

CORE CURRICULUM IN NEPHROLOGY

Hemodialysis: Techniques and Prescription

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INTRODUCTION

HEMODIALYSIS (HD) is the routine renal replacement therapy for more than 300,000 patients in the United States who have reached end-stage renal disease. The goals of HD are straightforward and include restoring the body's intracellular and extracellular fluid environment and accomplishing solute balance by either removal from the blood into the dialysate or from the dialysate into the blood. Optimal care of the patient receiving long-term HD requires broad knowledge of the HD technique and appropriate prescription according to patient- and device-dependent variables. This Core Curriculum aims to provide a comprehensive but also concise description of HD technique and prescription. Clinically relevant practical information is provided in appropriate sections.

HEMODIALYSIS TECHNIQUES

Components

Blood circuit

- The patient
- Vascular access:
 - Arteriovenous fistula
 - Polytetrafluoroethylene
 - Catheter:
 - Temporary
 - Tunneled
 - Needles:
 - Gauge

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- Back-eye
- Blood tubing:
 - Air traps
 - Air detectors
- HD machine:
 - Blood pump
 - Pressure monitors; pressure readings will vary according to blood flow:
 - Arterial: measure of excessive suction from artery
 - Venous: measure of resistance to blood return
 - Heparin pump
 - Blood leak detector (placed in dialysate outflow line)
 - Temperature gauge
 - Conductivity:
 - Measure of osmolarity of dialysate
 - Determined by electrical charge of electrolytes in dialysate
- Artificial kidney (dialyzer):
 - Hollow fiber; parallel plate
 - Membrane material:
 - Cellulosic (highest level of inflammatory response and complement activation; used less)
 - Semisynthetic
 - Synthetic (survival benefit in acute renal failure; most common dialyzer type)
 - Dialyzer reuse:
 - Technique (bleach, formaldehyde, hydrogen peroxide/peracetic acid, heat/citric acid)
 - Performance testing (fiber bundle volume, pressure gradient, in vitro ultrafiltration [UF] coefficient)
 - Clinical considerations (infection risk, adequacy, biochemical effects, metabolic effects, effect on mortality)

Dialysate circuit

- Dialysate
- Dialysate tubing
- Water treatment system:
 - Reverse osmosis:

- Effective and commonly used
- High capital, low operating costs
- Effective barrier against microbiological contaminants
- Deionization:
 - Uses ion exchange resins
 - Used as a secondary step following reverse osmosis
 - Deionizer performance must be monitored closely
- Carbon absorption:
 - Standard method for removing chloramines
 - Two carbon absorption beds installed in series (before reverse osmosis) to prevent inadvertent exposure
- Other purification processes:
 - Softeners (a form of deionization)
 - Filters (to control microbiological contaminants)
- Water storage and distribution:
 - Microbiological testing (at least once a month)
 - Chemical contaminant testing (at least once a year)

Operational Characteristics

- Scheduling:
 - Intermittent
 - Daily
 - Continuous
- Length: 2-24 hours
- Solute clearance
- Fluid removal
- Prescription
- Clinical indication:
 - HD for end-stage renal disease:
 - Conventional HD
 - Daily HD
 - Short daily HD
 - Nocturnal HD
 - HD for acute renal failure:
 - Conventional HD
 - Slow low-efficiency dialysis (SLED)
 - Continuous renal replacement therapy:
 - Slow continuous UF (SCUF)
 - Continuous arterio- and venovenous hemofiltration (CAVH and CVVH)
 - Continuous arterio- and venovenous HD (CAVHD and CVVHD)

- Continuous arterio- and venovenous hemodiafiltration (CAVHDF and CVVHDF)

HEMODIALYSIS PRESCRIPTION

Elements of the HD Prescription

Dialyzer type

- Capacity for solute clearance:
 - Conventional, high efficiency
 - Refers to small solute transfer across membrane (expressed as mass transfer coefficient [KoA]); high-efficiency dialyzers have KoA urea > 450 mL/min
 - Determined by diffusive and convective clearance
 - Size, charge, protein binding, and volume of distribution of solute determine clearance rate
 - Large molecules (>300 d) have relatively lower diffusive clearance
 - Ideal dialyzer should have high clearance of small- and middle-molecular-weight uremic toxins and negligible loss of vital solutes
 - Clearance of larger solutes primarily depends on convection
- Biocompatibility:
 - Cellulosic
 - Semisynthetic
 - Synthetic
- Cost of synthetic material
- Low blood volume compartment
- High reliability

Capacity for UF (fluid removal)

UF coefficient (KUF).

