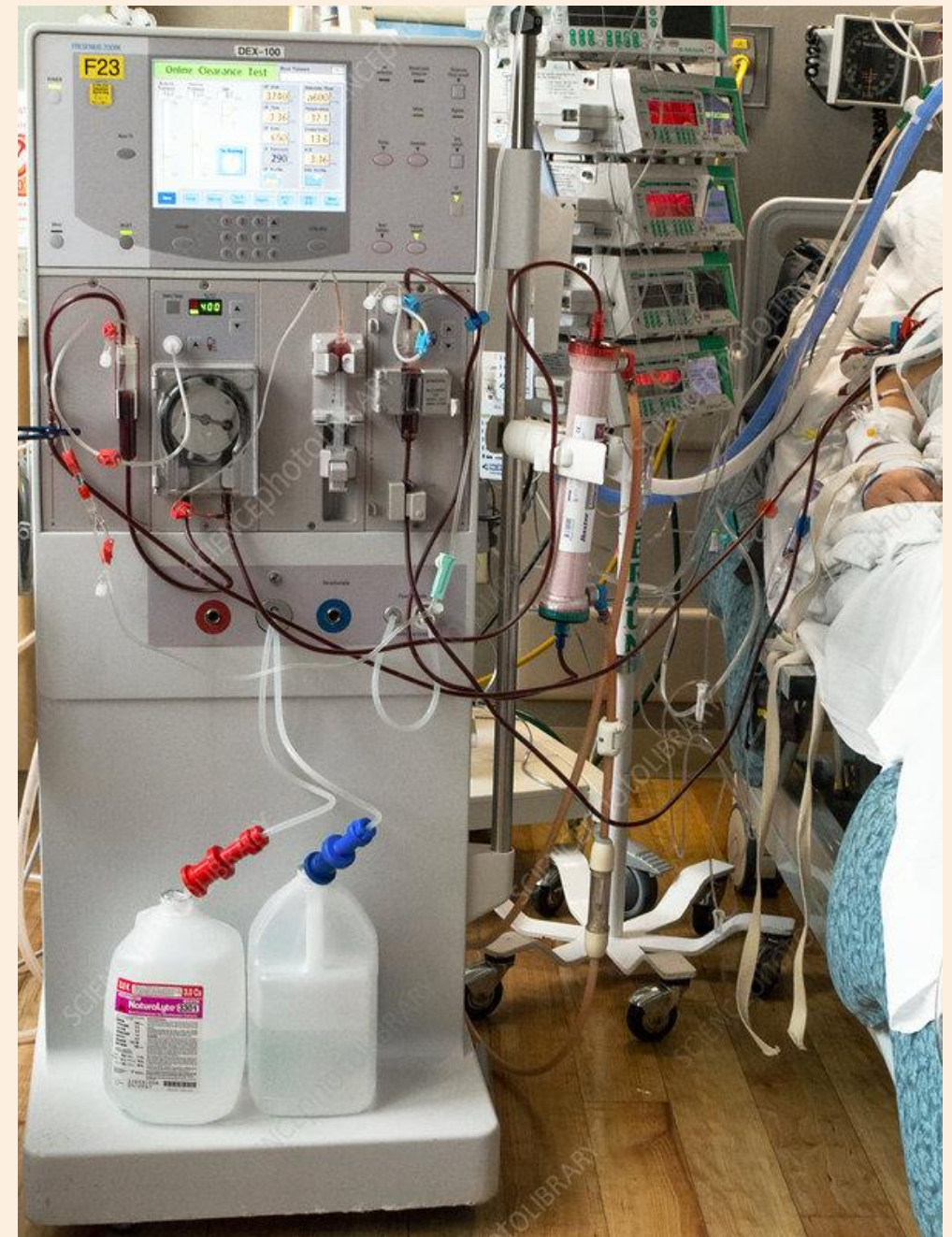


RENAL REPLACEMENT THERAPY



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- Renal replacement therapy (RRT) refers to medical treatments that replace the normal functions of the kidneys in patients with acute or chronic kidney failure.
- It helps in:
 1. Removal of waste products (urea, creatinine)
 2. Regulation of electrolytes
 3. Removal of excess fluid
 4. Maintenance of acid–base balance



General Indications

1. Acute Kidney Injury (AKI)
2. Chronic Kidney Disease
(CKD stage 4–5)
3. End-Stage Renal Disease
(ESRD / CKD stage 5)

Classical Indications

1. **Fluid overload** – Pulmonary edema, Diuretic resistance
2. **Electrolyte imbalance** – Severe hyperkalemia
3. **Metabolic acidosis** – Refractory acidosis
4. **Uremic complications** – Pericarditis, Encephalopathy
5. **Bleeding tendencies** (uremic platelet dysfunction)
6. **Dialyzable intoxications** – Lithium, Salicylates, Toxic alcohols
7. **Rapid fall in GFR**
8. **Risk of solute imbalance or toxicity**

