Principal Equations of Dialysis

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An Equation is…

- Math:
  - "A statement that each of two statements are equal to each other."

$$Y^2 = 3x^3 + 2x + 7$$

- Chemistry:
  - " A symbolic expression that represents a chemical change as observed in a laboratory".

$$2H_2O = H_3O^+ + OH^-$$

- Medical:
  - " An expression made up of two members connected by the sign of equality".

Clearance x Time = Volume (Kt/V = 1)

Equation Types

- Hypothesis
  - Relationships implied without supporting evidence
- Empirical
  - Based solely on experiment and observation
  - No reference to scientific principals
- Theoretical
  - A formulation of apparent relationships
  - Deals with science concepts and knowledge
  - Implies considerable evidence of support
  - Pure science as opposed to applied science

K/DOQI Guidelines for Classification

Stage	Description	GFR (mL/min)	Action
1	Damage with normal or high GFR	>90	CVD risk reduction; diagnose and treat; slow progression
2	Mild decrease in GFR	60-89	Monitor progression; nutritional assessment and intervention
3	Moderate decrease in GFR	30-59	Evaluate and treat complications
4	Severe decrease in GFR	15-29	Prepare for replacement therapy
5	Kidney Failure	<15	Replacement therapy if uremia is present

Question:

Is there a way to determine which classification a patient falls into and what information do we need to know to figure this out?

MDRD Study Equation for calculating GFR

GFR (mL/min per 1.73 m^2 body surface area) =

$186 \times (S_{Cr})^{-1.154} \times (Age)^{-0.203} \times (0.742 \text{ if female})$

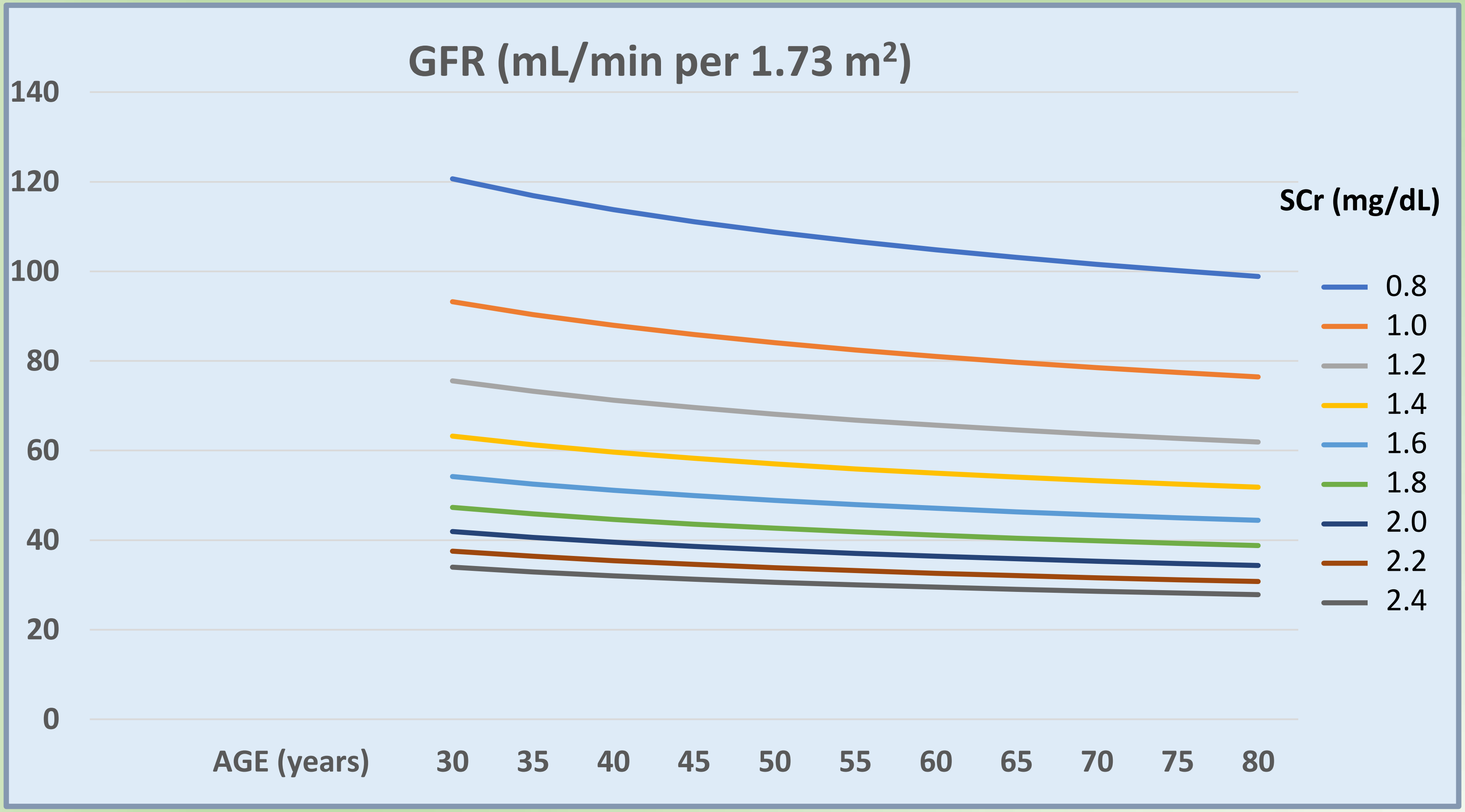
$\times (1.210 \text{ if African-American})$

