approach to UF is required

PD Transport:
A Complex Scheme



The “Three Pore” Model of Peritoneal Transport

- Large pores (>20 nm diameter)
  - Few in number (<10%)
  - Can permit protein transport
- Small pores (4 – 6 nm diameter)
  - Majority (90%)
  - Transport most small molecules
- Ultra-small pores (aquaporins)
  - 1–2%; account for nearly half of water flow

Peritoneal Transport: An Interaction of Three Separate Processes

- Diffusion
- Ultrafiltration
- Fluid absorption

Diffusion in PD: Key Factors

- Concentration gradient of solute (D/P)
- Mass transfer area coefficient (MTAC)
  - Effective peritoneal surface area
    - Surface area + vascularity
  - Diffusive characteristics of membrane for solute in question (permeability)

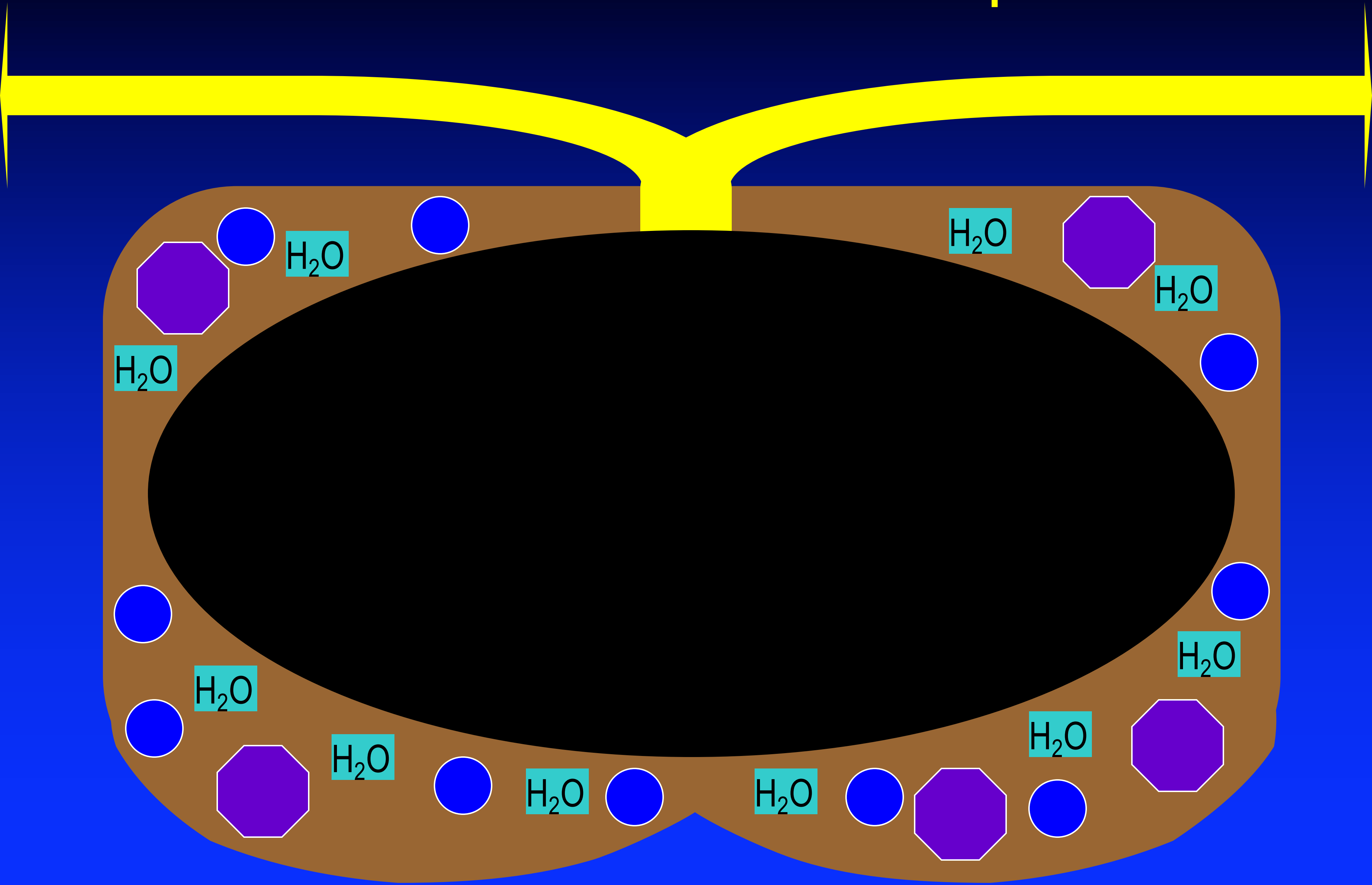
Ultrafiltration in PD: Key Factors

- Osmotic gradient
- Reflection coefficient
  - i.e., how well the osmotic particle stays in the dialysate ("1" would be perfect)
- UF coefficient
- Hydrostatic and oncotic pressure gradients

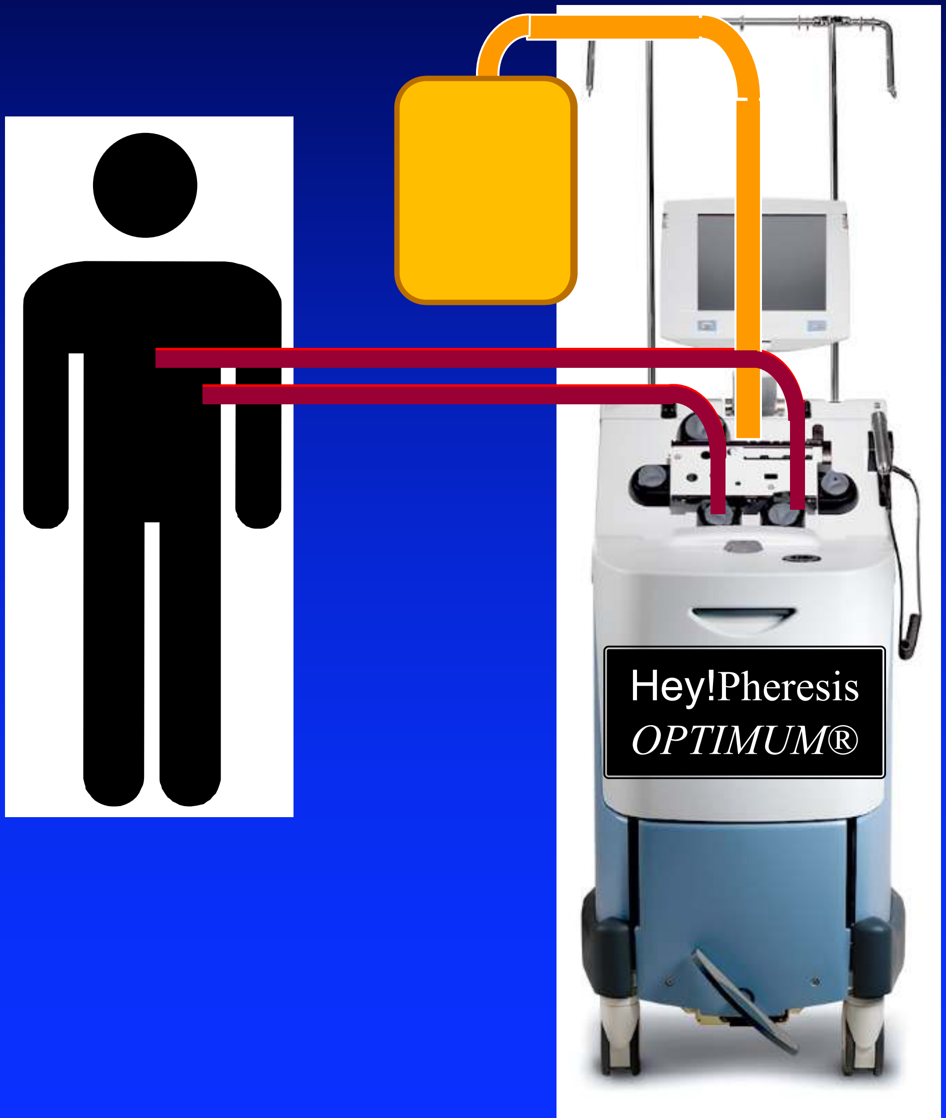
Fluid Absorption in PD

- Direct lymphatic absorption of peritoneal fluid
- Tissue absorption of peritoneal fluid
- Limits ultrafiltration and mass transfer
  - Higher levels of peritoneal absorption reduce net ultrafiltration

