Comprehensive Hemodialysis and Nephrology Lecture Series

Choosing Nephrology: A Career Path in Internal Medicine

- Nephrology is a natural extension of internal medicine, requiring focused study primarily in transplant medicine and dialysis.
- Dialysis involves new physical chemistry concepts such as diffusion, osmosis, and ultrafiltration, often unfamiliar to trainees.
- The speaker emphasizes that thorough understanding of hemodialysis is essential for exams and clinical practice.
- Only a small fraction of postgraduate students pursue specialties; nephrology offers a balanced mix of diagnostic and management skills.
- Historical figures in dialysis include **Thomas Graham** (coined "dialysis", formulated Graham's Law), **Georg Haas** (first human dialysis), and **Willem Kolff** (father of hemodialysis, invented rotating drum dialyzer).
- Modern machines like the **Fresenius 4008S** retain core principles but include advanced features like the **Online Continuous Monitor (OCM)**.
- The course will systematically cover vascular access, blood and dialysate circuits, dialyzer function, mechanisms of dialysis, complications, and advanced modalities like **SLED**, **CRRT**, and **CVVHDF**.
- Dialysate is prepared using a **1:34:1.83 ratio** (acid:water:base) and requires highly purified **reverse osmosis (RO)** water.
- Water quality is critical; nephrologists often inspect water tanks first in dialysis centers.
- Mastery of hemodialysis components-access, circuits, dialyzer, mechanisms-is foundational for nephrology.

Historical Milestones and Core Principles of Hemodialysis

- **Thomas Graham** introduced the term "dialysis" and formulated the law of diffusion.
- **Georg Haas** performed the first human dialysis.
- **Willem Kolff** is recognized as the **father of hemodialysis**, having built the first functional rotating drum machine using cellophane tubing and hirudin as anticoagulant.
- The evolution from Kolff's machine to modern systems like **Fresenius 4008S** reflects technological upgrades while retaining core principles.
- Modern dialysis machines incorporate real-time monitoring via **Online Continuous Monitor (OCM)**.
- The foundational science of dialysis is rooted in 12th-grade physical chemistry (e.g., diffusion, osmosis).
- Despite procedural training, medical trainees often lack deep understanding of dialysis mechanics.

Diffusion and Ultrafiltration: The Dual Mechanisms of Dialysis

- The dialyzer contains a **semipermeable membrane** separating blood and dialysate compartments.
- **Diffusion:** Movement of solutes from high (blood) to low (dialysate) concentration; effective for **small molecules** like **urea (60 Daltons)** and **creatinine.**
- Molecular mass is the key factor-smaller molecules diffuse faster.
- **Ultrafiltration (convection):** Movement of fluid across the membrane driven by **transmembrane pressure (TMP).**
- Water carries solutes via **solvent drag**, limited to molecules smaller than membrane pores.
- **Convection** complements diffusion, especially for larger solutes.
- Counter-current flow of blood and dialysate maintains optimal concentration gradient.

Dialyzer Characteristics: KUF, KOA, Flux, and Membrane Materials

- **Ultrafiltration Coefficient (KUF)**
  : Volume of fluid removed per hour per mmHg of TMP; determines **flux.**
  - **Low-flux:** KUF < 8 mL/h/mmHg
  - **Intermediate-flux:** KUF = 8-20 mL/h/mmHg
  - **High-flux:** KUF > 20 mL/h/mmHg (preferred clinically)
- High-flux dialyzers remove **middle molecules** (500-20,000 Daltons), including **beta-2 microglobulin** and **PTH.**
- **KOA (Mass Transfer Area Coefficient)**
  : Theoretical maximum clearance; high-efficiency dialyzers have KOA > **800 mL/min.**
- **Clearance** = Extraction Ratio × Blood Flow Rate (QB); increases with higher QB.
- Modern dialyzers are **hollow fiber** and mostly made of **polysulfone.**
- Examples: **F6 (low flux)**, **F8 (intermediate flux)**, **FX60 (high flux).**
- Surface area (0.8-2.5 m^2) has limited impact compared to membrane permeability.

Hemodialysis Blood Circuit: Components, Flow Dynamics, and Safety Monitoring

- **Pre-pump segment**
  : Arterial needle to pump; negative pressure (normal: -50 to -200 mmHg); contains saline port, sampling port, and P1 monitor.
- **Roller pump:** Propels blood; flow rate = rpm × segmental volume (typically 250-400 mL/min).
- **Post-pump segment**
  : From pump to dialyzer; positive pressure; includes heparin port and P2 monitor.

- **Outflow segment:** From dialyzer to venous access; includes **P3 (venous pressure monitor)**, **air trap** , and **blood leak detector**-critical for safety.
- **Exam Mnemonic:** Pre-pump = **S-P1-S** (Saline, P1, Sampling); Post-pump = **P2 + Heparin**; Outflow = **P3 + Air detector**.
- P3 alarms signal venous hypertension or thrombosis.

