

Dialysis Fundamentals: Student Handout

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March 2026

Dialysis Fundamentals: PA/Medical Student Handout

Learning Objectives

By the end of this module, students will be able to:

1. Explain the fundamental principles of dialysis (diffusion, convection, ultrafiltration)
2. Describe the mechanisms controlling solute clearance and adequacy parameters
3. Compare hemodialysis and peritoneal dialysis modalities, including indications and contraindications
4. Apply KT/V and URR calculations to assess dialysis adequacy
5. Identify intradialytic complications and their management strategies
6. Distinguish vascular access types and assess for functionality

Section 1: Fundamental Principles of Dialysis

Clearance Concept

Definition: Clearance represents the volume of plasma completely cleared of a substance per unit time (mL/min). It forms the foundation for understanding dialysis efficiency.

The Clearance Formula:

$$\text{Clearance} = \text{Dialysate Flow Rate} \times \text{Extraction Ratio}$$

Where the **extraction ratio** = $(C_{in} - C_{out}) / C_{in}$

- **C_{in}** = inlet concentration
- **C_{out}** = outlet concentration

Clinical Pearl: Higher extraction ratios indicate more efficient solute removal. The relationship between blood flow and clearance is curvilinear with diminishing returns at higher rates due to membrane limitations.

Three Transport Mechanisms

Mechanism	Definition	Molecules Removed	Clinical Relevance
Diffusion	Movement from high to low concentration	Small (urea 60 Da, creatinine 113 Da)	Primary mechanism; concentration-dependent
Convection	Solvent drag across membrane	Middle molecules (500-5000 Da)	More effective for larger molecules
Ultrafiltration	Pressure-driven fluid removal	All solutes in fluid	Creates concentration gradients for diffusion

Section 2: Factors Affecting Dialysis Efficiency

Blood Flow Rate Effects

- **Typical range:** 300-450 mL/min
- **Mechanism:** Maintains concentration gradients by reducing recirculation of partially cleared blood
- **Limitation:** Curvilinear relationship with clearance; diminishing returns above certain rates
- **Clinical consideration:** Must match vascular access capacity

Dialysate Flow Rate

- **Standard rate:** 500-800 mL/min (exceeds blood flow)
- **Mechanism:** Counter-current flow maximizes concentration gradients throughout dialyzer length
- **Optimization:** Rates >600-700 mL/min show marginal improvements in small solute clearance

Membrane Characteristics

Surface Area: 1.0-2.5 m² (larger = better clearance)

Pore Size Distribution: - **Low-flux membranes:** Small pores □ excellent urea clearance, poor middle-molecule removal - **High-flux membranes:** Larger pores □ improved creatinine and beta-2 microglobulin removal

Clinical Pearl: Beta-2 microglobulin (11,800 Da) accumulates with low-flux membranes, causing dialysis-related amyloidosis. High-flux dialysis significantly reduces this risk.

Treatment Duration

- Linear relationship with solute removal
- Allows more complete equilibration between compartments
- Particularly important for middle-molecule clearance

Section 3: Dialysis Adequacy Parameters

KT/V Ratio

Definition: Dimensionless parameter quantifying fractional clearance of body water per session - **K** = dialyzer clearance (mL/min) - **T** = treatment time (minutes) - **V** = patient's urea distribution volume (mL)

Target Values: - Hemodialysis: $KT/V > 1.2$ per session - Peritoneal dialysis: Weekly $KT/V > 1.7$ - Higher KT/V correlates with improved patient outcomes

Single-Pool vs. Equilibrated KT/V : - **Single-pool:** Assumes instantaneous equilibration; overestimates delivered dialysis - **Equilibrated KT/V :** Accounts for urea rebound post-dialysis; typically 10-15% lower

Urea Reduction Ratio (URR)

$$URR = \frac{\text{Pre-BUN} - \text{Post-BUN}}{\text{Pre-BUN}} \times 100\%$$

Target: $URR > 65\%$ (higher percentages indicate more effective treatment)

Advantages: Simpler calculation than KT/V ; similar clinical utility

Section 4: Molecular Weight and Clearance Patterns

Small Molecules: Urea vs. Creatinine

Parameter	Urea	Creatinine
Molecular Weight	60 Da	113 Da
Membrane Permeability	Excellent	Moderate (size-limited)
Protein Binding	Minimal	Minimal
Removal by HD	>90%	70-80%
Clinical Issue	Rebound post-dialysis	Underestimation of efficacy by URR

Clinical Pearl: BUN clearance may appear adequate while creatinine remains elevated. This “creatinine lag” is an important limitation of hemodialysis adequacy, particularly in underdialyzed patients.