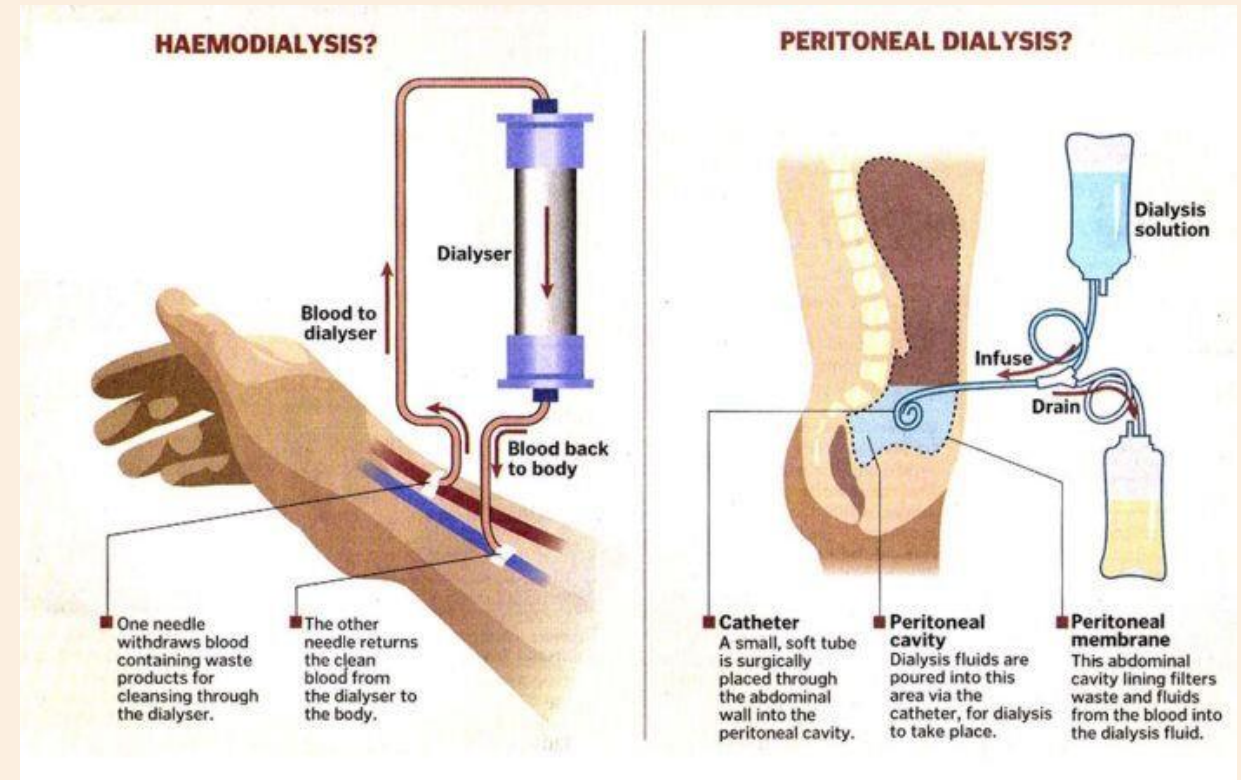
Types (Forms) of Renal Replacement Therapy

1. Primary modalities

1. Hemodialysis (HD)
2. Peritoneal Dialysis (PD)
3. Kidney Transplantation

2. Other extracorporeal techniques

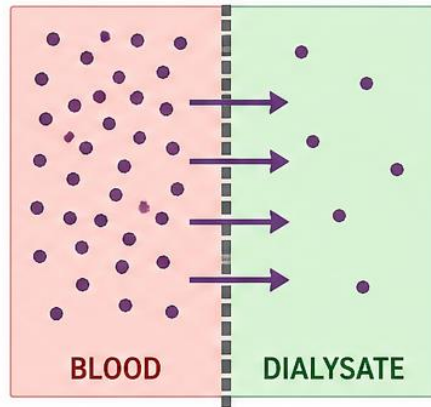
1. Hemofiltration
2. Hemodiafiltration



PRINCIPLES OF RENAL REPLACEMENT THERAPY (RRT)

1. DIFFUSION

Movement of solute from higher concentration to lower concentration across a semipermeable membrane.

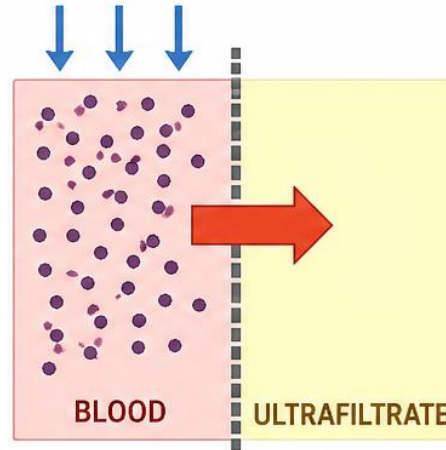


Solute moves down its concentration gradient.

Best for small molecules (e.g., urea, creatinine, K^+)

2. ULTRAFILTRATION

Movement of water across a semipermeable membrane driven by a pressure gradient.

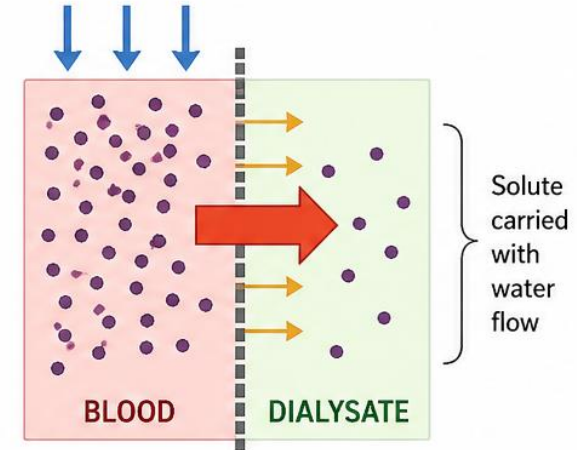


Water moves from blood to dialysate due to hydrostatic pressure gradient.

Mainly responsible for fluid removal.

3. CONVECTION

Movement of solute along with the flow of water (solvent drag) across the membrane.



Solutes are dragged with water across the membrane.

Effective for middle and large molecules.



ULTRAFILTRATION RATE IS DETERMINED BY:

- Transmembrane pressure
- Surface area of the membrane
- Water permeability of the membrane
- Membrane thickness
- Pore size of the membrane

Basic Principle of RRT

All RRT modalities work on a common principle: Blood is exposed to a dialysate across a semipermeable membrane

This allows removal of: Low molecular weight solutes, Excess fluids and Electrolytes

Molecular Clearance Concept: Low molecular weight solutes (generally < 50,000 Daltons) pass easily, Larger molecules require convection-based techniques

Mechanisms of Solute and Fluid Removal

1. **Diffusion: Passive movement of solutes from high → low concentration.**

- a. Diffusion in renal replacement therapy is the passive movement of solutes across a semipermeable membrane from the blood compartment to the dialysate compartment (or vice versa) down a concentration gradient.
- b. Occurs between blood and dialysate
- c. Driven by concentration difference
- d. Most effective for small molecular weight solutes (e.g., urea, creatinine, potassium)
- e. Primary mechanism in hemodialysis
- f. Depends on: Concentration gradient and Molecular size