- KUF determines quantity of pressure that must be exerted across dialysis membrane (transmembrane pressure) to generate a given volume of ultrafiltrate per unit time
- High-flux membranes are defined as having UF coefficient > 15 mL/h/mm Hg
- KUF is dialyzer specific and determined by membrane composition, surface area, and geometry

Flux characteristics.

- Low flux
 - KUF < 15 mL/h/mm Hg or β_2 -microglobulin clearance < 10 mL/min

- High flux:
 - KUF > 15 mL/h/mm Hg or β_2 -microglobulin clearance > 20 mL/min; KoA > 450 mL/min
 - Subgroup analysis of the HEMO Study suggested cardiovascular survival advantage in patients randomized to high-flux arm of study

Net pressure gradient.

- Difference between blood and dialysate hydraulic pressures (calculated as arithmetic mean of inlet and outlet pressures of dialyzer)

Transmembrane pressure.

- Effective pressure required to achieve a particular fluid loss (transmembrane pressure = desired weight loss/[UF coefficient \times dialysis time])
- Can be varied by changing pressure in blood and dialysate compartments and therefore can selectively determine UF rate for a given dialyzer

UF rate prescription.

- Goal is to achieve estimated dry weight (lowest weight a patient can tolerate without development of signs or symptoms of intravascular hypovolemia)
- Tolerance determined by vascular refilling
- On-line monitoring of blood volume changes may help prescription
- UF modeling may reduce intradialytic complication

Length of treatment

- Clearance of a high-molecular-weight solute can be increased by lengthening HD treatment
- Increasing time decreases low-molecular-weight solute removal and does not result in equivalent increases in low-molecular-weight solute removal (diminishing return)

Flow

Blood flow (Q_b).

- Flow-limited mass transfer and membrane-limited mass transfer (defined by specific dialyzer and solute being measured) together determine clearance characteristics
- As blood and dialysate flow rates increase, resistance and turbulence within dialyzer also increase

- Efficacy of vascular access may affect solute clearance due to recirculation (stenosis at venous or arterial anastomoses or mid-graft):

- Recirculation can be measured by simultaneous measurement of a solute (usually blood urea nitrogen) from arterial line and from a peripheral blood source—this method is inaccurate due to “cardiopulmonary recirculation” and worse during high-efficiency HD; it is of historical curiosity and should not be performed routinely
- Slow-flow method is routinely used to measure recirculation
- Newer methods, such as indicator technique, demonstrate that recirculation is rare during HD

Dialysate flow (Q_d).

- Practical upper limit of effective dialysate flow is twice blood flow rate, beyond which gain in solute removal is minimal
- High flow rates should be confined to blood flows > 300 mL/min

Anticoagulation

- Interaction of plasma with dialysis membrane leads to activation of clotting cascade
- Dialyzer thrombogenicity is determined by:
 - Dialysis membrane composition
 - Surface charge, area, and configuration
 - Rate of blood flow through dialyzer
 - UF rate (due to hemoconcentration)
 - Length, diameter, and composition of blood lines
 - Patient-specific variables
- Most common anticoagulant is systemic heparin:
 - Easy to administer
 - Low cost
 - Short biological half-life
 - Bolus and/or incremental administration during HD; occasionally regional administration or no heparin (saline flushes)
 - In routine clinical practice, intensity of anticoagulation is not measured; anticoagulant therapy can be used under some circumstances (~50% above baseline)
- Low-molecular-weight heparin:
 - Limited data

- For patients at high risk for serious adverse events from hemorrhage, guidelines for anticoagulation must be based on comorbid conditions:
 - Regional methods
 - Saline flushes
 - Citrate infusion or citrate based dialysate

Determination of HD Dose/Adequacy

Historical perspective

- National Cooperative Dialysis Study (NCDS) showed that a minimum clearance per HD is required
- Subsequent analysis of NCDS suggested clinical applicability of Kt/V, a dimensionless term that describes aspects directly related to the HD treatment factored by volume of urea distribution in patient
- Kidney Disease Outcomes Quality Initiative (K/DOQI) Guidelines defined adequate dialysis dose:
 - Kt/V of at least 1.2 per treatment (single pool, variable volume) for both adult and pediatric HD patients
- HEMO Study results indicated that within conventional schedule of thrice-weekly HD (Kt/V of 1.3 in clinical practice), neither increased dose of dialysis nor use of high-flux membrane improves survival, reduces hospitalization rate, or maintains higher serum albumin level than standard HD dose and use of low-flux membranes

HD dose prescription components

Patient variables.