S_{Cr} = serum creatinine measured in mg/dL

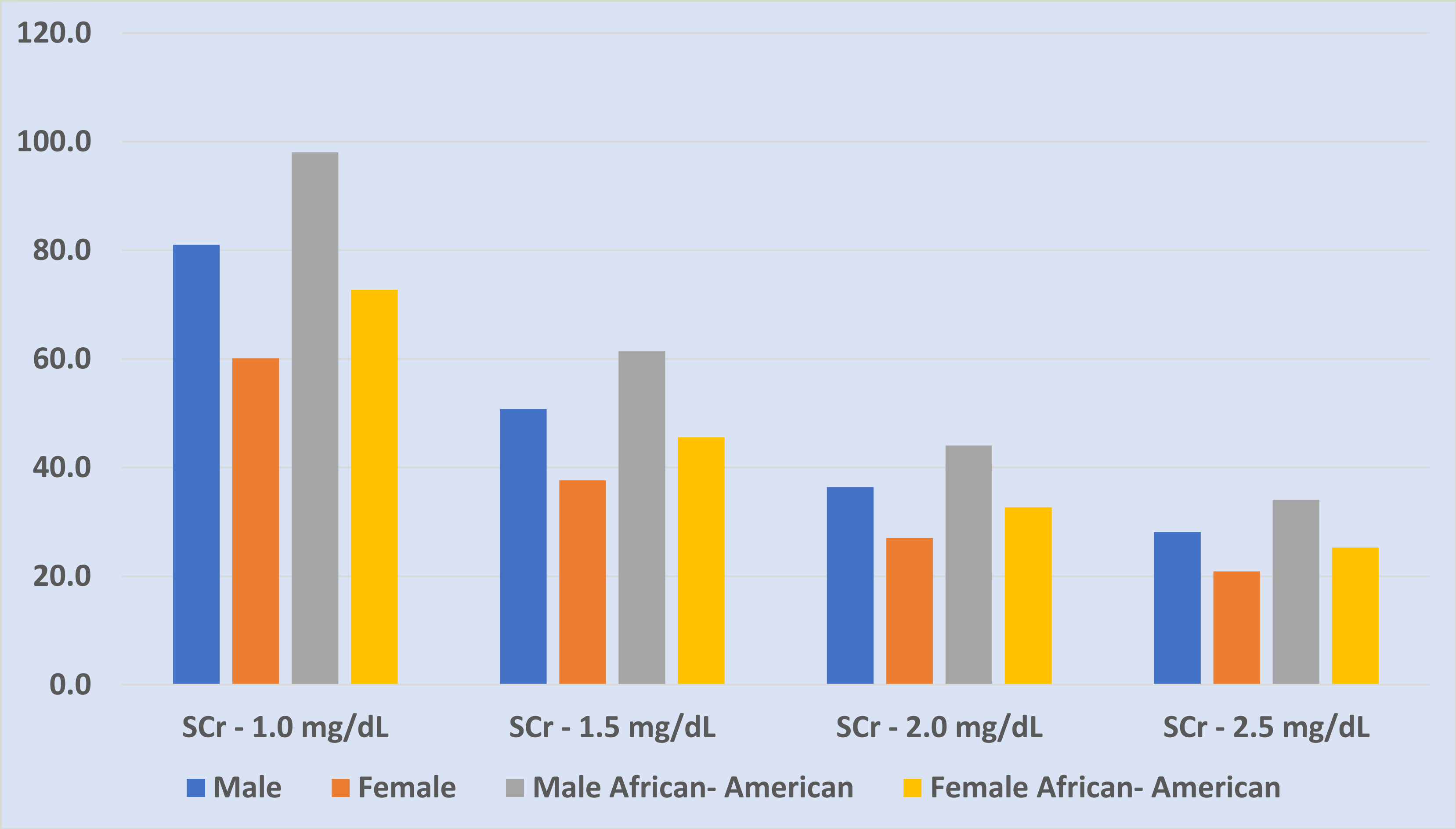
- Not validated in:
  - Diabetic kidney disease
  - Patients with serious comorbid conditions
  - Normal persons
  - Persons older than 70.

MDRD = Modification of Diet in Renal Disease

GFR vs. Age and Serum Creatinine



GFR (mg/min) vs. Serum Creatinine (mg/dL)
(Gender and Race)



Question:

If we are going to treat the patient, we need a way to measure our success. Urea is the major marker used.

Is there a way to know how much urea a patient will generate based on their diet intake of protein?