Schematic of Molecular Transport in PD

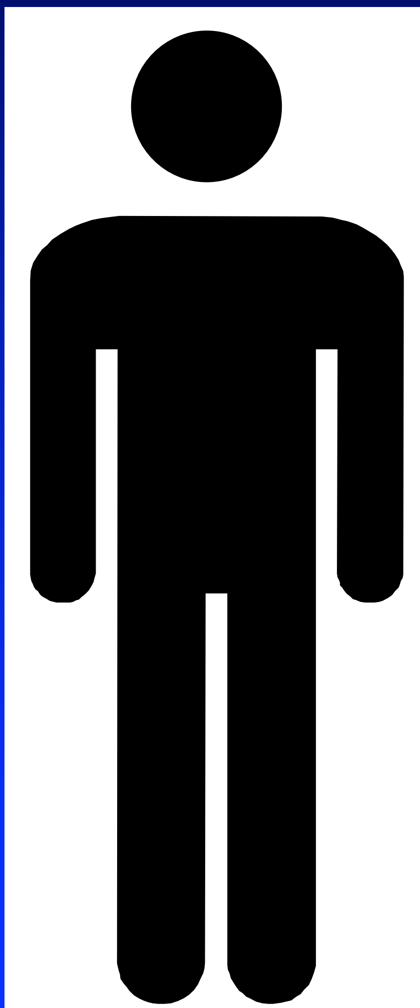


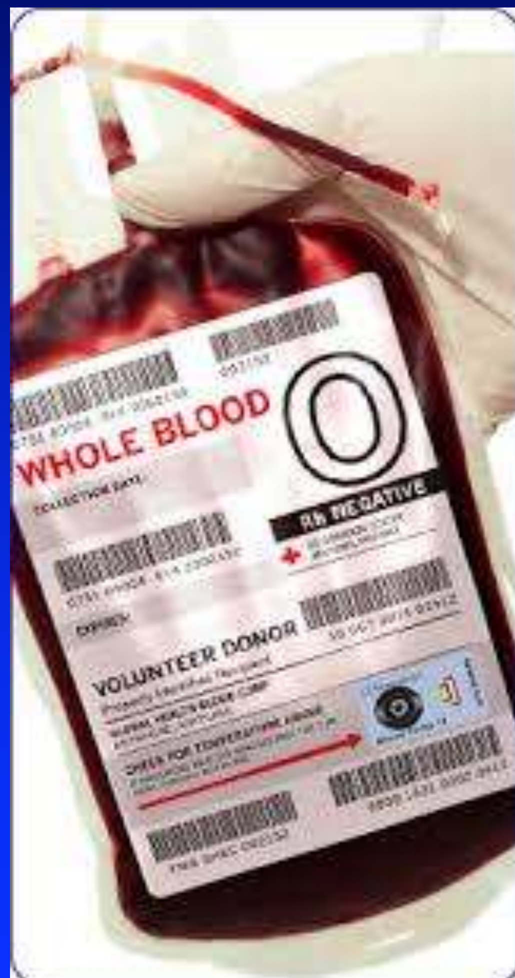
Apheresis



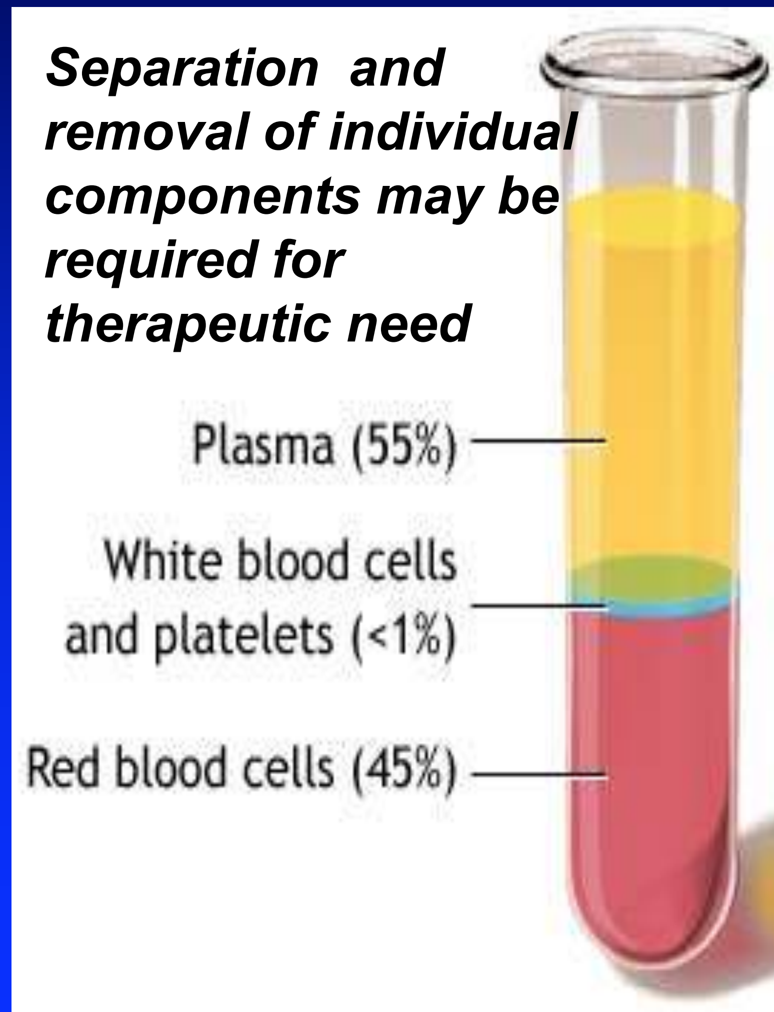
- “*Apheresis*”: Greek, “To take away or separate”
- Blood perfuses extracorporeal circuit
- Blood components separated; selected component removed
- If large volume removed replacement is required
- Uses include therapeutic indications or for blood component harvest

Components of Whole Blood





Separation and removal of individual components may be required for therapeutic need