Measuring Dialysis Adequacy: Kt/V, URR, and the Fish Tank Model

- **Kt/V** is the primary measure of dialysis adequacy:
  - **K** = urea clearance (mL/min)
  - **t** = time (min)
  - **V** = volume of distribution of urea (total body water)
  - Target: **≥1.4 per session** (acceptable: 1.2-1.4)
- **URR (Urea Reduction Ratio):** Simple percentage; target **65-70%**.
- **Fish Tank Model** explains why complete clearance isn't achieved due to urea rebound and dilution; **Kt/V of 1.2 ≈ 63% URR**.
- Types of Kt/V:
  - **spKt/V**: Single-pool, most common, does not account for rebound.
  - **eKt/V** : Equilibrated, measured 30-60 mins post-dialysis; accounts for rebound; always lower than spKt/V.
  - **stdKt/V**: Weekly adequacy; target **>2.3**.
- Low Kt/V causes: access stenosis, recirculation, low blood flow, inefficient dialyzer, high interdialytic weight gain.
- **Dialyzer reuse** is discouraged; disinfectants include **sodium hypochlor 20 mL/h/mmHg and KOA > 800 mL/min.
- **Buttonhole cannulation** reduces tissue damage and aneurysms; **rope-ladder** is alternative.

Complications of Hemodialysis: From Hypotension to Dialysis Disequilibrium

- **Intradialytic hypotension** : Most common and serious; causes include high ultrafiltration, low dialysate sodium, eating during dialysis, warm dialysate, anemia.
  - Management: Trendelenburg, 100 mL saline bolus.
- **Muscle cramps** : Linked to hypovolemia; prevent with high sodium dialysate, carnitine, proper calcium/magnesium.
- **Nausea/vomiting:** Often due to hypotension or **dialysis disequilibrium syndrome (DDS)**.
- **Headache:** May be from caffeine withdrawal, migraine, or DDS.
- **Chest/back pain:** Rule out ACS; consider **hemolysis** (port-wine blood), **type B dialyzer reaction**.
- **Pruritus:** Indicates inadequate dialysis or high PTH.

- **Type A dialyzer reaction:** Anaphylactic, linked to **ethylene oxide**; rare now.
- **Type B:** Complement-mediated, mild chest pain.
- **Hemolysis:** Caused by contaminated dialysate; stop dialysis, clamp lines.
- **Air embolism:** Foam in lines; clamp venous line, left Trendelenburg.
- **DDS:** Due to rapid osmolality shift → cerebral edema; occurs in first dialysis with high urea.
  - Prevention: limit session to 2 hours, URR < 40%, low blood flow, low UF, co-current flow.

Advanced Dialysis Modalities: SLED, CRRT, and CVVHDF

- **SLED (Sustained Low-Efficiency Dialysis)**
  : Prolonged IHD (6-12 hours), blood flow 100-200 mL/min, dialysate flow 100-300 mL/min.
  - Advantages: Cardiovascular stability, cost-effective (~$50-100/session), uses standard machines.
- **CRRT:** Gold standard for hemodynamically unstable AKI; continuous, expensive (~$20K-30K/day).
- **SLED vs. CRRT:**
  - SLED: Lower cost, good stability, moderate clearance.
  - CRRT: Excellent stability, higher clearance in sepsis, high cost.
- **CRRT modes:**
  - **CVVH:** Replacement fluid only.
  - **CVVHD:** Dialysate only.
  - **CVVHDF:** Both; most effective.
- CRRT dose: **25-35 mL/kg/hour**; for 60 kg: ~2 L/hour, ~48 L/day.
- CRRT indications: unstable patients, sepsis, hypercatabolic states, fluid overload.

Therapeutic Plasma Exchange: Indications, Procedure, and Nephrology Applications

- **Types:**
  - **Hollow fiber membrane plasmapheresis**
  - **Centrifugal plasmapheresis**
- **Procedure:** Plasma separated and discarded; replaced with **albumin** or **fresh frozen plasma (FFP)**.
- **Plasma volume** ≈ 3 L (70 kg, Hct 40%); exchange 1-1.5 times volume (3-4.5 L).
- **Anticoagulation:** Heparin; calcium gluconate post-procedure if using citrate/FFP.
- **Albumin vs. FFP:**
  - **Albumin:** Safer, no group issues; preferred in **TTP.**
  - **FFP:** Cheaper, contains clotting factors; used in **HUS, TTP, pancreatitis**.
- **Indications (ASFA guidelines):**
  - **Anti-GBM disease / Goodpasture's syndrome**
    : 14 cycles if creatinine < 5.8 mg/dL, pulmonary hemorrhage.
  - **ANCA vasculitis:** Severe RPGN, pulmonary hemorrhage.
  - **Transplant:** HLA desensitization (4-6 cycles), recurrent FSGS, AMR.
  - **Neurological: Guillain-Barré Syndrome (GBS)**, **Myasthenia Gravis (MG)**.

- **TTP, HUS, hyperviscosity, cryoglobulinemia.**

• **Complications:** Hypocalcemia (common), thrombocytopenia (rare), infections.

• Plasmapheresis is safe and life-saving when properly indicated.