The Conversion Equation
Protein to Urea Nitrogen

$$DPI = PCR = 9.35\,G + 11.04$$

or

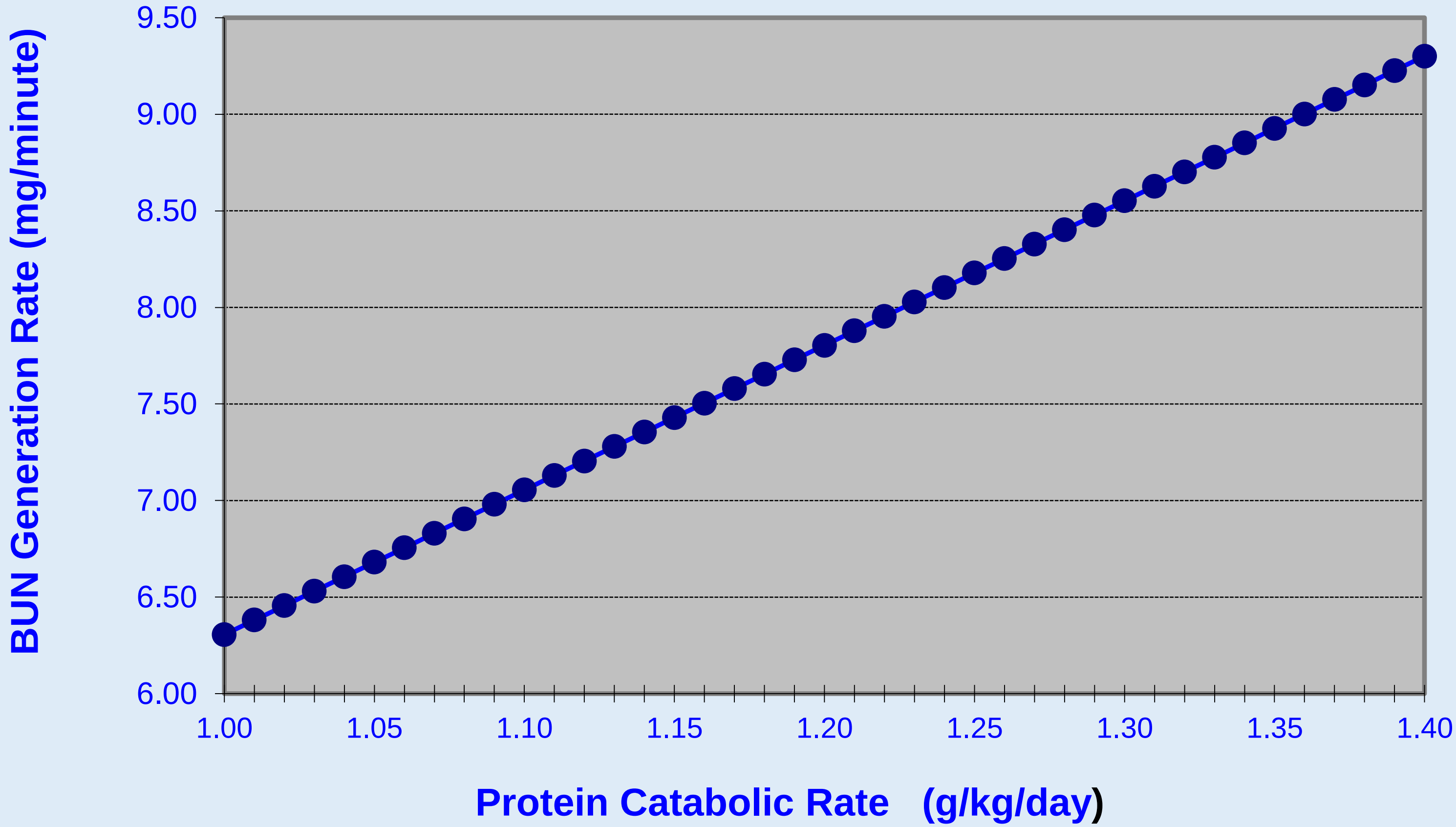
$$G = (PCR - 11.04) / 9.35$$

DPI = Dietary Protein Intake (grams/day)

PCR = Protein Catabolic Rate (grams/day)

G = Generation Rate (milligrams of urea nitrogen/minute)

BUN Generation Rate vs. Protein Catabolic Rate



BUN Generation Rate (milligrams/minute)

PCR g/kg/day	Patient Weight (kg)						
	50.0	**60.0**	**70.0**	**80.0**	**90.0**	**100.0**	**110.0**
0.80	3.10	3.95	4.81	5.66	6.52	7.38	8.23
0.90	3.63	4.59	5.56	6.52	7.48	8.44	9.41
1.00	4.17	5.24	6.31	7.38	8.44	9.51	10.58
1.10	4.70	5.88	7.05	8.23	9.41	10.58	11.76
1.20	5.24	6.52	7.80	9.09	10.37	11.65	12.94
1.30	5.77	7.16	8.55	9.94	11.33	12.72	14.11
1.40	6.31	7.80	9.30	10.80	12.30	13.79	15.29

BUN Increase/Day in a ESRD Patient - Example

- Assume:
  - Patient's Weight = 70.0 kilograms
  - PCR = 1.2 g/kg/day = Generation rate of 7.80 mg/min
  - Patient's Fluid Volume = 58% of Patient Weight
- Then:
  - 70 x 0.58 = 40.6 liters = 406 deciliters
  - BUN generated /day = 7.80 mg/min x 1440 min/day = 11,232 mg/day
  - 11,232 mg/day / 406 dL = 27.7 mg/dL/day.