2. Ultrafiltration: Movement of fluid due to a pressure gradient

Fluid moves from high pressure → low pressure

1. Ultrafiltration in renal replacement therapy is the movement of water across a semipermeable membrane from the blood to the dialysate side due to a transmembrane pressure gradient.
2. Driven by hydrostatic pressure difference or osmotic pressure
3. Responsible for removal of excess body fluid
4. Occurs in: Hemodialysis, Hemofiltration, Peritoneal dialysis

3. Convection: Solutes are carried along with fluid movement (solvent drag)

1. Convection in renal replacement therapy is the transport of solutes across a semipermeable membrane along with the movement of water during ultrafiltration (solvent drag).
2. Solutes are carried with bulk flow of fluid
3. Effective for middle and larger molecular weight solutes
4. Primary mechanism in hemofiltration and hemodiafiltration

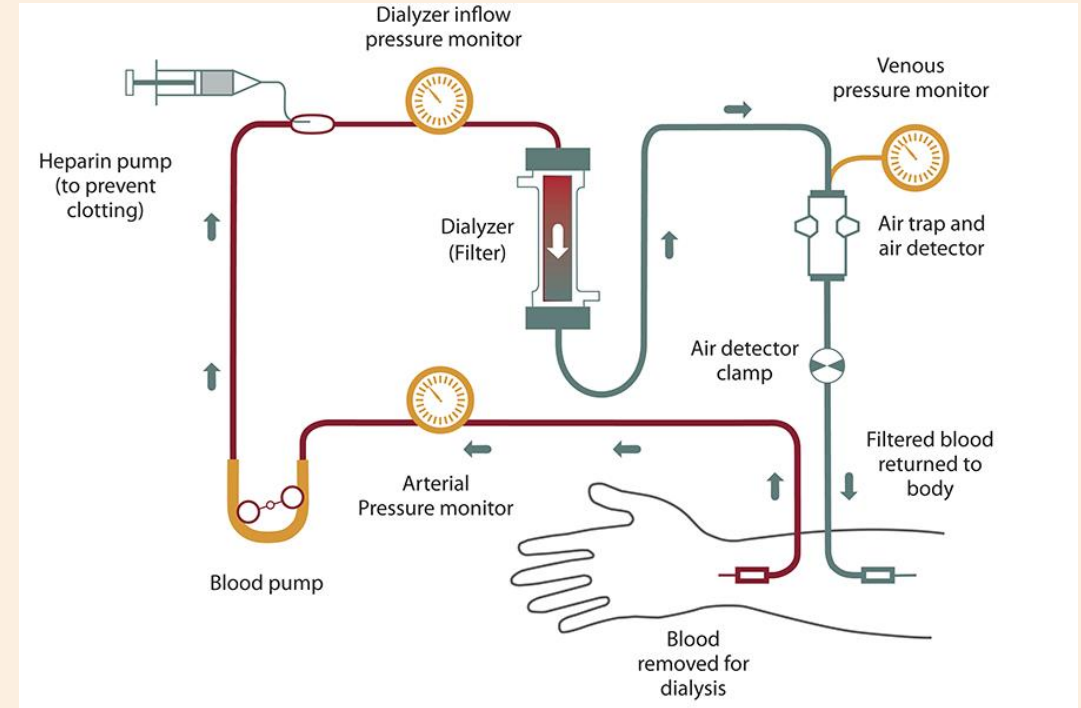
Hemodialysis (HD)

- ▶ Hemodialysis is a renal replacement therapy in which blood is circulated outside the body and purified through a dialyzer (artificial kidney), where waste products, excess fluids, and electrolytes are removed across a semipermeable membrane.

- ▶ Principle of Hemodialysis

1. Diffusion
2. Ultrafiltration
3. Convection

- ▶ Blood and dialysate flow on opposite sides of a semipermeable membrane.



Mechanisms involved

- ▶ **Diffusion** : Movement of solutes from high → low concentration
 1. Depends on: Concentration gradient, Molecular size, Charge of molecules, Membrane characteristics, Blood and dialysate flow rate
 2. More effective for small molecules (urea, creatinine)
- ▶ **Ultrafiltration**: Movement of water due to pressure gradient (hydrostatic/osmotic)
 1. Responsible for removal of excess fluid
- ▶ **Convection**: Solutes move along with water (solvent drag)
 1. Effective for larger molecules
- ▶ Diffusion and convection can be independently controlled and individualized

Vascular Access for Hemodialysis

- ▶ Access is required to remove and return blood:
- ▶ Common sites: Internal jugular vein, Femoral vein, Subclavian vein
- ▶ Types: Double-lumen catheter: One lumen: arterial (blood removal), Other lumen: venous (blood return)
- ▶ Long-term access (important addition): Arteriovenous (AV) fistula (preferred), AV graft

Procedure of Hemodialysis

1. Blood is withdrawn from the patient through vascular access
2. Heparin is added to prevent clotting, Reduced or avoided in patients with high bleeding risk
3. Blood is pumped into the dialyzer (artificial kidney)
4. Inside the dialyzer: Blood flows through hollow fibers or flat plates
5. Dialysate flows in the opposite direction (countercurrent flow) to maximize diffusion
6. Waste products and excess fluid move into dialysate
7. Purified blood is returned to the patient

► **Dialyzer Structure:** Contains a semipermeable membrane
Types: Hollow fiber dialyzer (most common), Flat plate dialyzer

► **Composition of Dialysate:** Dialysate is a solution resembling extracellular fluid, containing:

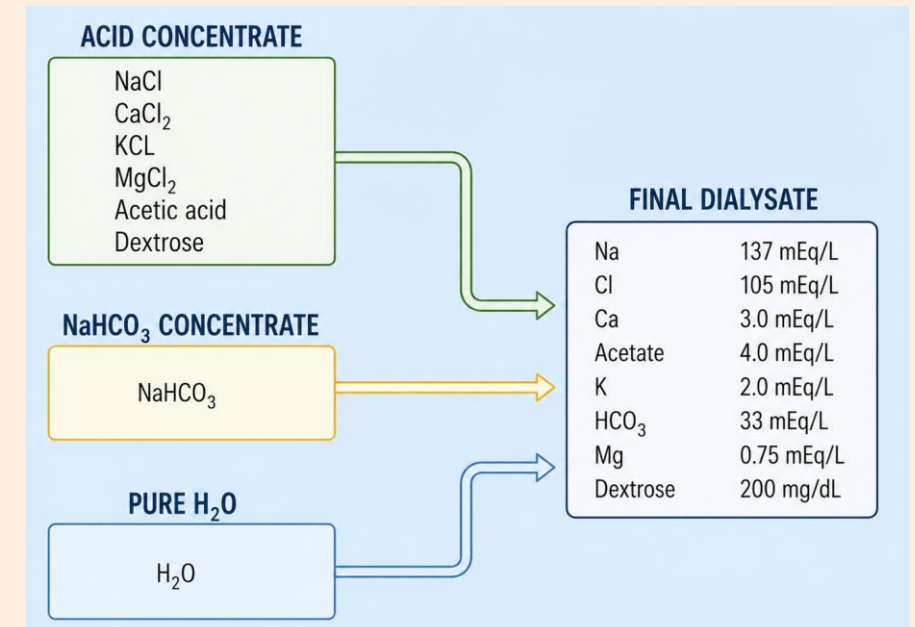
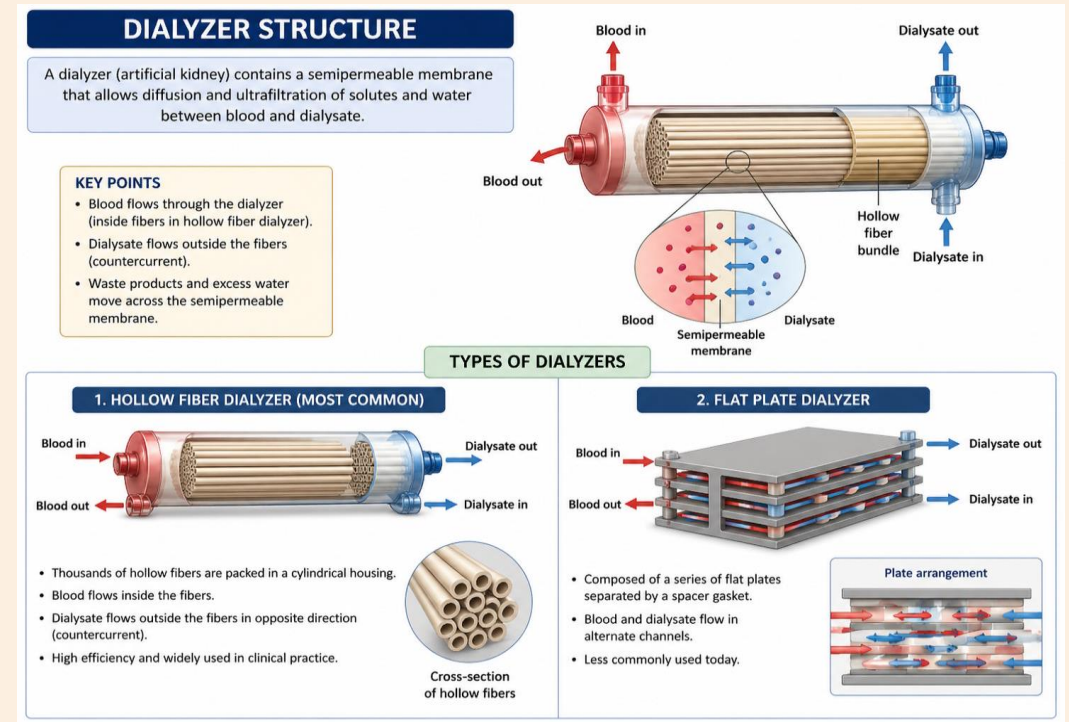
1. Water + electrolytes:
2. Sodium
3. Potassium
4. Calcium
5. Magnesium

► **Composition can be modified:**

1. Adjust potassium for hyperkalemia
2. Increase bicarbonate for acidosis
3. Adjust calcium levels as needed

► **Control of Fluid Removal**

1. Achieved by manipulating:
2. Hydrostatic pressure gradient
3. Dialysate and blood circuit pressures
4. Determines rate of ultrafiltration



Feature	Intermittent Hemodialysis (IHD)	Continuous Hemodialysis (CRRT)
Definition	Hemodialysis performed at intervals (sessions)	Hemodialysis performed continuously over 24 hours
Frequency	3–4 times per week	Continuous (24 hours/day)
Duration	Short sessions (3–5 hours)	Prolonged therapy (24 hours or longer)
Solute Clearance	Rapid and efficient	Slow and gradual
Fluid Removal	Rapid fluid removal	Gradual fluid removal
Hemodynamic Stability	Less stable (risk of hypotension)	Better stability (preferred in unstable patients)
Indications	Stable patients with ESRD	Critically ill patients (ICU, AKI)
Electrolyte Control	Rapid correction	Controlled, gradual correction
Setting	Usually dialysis center	ICU setting
Advantages	Faster toxin removal, shorter duration	Better tolerated, precise fluid and electrolyte control
Disadvantages	Rapid shifts → hypotension, not suitable for unstable patients	Requires continuous monitoring, more complex and costly