Middle Molecules: Critical for Long-Term Outcomes

Molecule	MW	Pathophysiology	Clearance Strategy
Beta-2 microglobulin	11,800	Accumulation \square dialysis amyloidosis, joint pain	High-flux HD or HDF
Vancomycin	1,449	Protein binding limits removal; post-dialysis dosing	Monitor levels; adjust dosing

Molecule	MW	Pathophysiology	Clearance Strategy
Phosphate	95	Rapid intracellular redistribution; rebound hyperphosphatemia	Extended dialysis times; frequent sessions

Clinical Pearl: Phosphate control requires extended treatment times to allow complete equilibration between intracellular and extracellular compartments. Standard 3x/week dialysis often fails to maintain phosphate balance.

Section 5: Hemodialysis Vascular Access

Gold Standard: Arteriovenous Fistula

Surgical Creation: Direct connection between artery and vein (typically forearm)

Advantages: - Lowest infection rates - Superior longevity (often 10-15+ years) - Highest achievable blood flow rates (400-600+ mL/min) - Reduced thrombosis compared to grafts

Disadvantages: - 6-12 week maturation period (requires advance planning) - Cannot be used immediately - Risk of steal syndrome and cardiac effects

Assessment: - **Bruit:** Whooshing sound indicating turbulent flow (normal finding) - **Thrill:** Vibration palpable over fistula (normal finding) - **Absence of bruit/thrill:** Suggests clotting or stenosis

Arteriovenous Graft

Composition: Synthetic conduit (typically PTFE) connecting artery to vein

Advantages: - Usable within 2-4 weeks (shorter maturation) - Suitable when native vessels inadequate

Disadvantages: - Higher infection rates than fistulas - Increased thrombosis risk (synthetic material provides nidus for colonization) - Shorter functional lifespan - Stenosis more common than fistulas

Central Venous Catheters (Permcaths)

Design: Dual-lumen tunneled catheter, often placed in internal jugular vein

Indications: - Acute dialysis situations - Bridge therapy while permanent access matures - Failure of permanent access options

Complications: - Catheter-related bloodstream infections (highest complication rate) - Central venous stenosis/thrombosis - Mechanical dysfunction - Cannot be used repeatedly without increasing infection risk

Clinical Pearl: Each session using a catheter carries ~2.1 infections per 1000 catheter-days. Permanent access should always be prioritized.

Section 6: Vascular Access Complications

Steal Syndrome

Pathophysiology: Arteriovenous access diverts excessive blood flow away from distal extremity

Clinical Manifestations: - Digital ischemia, pain, numbness - Tissue necrosis in severe cases - Hand coldness and discoloration

Risk Factors: Diabetes, peripheral vascular disease, high-flow access creation

Management: Access modification, surgical revision, or closure in severe cases

Cardiac Effects of High-Flow Access

Hemodynamic Impact: - Increased cardiac output required to compensate for fistula flow - Chronic volume overload □ left ventricular hypertrophy - Right heart failure and pulmonary hypertension in susceptible patients

Risk Threshold: Access flow rates >2 L/min significantly increase cardiovascular risk

Clinical Pearl: Monitor cardiac function regularly in patients with high-flow fistulas. Some patients may require access modification if cardiac decompensation develops.