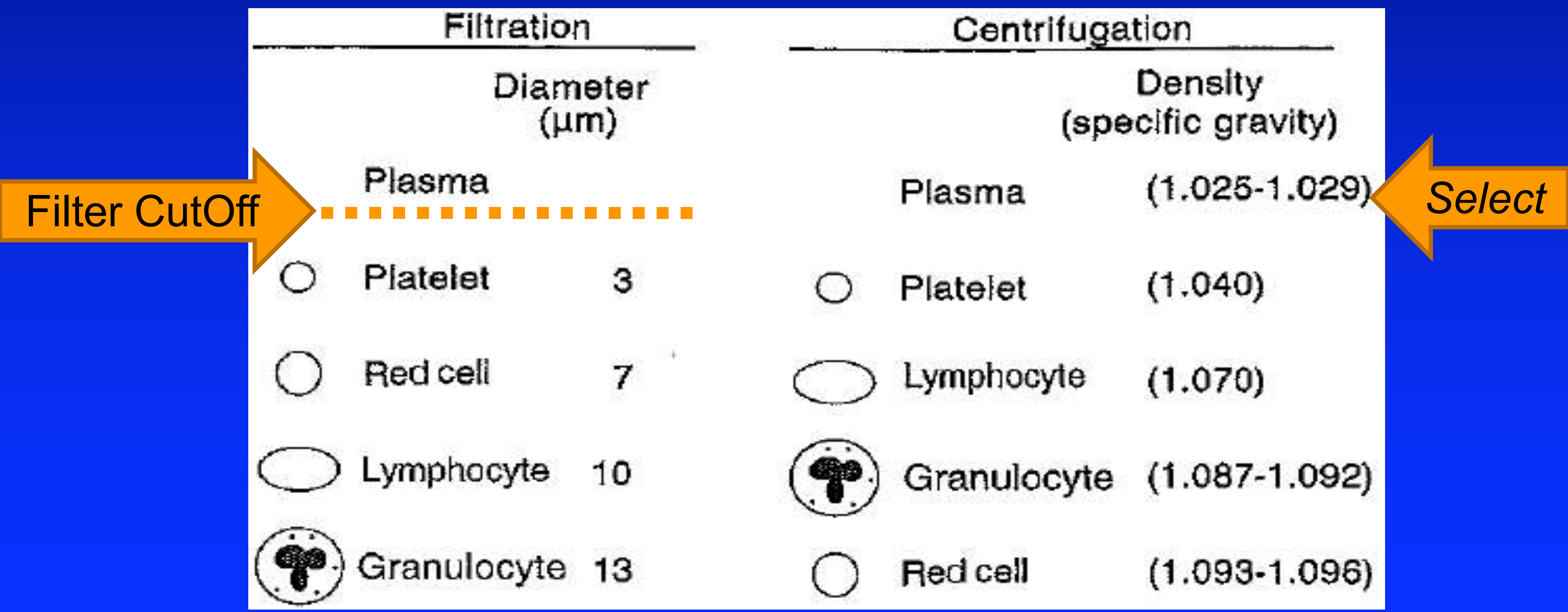
Apheresis Methods

Filtration

- Blood separation across a membrane by ***size***