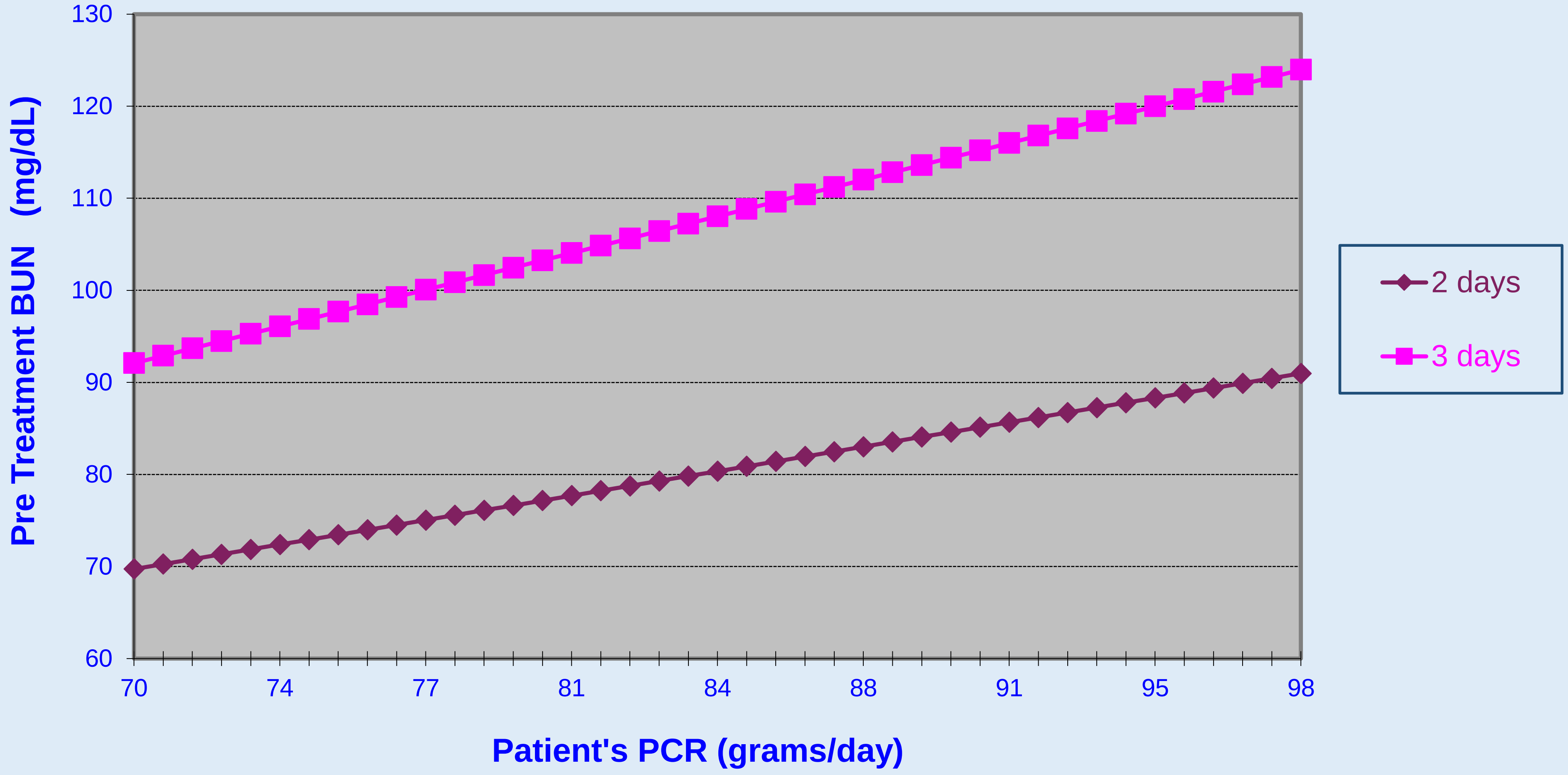
BUN Generated/day (grams)

PCR g/kg/day	Patient Weight (kg)						
	50.0	**60.0**	**70.0**	**80.0**	**90.0**	**100.0**	**110.0**
0.80	4.46	5.69	6.92	8.16	9.39	10.62	11.85
0.90	5.23	6.62	8.00	9.39	10.77	12.16	13.55
1.00	6.00	7.54	9.08	10.62	12.16	13.70	15.24
1.10	6.77	8.46	10.16	11.85	13.55	15.24	16.94
1.20	7.54	9.39	11.24	13.08	14.93	16.78	18.63
1.30	8.31	10.31	12.31	14.32	16.32	18.32	20.32
1.40	9.08	11.24	13.39	15.55	17.71	19.86	22.02

Patient BUN Gain/Day (mg/dL)

PCR g/kg/day	Patient Weight (kg)						
	50.0	60.0	70.0	80.0	90.0	100.0	110.0
0.80	15.38	16.36	17.05	17.58	17.99	18.31	18.58
0.90	18.04	19.01	19.71	20.23	20.64	20.97	21.23
1.00	20.69	21.67	22.37	22.89	23.30	23.62	23.89
1.10	23.35	24.32	25.02	25.54	25.95	26.28	26.54
1.20	26.00	26.98	27.68	28.20	28.61	28.93	29.20
1.30	28.66	29.63	30.33	30.86	31.26	31.59	31.85
1.40	31.31	32.29	32.99	33.51	33.92	34.24	34.51

Patient's PCR vs. Pre Treatment BUN mg/dL
(Patient's previous post Tx BUN = 25 mg/dL)



Question:

Since the patient will need to have his/her urea removed, and there are so many different dialyzers, is there a simple way to measure urea removal performance for a given dialyzer?