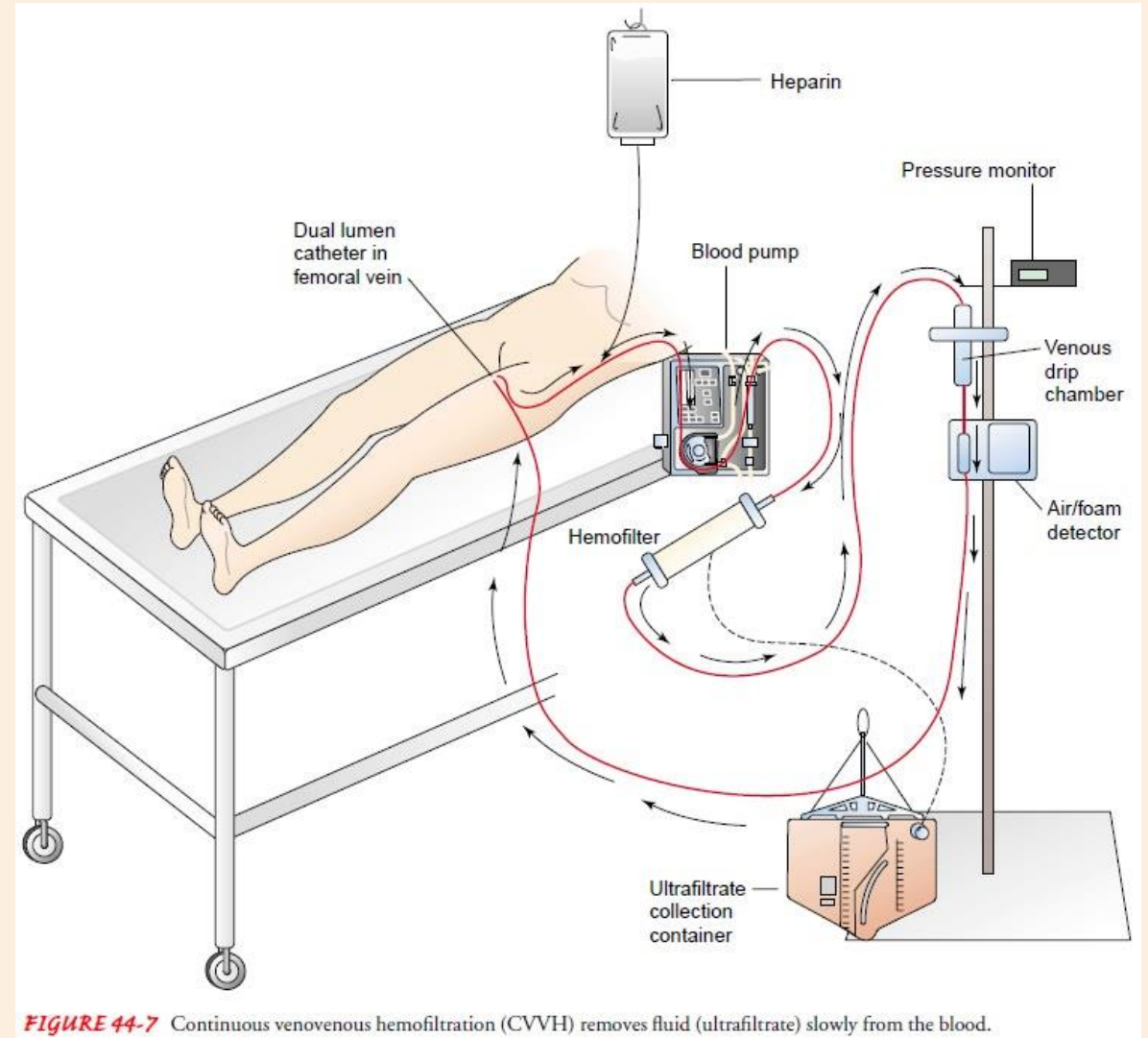
Complications	Advantages of Hemodialysis	Disadvantages of Hemodialysis
1. Hypotension (most common), Hypertension 2. Muscle cramps 3. Nausea, Vomiting 4. Headache 5. Chest pain, Back pain, Fever and chills (infection) 6. Infection, Thrombosis	High solute clearance efficiency Rapid correction of electrolyte imbalance Rapid removal of fluid overload Well monitored in center-based dialysis Effective for acute conditions	Requires frequent hospital visits (2–3 times/week) Loss of patient independence Risk of infections (vascular access related) Risk of thrombosis (vascular access) Hemodynamic instability (e.g., hypotension) Long-term decline in residual kidney function

Hemofiltration (HF)

1. Hemofiltration is a form of renal replacement therapy (RRT) in which plasma water and solutes are removed from blood by ultrafiltration through a semipermeable membrane, and the filtered fluid is replaced with a substitution (replacement) fluid.
2. Unlike hemodialysis, dialysate is not primarily used, and solute removal occurs mainly by convection.
3. Hemofiltration works mainly on:
 1. Ultrafiltration
 2. Convection (solvent drag)
4. Mechanism:
 1. A hydrostatic pressure gradient forces plasma water across a highly permeable membrane
 2. Solutes are carried along with water (convection)
 3. Larger molecules (up to ~20,000–30,000 Daltons) can be removed more effectively than in diffusion-based dialysis
5. No significant role of diffusion (since dialysate is absent or minimal)

Procedure of Hemofiltration

1. Vascular access is established (venous or arterial-venous)
 2. Blood is withdrawn from the patient
 3. Blood is passed through a hemofilter (high-permeability membrane)
 4. Ultrafiltrate (fluid + solutes) is removed
 5. Replacement fluid (sterile electrolyte solution) is infused: Either before (pre-dilution) or After (post-dilution) the filter
 6. Filtered blood is returned to the patient
- Blood flow is usually pump-driven (especially in venovenous methods)



Vascular Access Routes

Feature	CVVH (Venovenous)	CAVH (Arteriovenous)
Pathway	Vein → filter → vein	Artery → filter → vein
Driving force	Pump	Arterial pressure
Pump required	Yes	No
Use	Common (ICU)	Rare