Centrifugation

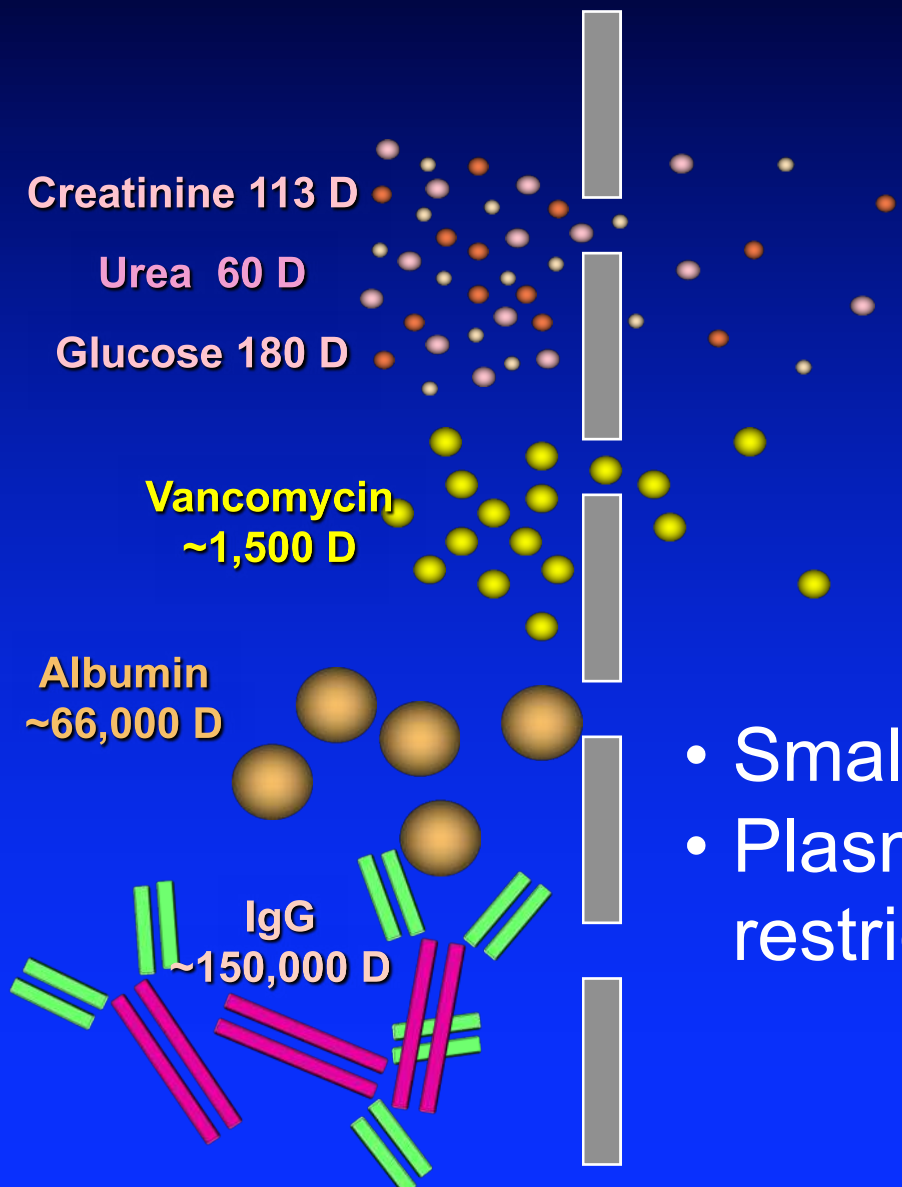
- Blood component separation by ***density***