Dialyzer BUN Clearance

THE EMPIRICAL FORMULA FOR BLOOD CLEARANCE IS:

$$C_X = \left(\frac{A_X - V_X}{A_X} \right) Q_B$$

WHERE:

C_X = CLEARANCE OF SOLUTE X. (mL/min)

A_X = ARTERIAL CONCENTRATION OF X. (mg/dL)

V_X = VENOUS CONCENTRATION OF X. (mg/dL)

Q_B = BLOOD FLOWRATE (mL/min)

Urea Clearance in Blood and Dialysate

$$C_X = ((80 - 10)/80) \times 300 = 262 \text{ mL/min}$$

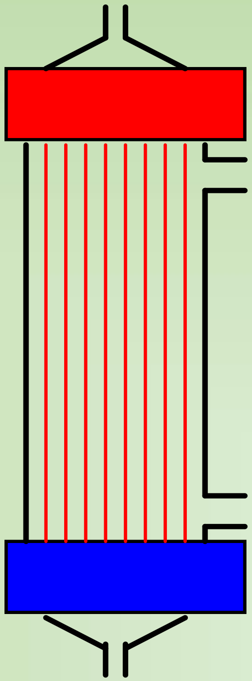
Dialyzer: iP4U

K_OA = 900 mL/min
Q_B = 300 mL/min
Q_D = 600 mL/min

$$Q_B \times \Delta BUN_B = Q_D \times \Delta BUN_D$$

300 x (80 – 10) = 600 x (35 – 0)
300 x 70 = 600 x 35
21,000 = 21,000

ARTERIAL BLOOD
80 mg/dL



⇒ DIALYSATE OUT
35.0 mg/dL

⇐ DIALYSATE IN
0.0 mg/dL

VENOUS BLOOD
10.0 mg/dL

Question:

It's not very practical to measure blood urea nitrogen concentrations to determine clearance.

Is there an equation that can calculate the expected clearance based on a known blood flowrate, dialysate flowrate and dialyzer used?

Determining the $K_O A$ for a Dialyzer

$$KoA = \left[Q_B \Big/ 1 - \frac{Q_B}{Q_D} \right] 1n \left[\frac{1 - \dfrac{C_X}{Q_D}}{1 - \dfrac{C_X}{Q_B}} \right]$$

Where: C_X = Clearance of solute, X

Q_B = Blood flowrate

Q_D = Dialysate flowrate

ln = Natural logarithm

= e = 2.718281828......

Calculating Clearance using KoA

$$C_X = \frac{Q_B\left(e^{KoA\left(\frac{1}{Q_B}-\frac{1}{Q_D}\right)}-1\right)}{e^{KoA\left(\frac{1}{Q_B}-\frac{1}{Q_D}\right)}-\frac{Q_B}{Q_D}}$$

C_x = Clearance of x.

Q_B = Blood Flowrate

Q_D = Dialysate Flowrate

$Q_B \neq Q_D$

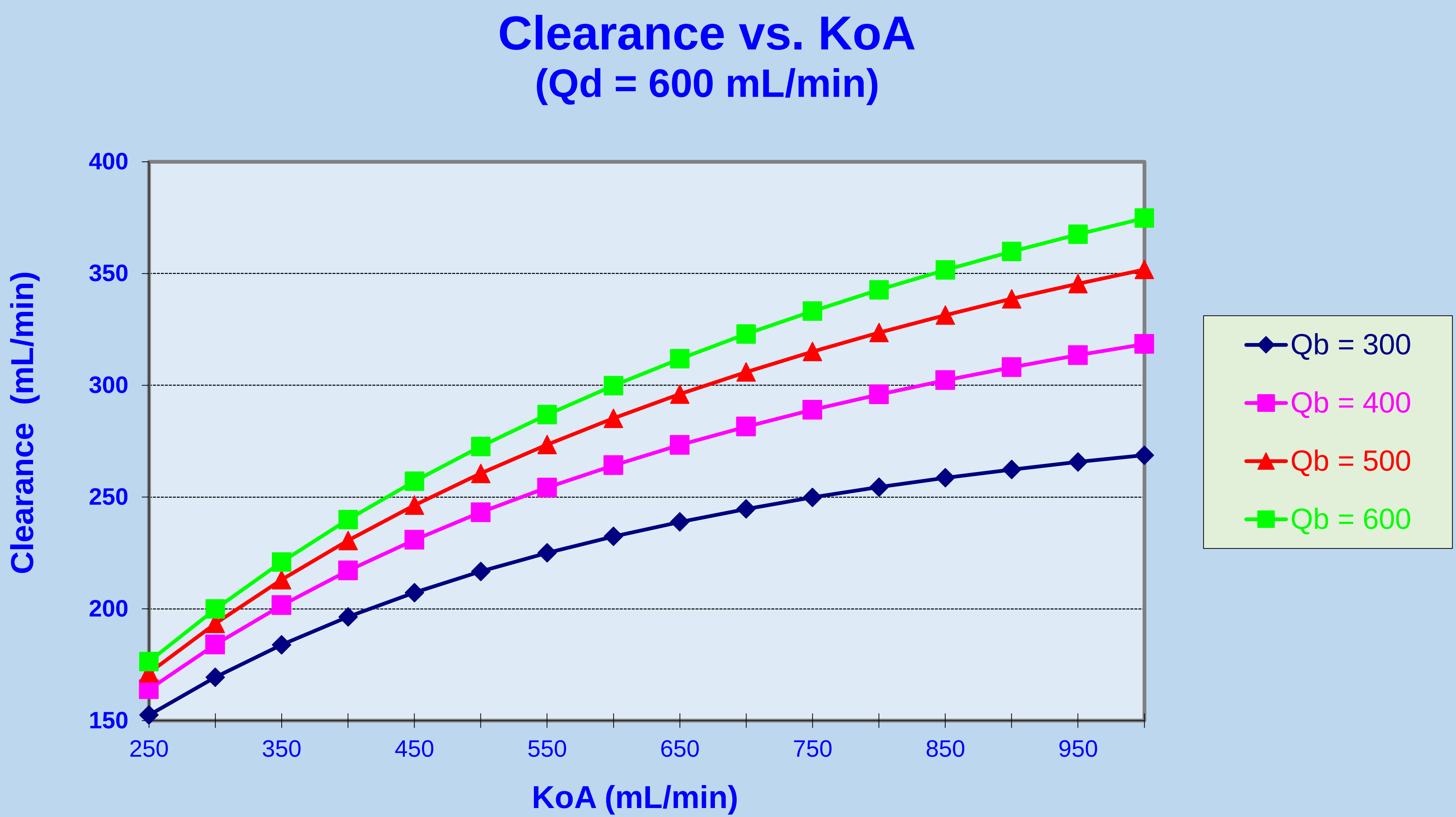
KoA = Clearance Coefficient

e = 2.718281828….