- Total-body water (urea volume of distribution)
- Urea generation
- Residual renal function
- Fluid accumulation

Dialysis variables.

- Dialyzer-related components
- Length of dialysis
- Schedule

Measurement of dialysis dose

Urea reduction ratio.

- The fractional decrease in blood urea nitrogen during a single HD
- Simple to calculate

- Assumes constant urea volume and no disequilibrium
- Does not include effects of UF
- K/DOQI guidelines suggest urea reduction ratio at least 65%

Single-compartment urea kinetics.

- Most commonly applied method for quantifying HD in clinical practice
- Two blood urea nitrogen method
- Equilibrated Kt/V to account for rebound

Multiple-compartment urea kinetics.

- Developed to account for solute disequilibrium:
 - Diffusion-dependent disequilibrium
 - Flow-dependent disequilibrium
 - Cardiopulmonary recirculation
- More consistent with actual data
- Not recommended for clinical practice due to its complexity

Continuous equivalent of urea clearance.

- Allows comparison of dialysis dose between different modalities
- No standard for adequacy limits
- Difficult to calculate

Normalized Kt/V.

- Not practical

Standard Kt/V.

- Measures and compares dialysis dose regardless of schedule

Solute removal index (SRI).

- No standards of adequacy for SRI
- Lower than blood-based Kt/V

Dialysate

Dialysate characteristics influence the final concentration of blood solute, intermediary protein, carbohydrate, and lipid metabolism and affect systemic vasomotor tone, cardiac contractility and rhythm, pulmonary gas exchange, and bone turnover.

Composition

Sodium.

- “Standard” to have a dialysate sodium concentration similar to plasma sodium concentration
- Use higher dialysate sodium or sodium modeling in patients prone to intradialytic hypotension

Potassium.

- Efficacy of intradialytic potassium removal is highly variable, difficult to predict, and influenced by dialysis-specific and patient-specific factors
- Dialysate potassium concentration of 1-3 mEq/L is used in most patients
- Low dialysate potassium concentrations should be used with caution (due to association between use of low dialysate potassium with sudden cardiac death)

Buffer.

- Correction of acidosis is largely achieved by using a dialysate with higher concentration of alkaline equivalents than are present in blood, promoting flux of base from dialysate into blood
- Base transfer across dialysis membrane can be achieved using either bicarbonate- or acetate-containing dialysate:
 - Acetate:
 - Introduced in 1964 and was clinical standard of practice for >20 years
 - Biochemically more stable and less frequent bacterial contamination
 - Associated with cardiovascular instability and intradialytic hypotension due to slow conversion of acetate into bicarbonate
 - Acetate accumulation also can cause nausea, vomiting, headache, fatigue, decreased myocardial contractility, peripheral vasodilatation, and arterial hypoxemia
 - Bicarbonate:
 - Replaced acetate as standard dialysate buffer
 - Dialysate bicarbonate concentrations of 30-35 mEq/L now commonly used (can be adjusted close to entry point of final dialysate into dialyzer)
 - Liquid bicarbonate concentrate and reconstituted bicarbonate-containing dialysate will support growth of gram-negative bacteria, filamentous fungi, and yeast (strict regulations by Association for the Advancement of Medical Instrumentation)

Calcium.

- In patients with hypocalcemia, positive intradialytic calcium balance may be desired

as adjunct therapy for control of metabolic bone disease

- Standard dialysate calcium concentration of 2.5-3.0 mEq/L is used in an effort to prevent interdialytic hypercalcemia
- Dialysate calcium concentration may also affect hemodynamic stability during HD procedure

Chloride.

- Major anion in dialysate
- Dialysate chloride concentration determined to maintain electrical neutrality

Glucose.

- Optimal dialysate glucose concentration is 100-200 mg/dL for most patients
- High dialysate glucose (>200 mg/dL) increases risk for hyperosmolar syndrome, postdialysis hyperglycemia and hyponatremia, and hypertriglyceridemia
- Glucose-free dialysate (losses of 25-30 g of glucose across dialyzer) may potentiate hypoglycemia (especially in diabetic patients) and may adversely affect HD-associated catabolism

Physical characteristics**Temperature.**

- Dialysate temperature is generally maintained between 36.5°C and 38°C at inlet of dialyzer
- Lower dialysate temperature may reduce intradialytic hypotension and also increase cardiac contractility, improve oxygenation, increase venous tone, and reduce complement activation during dialysis
- New accurate blood temperature monitors allow isothermic HD

Microbiological characteristics

- Association for the Advancement of Medical Instrumentation standards

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