Filtration	Diameter (µm)
Plasma	
Platelet	3
Red cell	7
Lymphocyte	10
Granulocyte	13

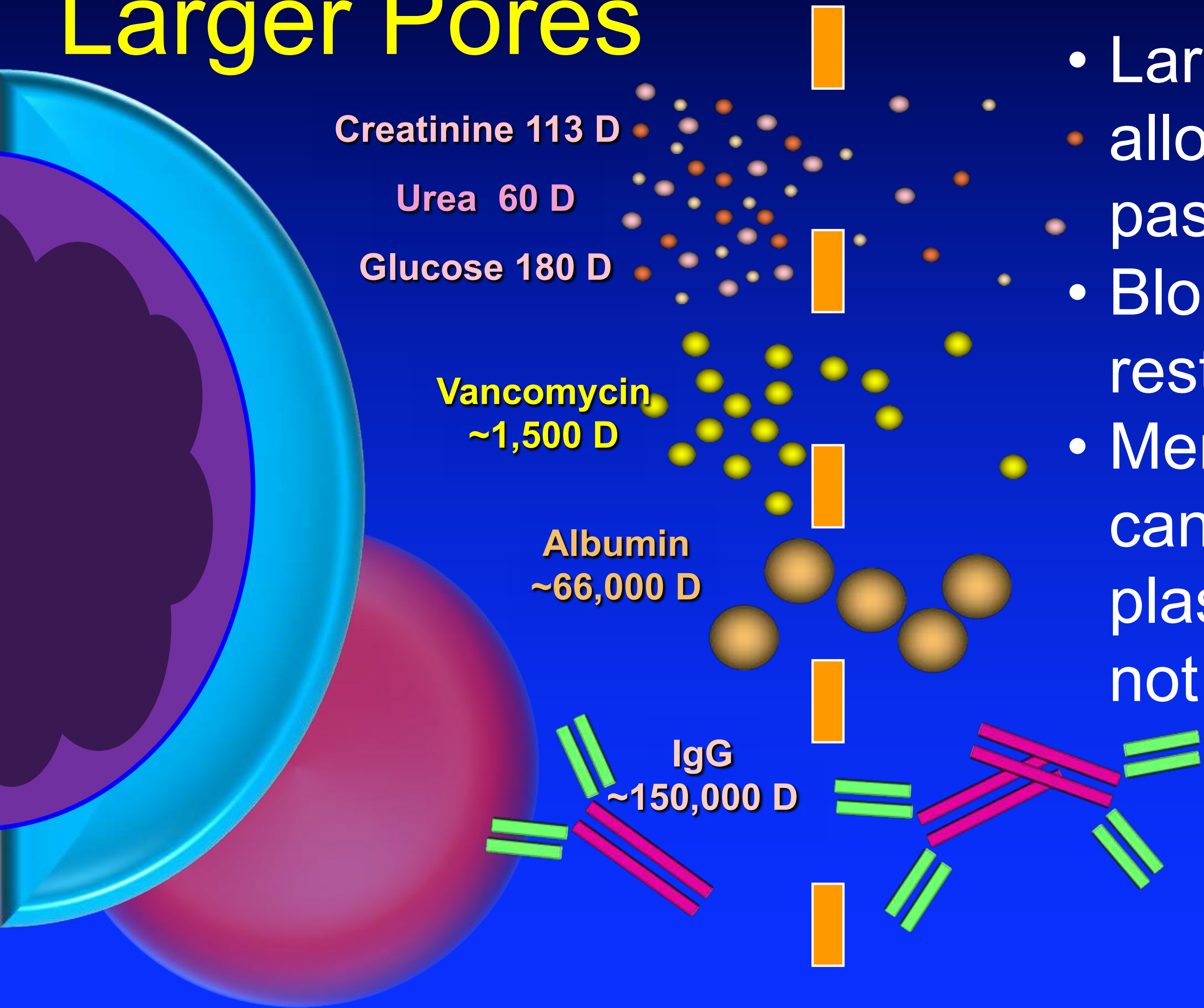
Centrifugation	Density (specific gravity)
Plasma	(1.025-1.029)
Platelet	(1.040)
Lymphocyte	(1.070)
Granulocyte	(1.087-1.092)
Red cell	(1.093-1.096)