Section 7: Intradialytic Complications and Management

Intradialytic Hypotension (Most Common Complication)

Epidemiology: Occurs in 20-30% of treatments; particularly problematic in heart failure patients

Pathophysiology: 1. Ultrafiltration removes fluid from intravascular compartment 2. Vascular refill cannot keep pace with fluid removal 3. Despite total body fluid overload, circulating volume depletes 4. Sympathetic compensation impaired in uremia 5. Warm dialysate and acetate solutions cause peripheral vasodilation

Clinical Manifestations: - Symptomatic BP reduction - Cramping, nausea, vomiting - Dizziness, altered mental status - Muscle cramping (from cellular dehydration)

Immediate Management: 1. **Stop ultrafiltration** (most effective) 2. **Trendelenburg positioning** (feet elevated above heart) 3. **Normal saline bolus** (100-250 mL typical; larger volumes if severe) 4. **Hypertonic saline or mannitol** (enhances plasma refilling from interstitium)

Prevention Strategies:

Strategy	Mechanism
Accurate dry weight determination	Prevents over/under-ultrafiltration
Gradual ultrafiltration rate adjustment	Allows physiological adaptation
Sequential ultrafiltration	Avoids rapid electrolyte shifts

Strategy	Mechanism
Higher dialysate sodium concentration	Maintains plasma osmolality; enhances vascular refill
Cool dialysate temperature	Reduces peripheral vasodilation
Antihypertensive medication timing	Avoid dosing immediately before dialysis

Advanced Management: Midodrine (alpha-agonist) 10 mg pre-dialysis may improve hemodynamic tolerance in recurrent cases. Alternatively, extended treatment times or peritoneal dialysis may be considered.

Muscle Cramps

Mechanism: Rapid fluid shifts and electrolyte changes; cellular dehydration

Risk Factors: Aggressive ultrafiltration, electrolyte shifts, low sodium dialysate

Management: - Reduce ultrafiltration rate - Increase dialysate sodium concentration - Longer treatment times with lower UF rates - Stretching and massage during treatment

Disequilibrium Syndrome

Pathophysiology: Rapid solute removal creates osmotic gradients brain cell swelling

Risk Factors: First dialysis treatments, severe uremia, large patients

Management: - Shorter first treatments with gradual escalation - Lower blood flow rates initially - Cooler dialysate

Section 8: Peritoneal Dialysis Overview

Fundamental Principle

The **peritoneal membrane** (~1-2 m² surface area) serves as the natural dialyzer. Dialysate introduced into the peritoneal cavity creates concentration and osmotic gradients for solute and fluid exchange.

Peritoneal Transport Characteristics

Peritoneal Equilibration Test (PET) classifies transport status at 4-hour dwell:

Transport Type	D/P Creatinine	Characteristics	Best Modality
High transporters	>0.81	Rapid equilibration; poor long-dwell ultrafiltration	Shorter, frequent exchanges (APD)
High-average	0.61-0.80	Moderate equilibration	APD or CAPD with short dwells

Transport Type	D/P Creatinine	Characteristics	Best Modality
Low-average	0.40-0.60	Slower equilibration; good ultrafiltration	Standard CAPD
Low transporters	<0.40	Slow equilibration; excellent long-dwell UF	Long CAPD dwells (8+ hours)

Clinical Pearl: High transporters achieve excellent small solute clearance but experience rapid glucose absorption and reduced ultrafiltration. Low transporters require longer dwells but maintain ultrafiltration capacity.

CAPD (Continuous Ambulatory Peritoneal Dialysis)

Prescription: 4 exchanges daily (2-3L each), 4-6 hour dwell times

Advantages: - Continuous treatment provides more physiologic clearance patterns - Gradual fluid removal (200-300 mL/hour) - Minimal cardiovascular stress - Independence and flexibility

Requirements: - Manual dexterity and visual acuity - Cognitive ability for sterile technique - Motivation for daily exchanges - Support system for emergencies

Automated Peritoneal Dialysis (APD)

System: Cyclor machine performs exchanges during sleep (8-10 hours)

Prescription: 3-6 cycles nightly with variable fill volumes and dwell times

Advantages: - Improved quality of life (daytime freedom) - Better clearance in high transporters through frequent short cycles - May improve ultrafiltration

Technical Requirements: - Reliable electrical supply - Dedicated space for cyclor - Storage for dialysate supplies - Competency with machine troubleshooting

Section 9: Hemodialysis Prescription Components

Core Parameters

Parameter	Range	Clinical Decision
Treatment frequency	2-6x/week	Standard 3x/week; more frequent for larger/symptom-prone patients
Treatment time	3-5 hours	Standard 3-4 hours; extended for inadequacy or symptom burden
Blood flow	300-450 mL/min	Match access capacity; higher = better clearance
Dialyzer selection	Varies by surface area, flux	High-flux preferred for middle-molecule clearance
Dialysate flow	500-800 mL/min	Optimize Kt/V without excess resource use