BUN of Venous Blood based on Dialyzer KoA

QB = 300 mL/min QD = 600 mL/min

KoA (mL/min)	Clearance (mL/min)	Arterial Blood BUN Values (mg/dL) 70	80	90	100	110
500	217	19.4	22.1	24.9	27.7	30.4
600	232	15.9	18.1	20.4	22.7	24.9
700	245	12.8	14.7	16.5	18.3	20.2
800	254	10.7	12.3	13.8	15.3	16.9
900	262	8.9	10.1	11.4	12.7	13.9
1000	269	7.2	8.3	9.3	10.3	11.4
1100	274	6.1	6.9	7.8	8.7	9.5
1200	278	5.1	5.9	6.6	7.3	8.1



Clearance vs. KoA
(Qd = 600 mL/min)
Clearance (mL/min)
400
350
300
250
200
150
250
350
450
550
650
750
850
950
KoA (mL/min)
Qb = 300
Qb = 400
Qb = 500
Qb = 600

Question:

Once the fluid volume of the patient is known and the dialyzer clearance calculated, is there an equation to determine the time of dialysis?

Length of Treatment

$$Kt/V = 1.3$$

K = Dialyzer Clearance (mL/min)

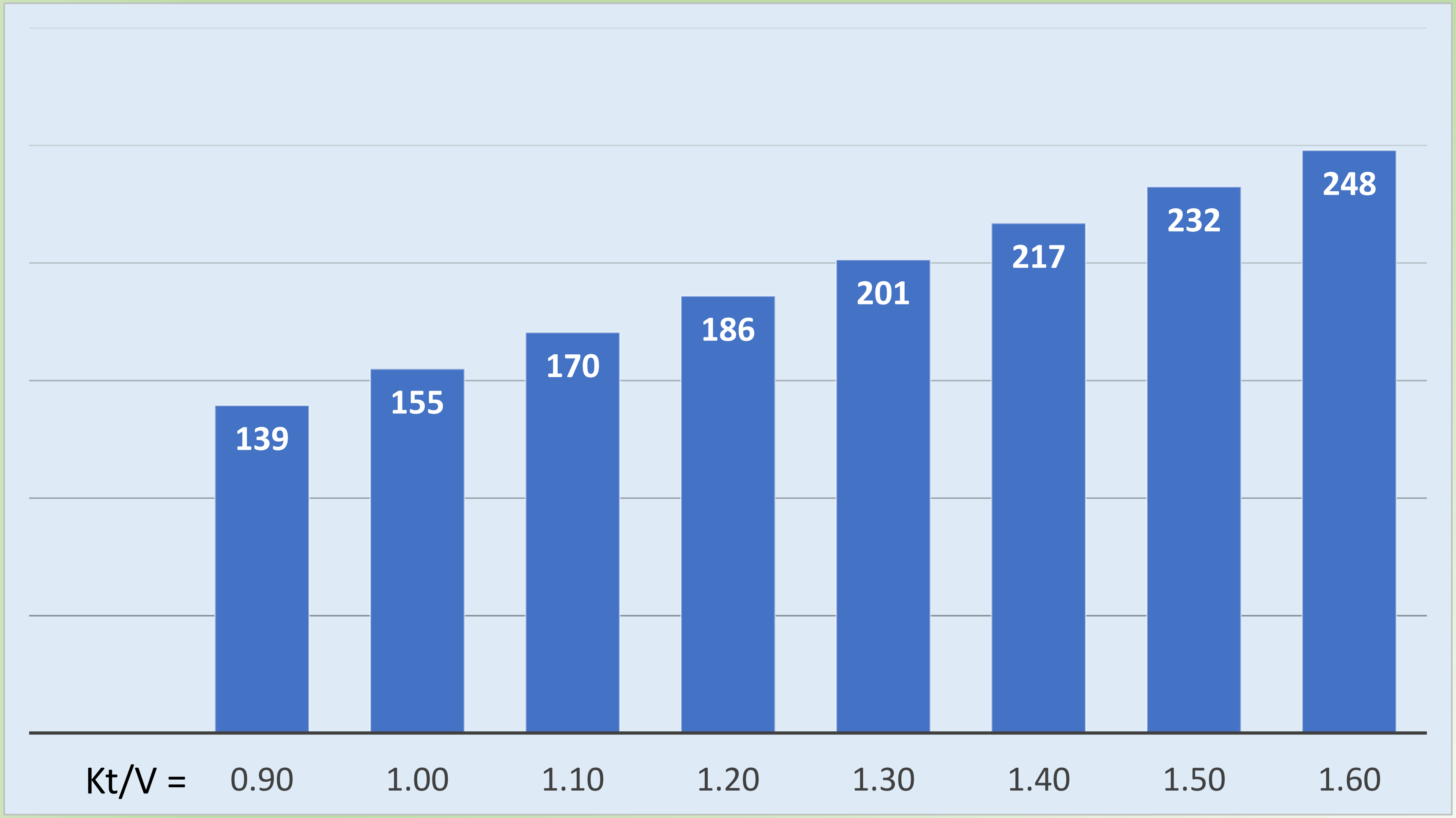
t = Time of Treatment (min)

V = Patient's volume (mL)

$$t = (1.3 \times V)/K$$

Treatment Time (minutes) vs. Kt/V

(Patient = 70 kg, C_x = 262 mL/min)



Question:

Once the clearance of the dialyzer and time of treatment are known, is there a way to estimate how the urea is reduced in the patient while she/he is being dialyzed?