Effect of Pore Size In Dialysis



- Small molecules pass;
- Plasma proteins are restricted

Membrane Apheresis Employs Larger Pores

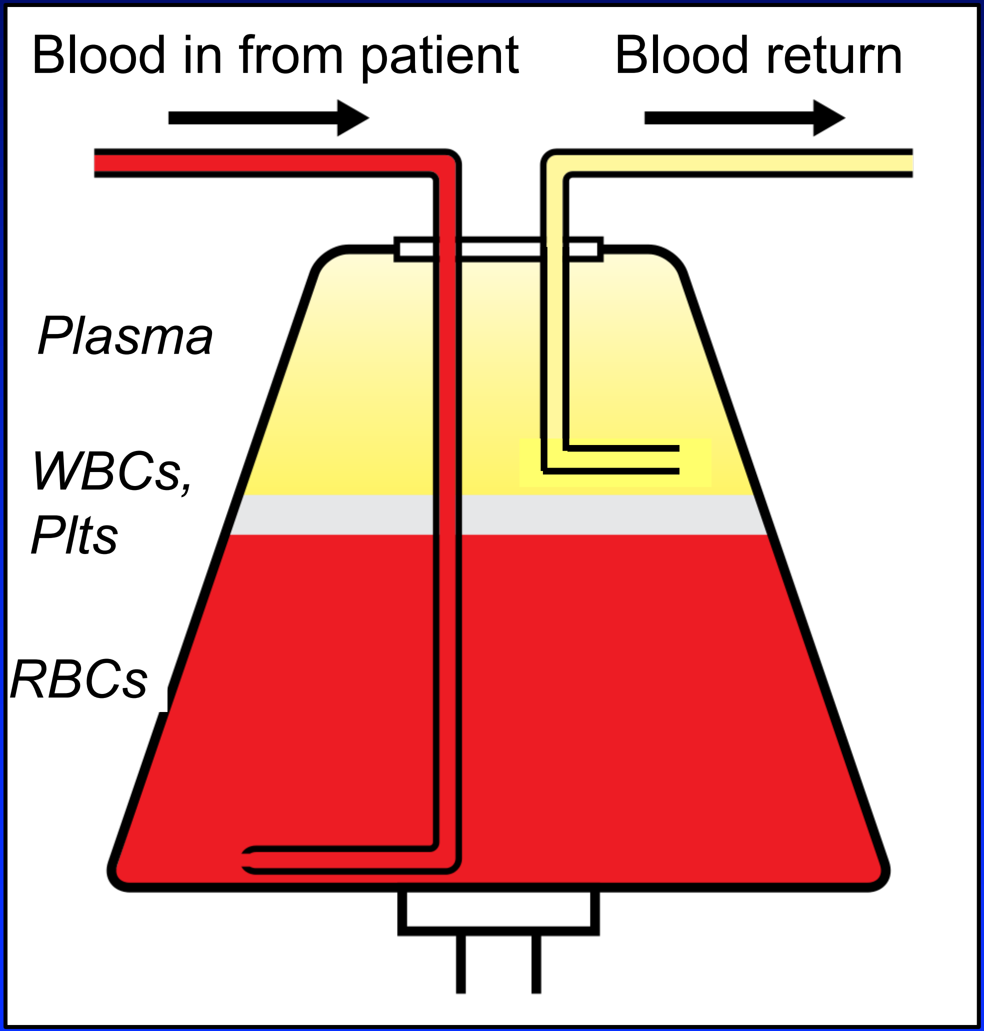


- Larger pores will allow proteins to pass through
- Blood cells are restricted
- Membrane system can be used for plasmapheresis, not cytapheresis