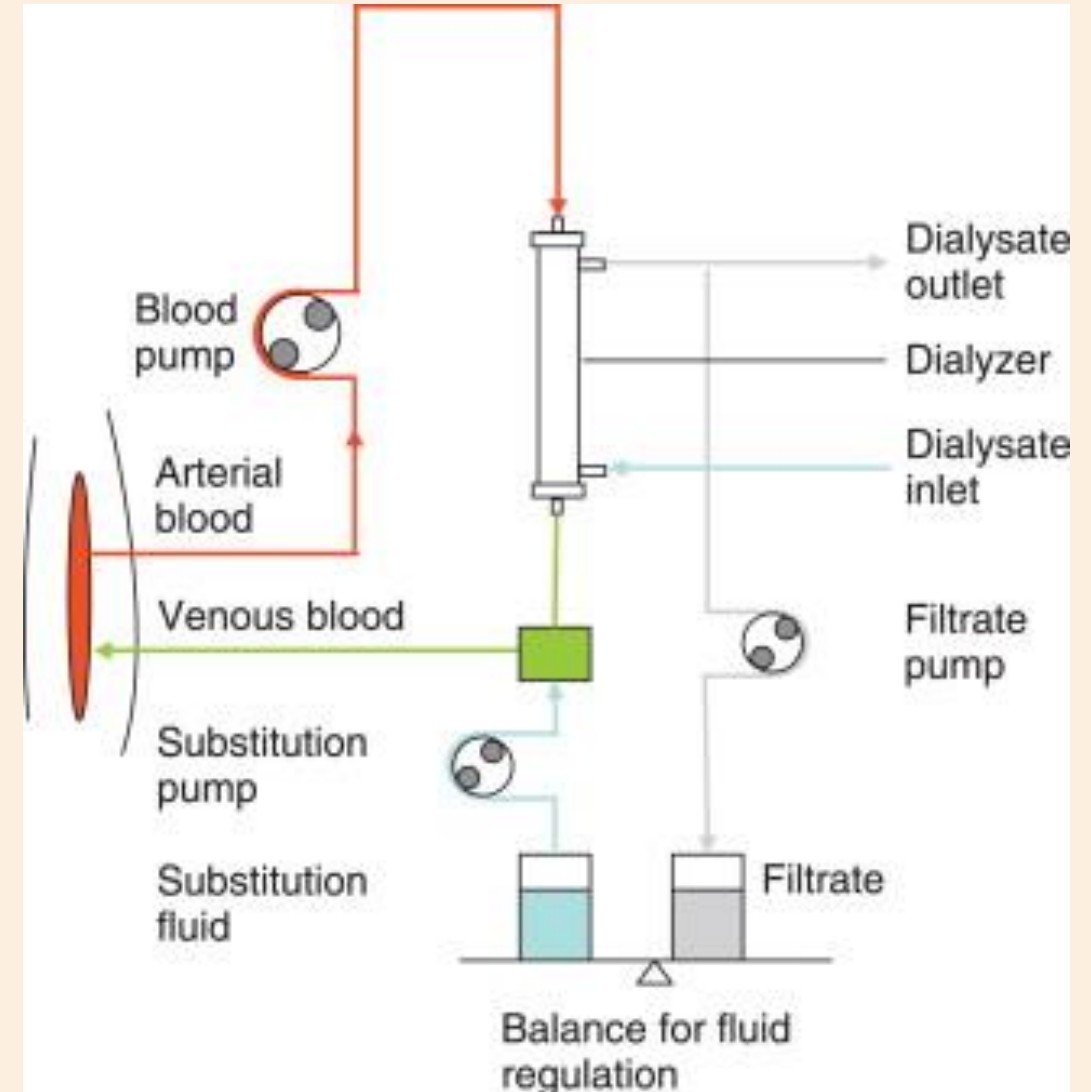
Types of Hemofiltration

Type	Key Features	Clinical Use / Notes
Intermittent Hemofiltration	Performed for short sessions; Similar to intermittent hemodialysis	Used less commonly
Continuous Venovenous Hemofiltration (CVVH)	Access via dual-lumen venous catheter; Blood flow maintained using a pump; Continuous (24-hour) therapy	Most commonly used in ICU
Continuous Arteriovenous Hemofiltration (CAVH)	Blood drawn from artery (e.g., femoral artery) and returned to vein; Flow driven by arterial pressure (no pump required)	Rarely used now

Advantages of Hemofiltration	Disadvantages of Hemofiltration
Continuous and gradual fluid removal	More complex than standard hemodialysis
Better hemodynamic stability (ideal for ICU patients)	Expensive (equipment and replacement fluids)
Precise control of fluid balance	Requires continuous monitoring
Effective electrolyte regulation	Risk of infection (vascular access)
Better removal of middle and larger molecules	Risk of thrombosis
Useful in critically ill patients	Requires trained personnel

Hemodiafiltration (HDF)

- ▶ Hemodiafiltration is a renal replacement therapy that combines the principles of hemodialysis and hemofiltration, allowing removal of both:
 1. Small molecular weight solutes (via diffusion)
 2. Middle and larger molecular weight solutes (via convection)
- ▶ It is considered an advanced form of dialysis with improved solute clearance.



► Principle of Hemodiafiltration: HDF works through a combination of two mechanisms:

1. Diffusion: Movement of solutes from high → low concentration

Efficient for: Urea, Creatinine, Electrolytes

2. Convection (Solvent Drag): Solutes are removed along with fluid movement

Effective for: Middle and large molecules (e.g., β 2-microglobulin)

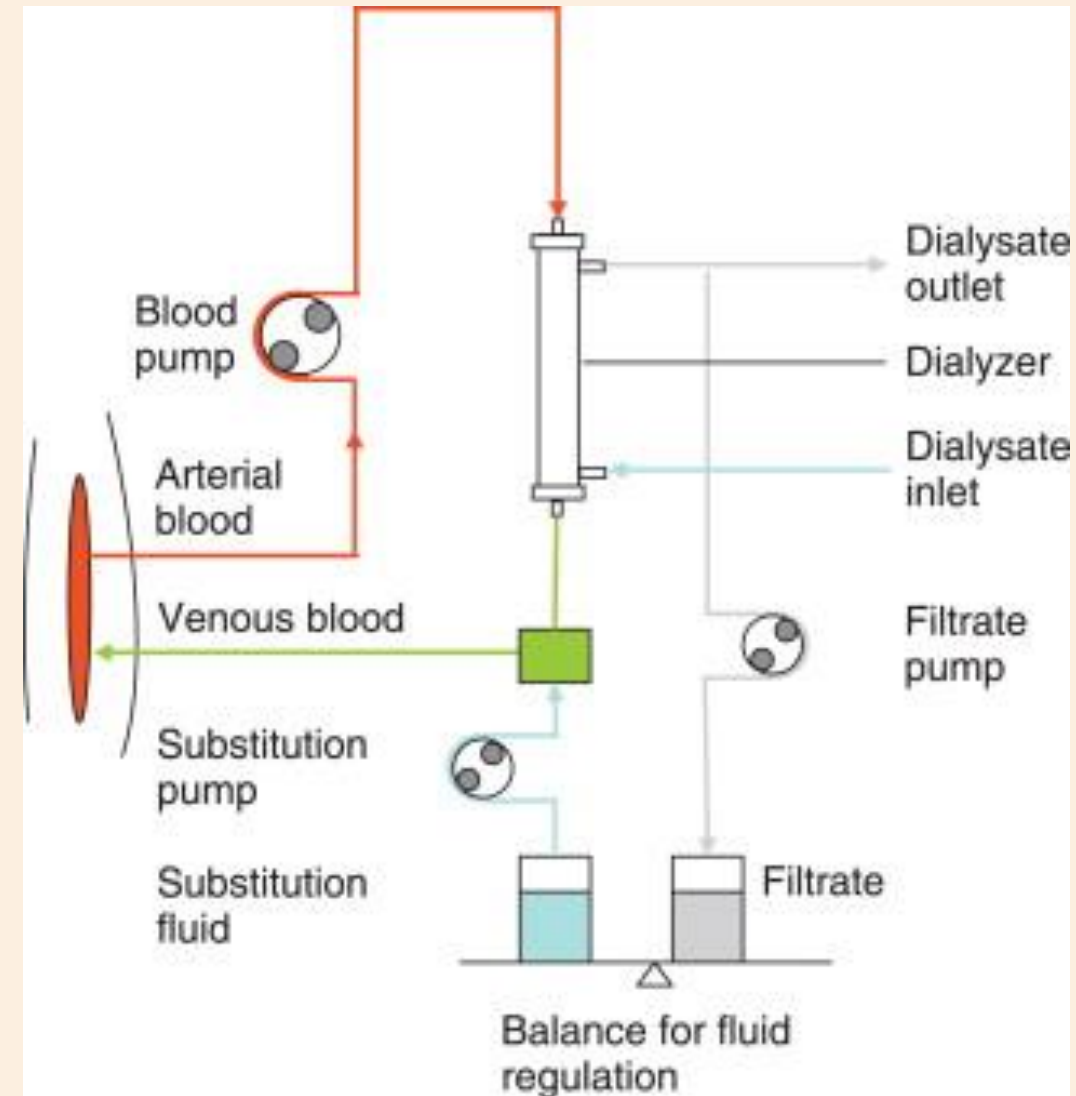
3. Ultrafiltration: A pressure gradient is applied to remove large volumes of fluid