Urea Reduction Equation

$$C = C_0 e^{-Kt/V} + G/K (1 - e^{-Kt/V})$$

C = Plasma BUN Concentration (mg/mL)*

C_0 = Predialysis BUN Concentration (mg/mL)*

K = Dialyzer Clearance (mL/min)

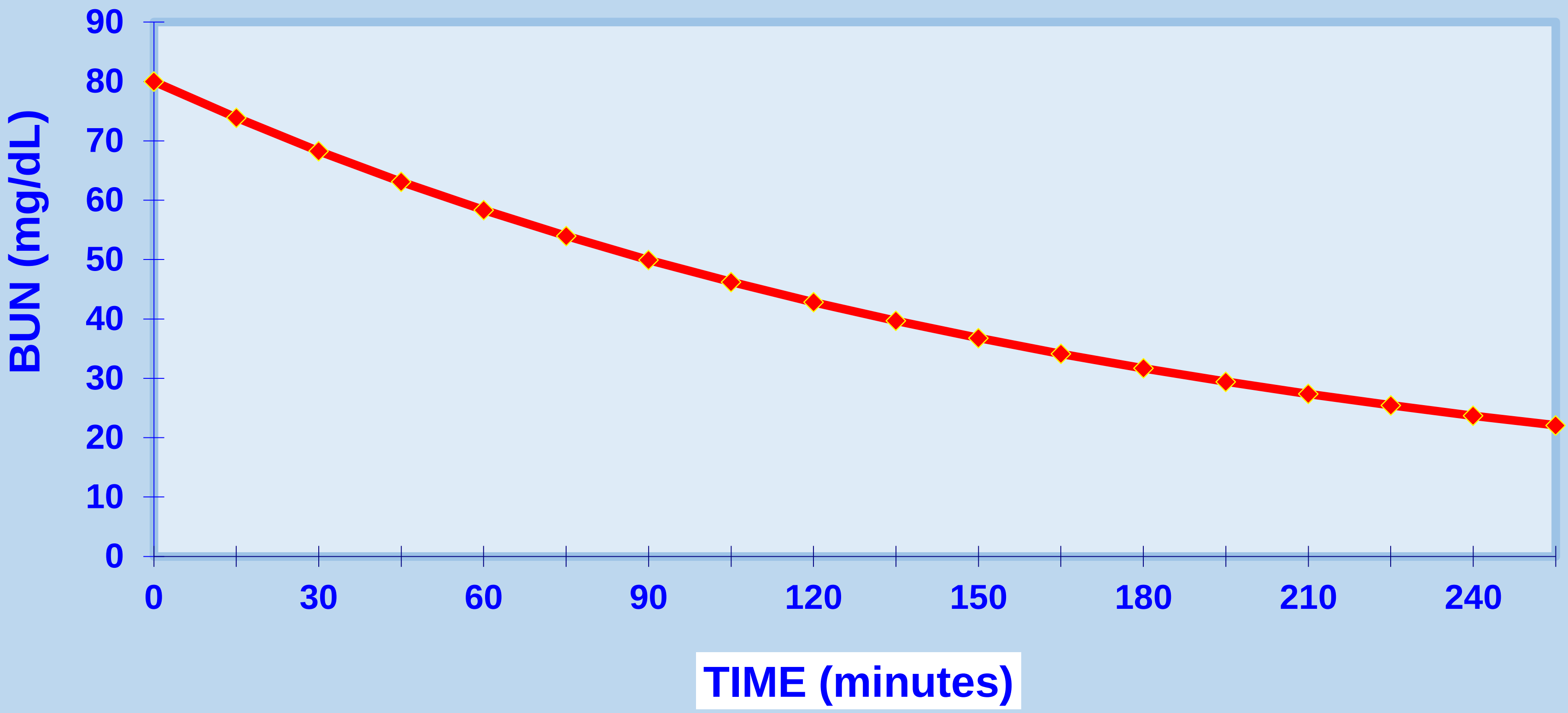
t = time (minutes)

V = Patient Volume (mL)

G = Generation of urea (mg/min)

* mg/mL equals mg/dL divided by 100.

Patient's Mid-week Urea Reduction



Question:

If the urea concentration at the beginning and end of the treatment are known, is there a relationship between Kt/V and these values?

URR and Kt/V

- URR = Urea Reduction Ratio

$$URR = (C_{PRE} - C_{POST}) / C_{PRE}$$

Patient = (80 – 24)/80 = 0.70

- Kt/V = Dialysis Treatment Index

Kt/V = Clearance x T_X time ÷ Patient V

Patient (in vitro) = 262 x 240 ÷ 40,600 = 1.55

Patient (in vivo) = 80% of In Vitro = 1.24

Saha, L. K. & Van Stone, J.C. Differences between Kt/V measured during dialysis and Kt/V predicted from manufacturer clearance data. The International Journal of Artificial Organs (1992): 15 (8).