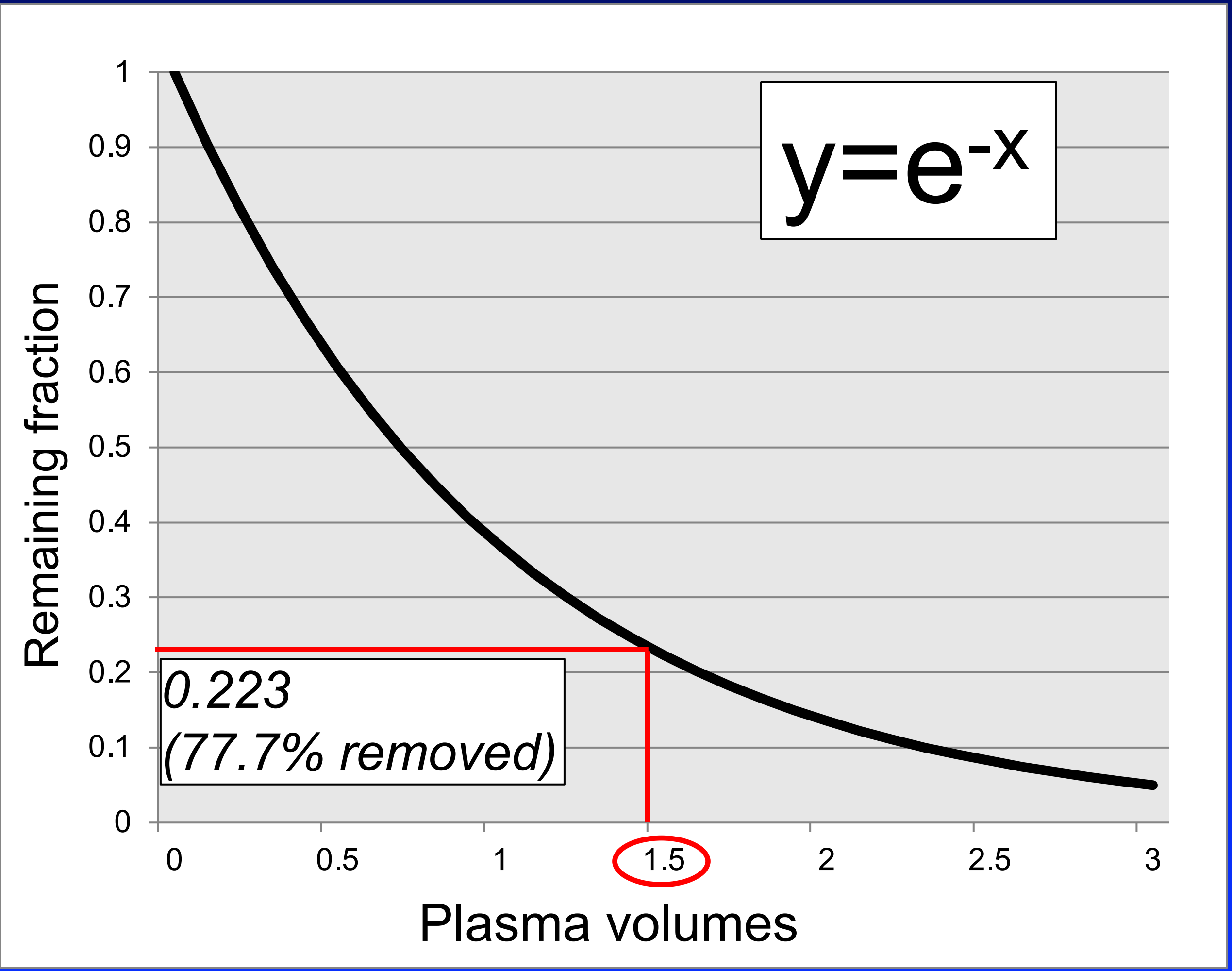
Apheresis by Centrifugation

- Spinning centrifuge separates blood components by density
- Specific component may be selected for removal by choosing appropriate layer
- Permits plasmapheresis and cytapheresis

Apheresis by Centrifugation



Fraction Removed from Plasma by Plasma Volume Replaced



- IgG: only 45% intravascular
- 1.5 vol removes ~35% of total body IgG
- Re-equilibration within ~2 days
- Repeated session QOD often needed

Physiology of Blood Purification: Summary

- Basic concepts of ***diffusion*** and ***convection*** underlie all dialysis methods
  - **HD**: Diffusion + hydrostatic-pressure UF
  - **CRRT**: Diffusion and/or convection + hydrostatic-pressure UF
  - **PD**: Diffusion + osmotic-pressure UF
- Blood components separated by centrifugation or membrane in **apheresis**