Lost fluid is replaced with sterile substitution fluid

Thus, HDF provides: High-efficiency clearance of a wide range of solutes

Procedure of Hemodiafiltration

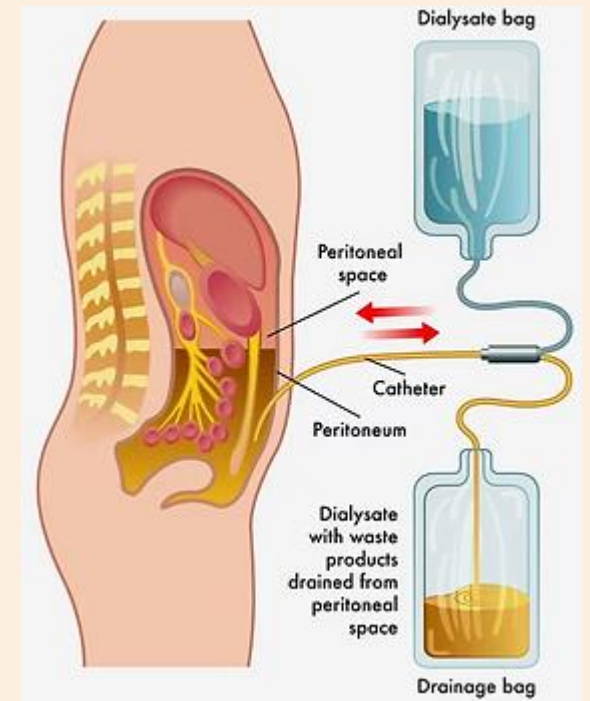
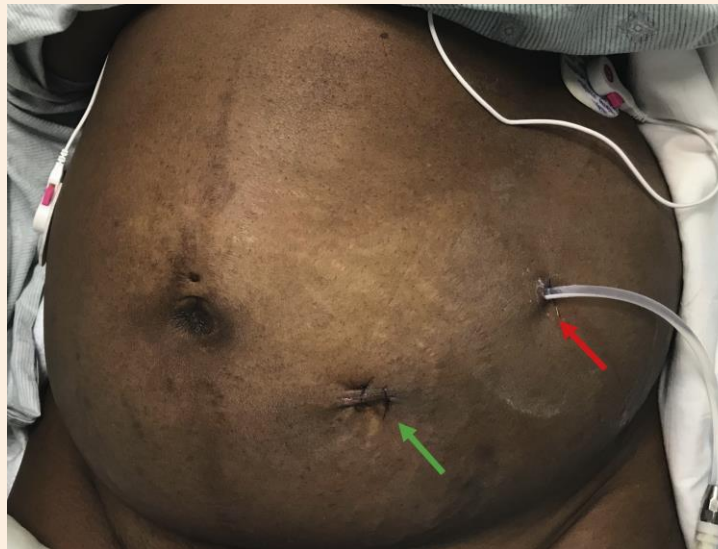
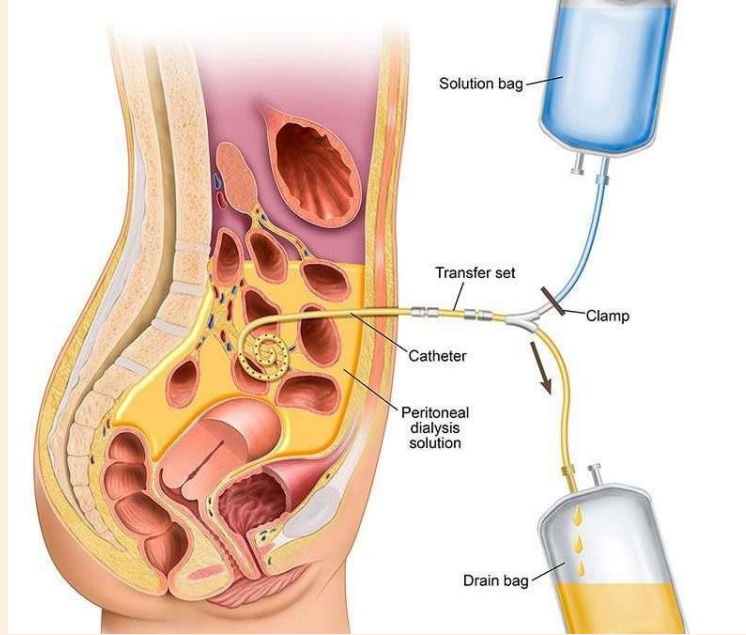
1. Blood is withdrawn via vascular access
2. Blood passes through a high-flux dialyzer
3. Simultaneously:
Dialysate flows for diffusion
Ultrafiltration occurs for convection
4. Large volumes of plasma water are removed
5. Replacement fluid is infused:
6. Pre-dilution or post-dilution
7. Purified blood is returned to the patient