Parameter	Range	Clinical Decision
Net ultrafiltration	0.5-4.0 L/session	Based on interdialytic weight gain and dry weight

Electrolyte Prescription

Electrolyte	Typical Range	Clinical Considerations
Sodium	135-145 mEq/L	Higher concentrations support hemodynamic stability but increase thirst
Potassium	0-4 mEq/L	Individualize based on pre-dialysis serum levels; lower for hyperkalemia
Calcium	2.5-3.5 mEq/L	Adjust for bone/mineral metabolism; consider calcium-based binders
Bicarbonate	32-40 mEq/L	Correct metabolic acidosis; avoid overcorrection causing alkalosis
Glucose	0-200 mg/dL	Add for diabetics or if aggressive UF required

Section 10: Clinical Monitoring and Outcomes

Monthly Adequacy Assessments

- **Kt/V measurement** (target ≥ 1.2)
- **Urea reduction ratio** (target $>65\%$)
- **Pre- and post-dialysis labs** (electrolytes, minerals, minerals)
- **Hemoglobin/hematocrit** (assess anemia management)
- **Phosphorus and PTH** (mineral metabolism)
- **Albumin** (nutritional status)

Interdisciplinary Care Model

Optimal team includes: - **Nephrologist:** Medical management, prescription - **Dialysis nurses:** Clinical assessment, medication administration - **Dietitians:** Nutrition counseling (potassium, phosphorus, fluid restriction) - **Social workers:** Psychosocial support, vocational rehabilitation - **Technicians:** Machine operation, patient monitoring

Practice Questions

1. A 70-kg male on hemodialysis has a pre-dialysis BUN of 80 mg/dL and post-dialysis BUN of 20 mg/dL. Calculate his urea reduction ratio (URR). - A) 65% - B) 75% - C) 85% - D) 95%

Correct Answer: B) 75% Calculation: $(80-20)/80 \times 100 = 75\%$. This exceeds the 65% target, indicating adequate treatment.

2. Which vascular access complication is characterized by inadequate distal hand perfusion despite fistula flow? - A) Venous stenosis - B) Access thrombosis - C) Steal syndrome - D) Catheter infection

Correct Answer: C) Steal syndrome *Steal syndrome results from excessive shunting of blood through the access, diverting flow from distal tissues.*

3. A patient with high-transport peritoneal membrane would benefit most from which dialysis modality? - A) CAPD with 8-hour dwells - B) APD with multiple short cycles - C) Standard hemodialysis - D) HVHDF

Correct Answer: B) APD with multiple short cycles *High transporters equilibrate rapidly but lose ultrafiltration with long dwells. Frequent short cycles in APD optimize both clearance and fluid removal.*

Key Takeaways

1. **Dialysis adequacy** depends on clearance (function of blood flow, dialysate flow, treatment time, and membrane) and ultrafiltration (achieving target dry weight)
 2. **Vascular access** quality directly impacts treatment efficacy; fistulas are superior to grafts and catheters
 3. **Intradialytic hypotension** is common and preventable through careful prescription, accurate dry weight, and hemodynamic monitoring
 4. **Modality selection** (HD vs PD) depends on patient factors, lifestyle, residual kidney function, and co-morbidities
 5. **Adequate monitoring** through KT/V, URR, and comprehensive lab assessment ensures optimal outcomes
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See Also

Related Student Handouts

- Dialysis Access Complications
- HVHDF and Advanced RRT Techniques
- Kidney Transplantation Basics
- AKI Workup and Diagnosis
- CKD Complications

Clinical Content (01-Clinical-Medicine/Nephrology)

- Dialysis and RRT Hub
- Essential Renal Laboratory Tests

Atomic Notes (ZK)

- CRRT Principles
- Hemodialysis Mechanism and Process
- Peritoneal Dialysis Fundamentals
- RRT Modality Selection

Butler-COM Resources

- Butler COM - Nephrology Deep Dive
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Related Resources

- Dialysis Student Guide
 - KRT Comprehensive Report
 - Nephrology Hub
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Created for PA and medical students as part of medical education curriculum. For clinical decision-making, consult current guidelines and attending physicians.