Renal Physicians Association Working Committee on Clinical Practice Guidelines. Clinical Practice Guideline on Adequacy of Hemodialysis. Clinical Practice Guideline, Number 1. Washington, D.C. December 1993.

Patient's Kt/V

C_{PRE} = 80 mg/dL C_{POST} = 24 mg/dL   URR = 70%

R = C_{POST} / C_{PRE} UF = Fluid Removed   W = Post Weight

R = 24/80 = 0.30   UF = 0.0 kg   W = 70 kg

$$Kt/V = 2.2 - 3.3(R - 0.03 - UF/W)$$

$$= 2.2 - 3.3[0.30 - 0.03 - (0/70)]$$

$$= 2.2 - 3.3(0.30 - 0.03 - 0.0)$$

$$= 2.2 - 3.3(0.27) = 2.2 - 0.89$$

$$= 1.31$$

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UF Effect on Kt/V

$$Kt/V = 2.2 - 3.3(R - 0.03 - UF/W)$$

$R = C_{POST} / C_{PRE}$ UF = Fluid Removed W = Post Weight = 70 kg

Column 3 = Post BUN effective reduction due to UF (mg/dL)

Column 4 = Needed dialyzer clearance for reduction in column 3

T_X UF (kg)	R = 0.30	Column 3	Column 4
0.0	1.31	24	221
1.0	1.36	22.8	230
2.0	1.40	21.8	236
3.0	1.45	20.6	245
4.0	1.50	19.4	253
5.0	1.54	18.4	260

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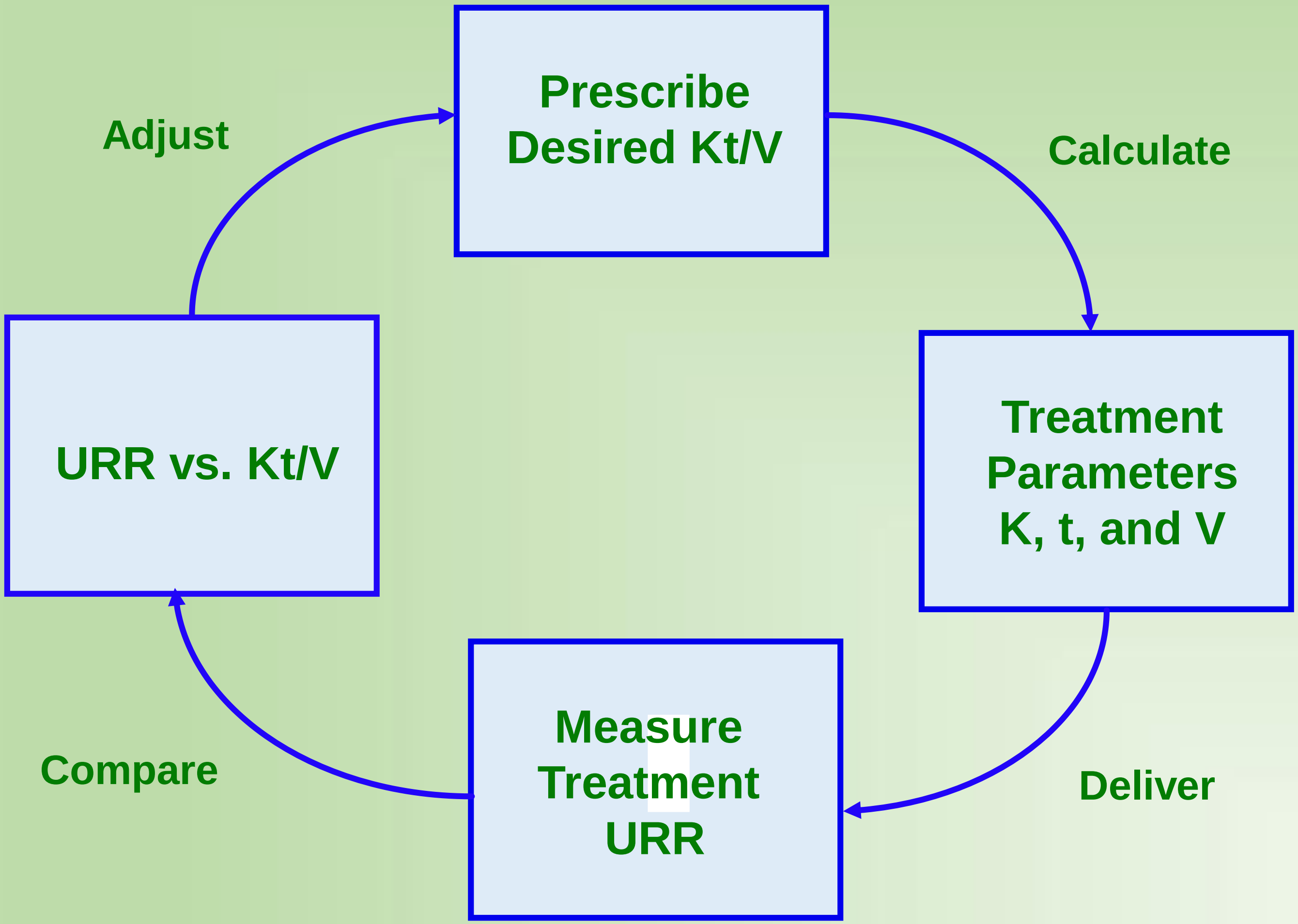
Achieving Quality Therapy



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