Advantages of HDF	Disadvantages of HDF
Superior solute clearance	Expensive (equipment + replacement fluid)
Removes both small and middle molecules	Requires high-quality ultrapure water
Better removal of uremic toxins	Needs specialized machines
Improved hemodynamic stability	More complex procedure
Reduced complications (e.g., dialysis-related amyloidosis)	Requires trained staff
Better long-term outcomes (in some patients)	Limited availability in some settings
Improved quality of life	

Peritoneal Dialysis (PD)

Peritoneal dialysis is a form of renal replacement therapy in which the peritoneal membrane acts as a semipermeable membrane, allowing removal of waste products, excess fluids, and electrolytes from the blood into a dialysis fluid instilled in the peritoneal cavity.



Principle of Peritoneal Dialysis

- ▶ PD works mainly through: Diffusion, Osmosis (Ultrafiltration)
- ▶ Mechanism: The peritoneal membrane is highly vascular and semi-permeable
- ▶ Solutes move from: Blood (higher concentration) → Dialysate (lower concentration) by diffusion
- ▶ Fluid removal occurs due to: Osmotic gradient (created by glucose in dialysate)
- ▶ Allows removal of:
 1. Urea, creatinine
 2. Electrolytes
 3. Excess water
- ▶ PD is preferred in:
 1. Hemodynamically unstable patients (hypotension)
 2. Patients with residual kidney function
 3. Patients preferring home-based/self-care therapy

► **Structure of Peritoneal Membrane**

1. Composed of: Mesothelial cells , Basement membrane , Interstitial tissue
2. Surface area: **~1–2 m² (similar to body surface area)**

► **Peritoneal Dialysis Access:** Indwelling peritoneal catheter (silastic, biocompatible)

1. Length: 40–45 cm
2. Positioned in pelvic cavity
3. Contains 1–2 cuffs:
 1. Prevent infection
 2. Provide stability
4. Exit site: Important for preventing infection
5. Maturation period: 2–6 weeks preferred

► Peritoneal Dialysis Solutions

Component	Details
Base	Sterile water with electrolytes
Electrolytes	Sodium (~132 mEq/L), Chloride (~96 mEq/L), Calcium (2.5–3.5 mEq/L), Magnesium (0.5 mEq/L), Lactate (~40 mEq/L buffer)
Osmotic Agents	Dextrose (1.5%, 2.5%, 3.86%, 4.25%) or Icodextrin (7.5%)
Function of Osmotic Agent	Creates osmotic gradient → removes excess fluid (ultrafiltration)
Osmolarity	Hyperosmolar (dextrose solutions), Iso-osmolar (icodextrin)
pH	Slightly acidic (~5–6 in standard solutions; newer solutions closer to physiological ~7.3)
Volume per exchange	1–3 liters

Type	Characteristics
Dextrose-based solutions	Most commonly used; effective ultrafiltration; may cause hyperglycemia and weight gain
Icodextrin-based solutions	Long-duration ultrafiltration; fewer metabolic effects; used for long dwell (8–16 hours)
Biocompatible solutions	Neutral pH, low glucose degradation products; better for peritoneal membrane

► Procedure / Process of Peritoneal Dialysis

1. A soft catheter is surgically inserted into the peritoneal cavity
2. Sterile, warmed dialysate (1–2 liters) is infused into the abdomen
3. The fluid remains in the cavity for a fixed time (dwell period)
4. Waste products and fluid move into dialysate
5. The fluid is then drained into a collection bag

► Phases of Peritoneal Exchange: Each cycle consists of:

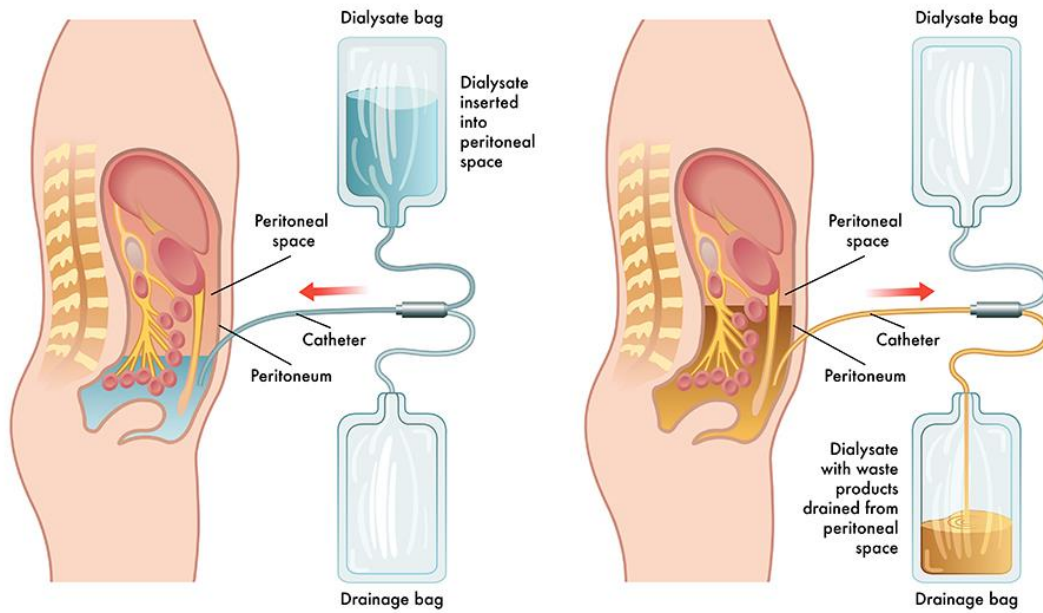
1. Fill phase – Dialysate is infused
2. Dwell phase – Exchange of solutes and fluid occurs
3. Drain phase – Used dialysate is removed

Feature	CAPD (Continuous Ambulatory PD)	APD (Automated PD)
Method	Manual exchanges by patient	Machine-assisted (cyclor)
Common use	Most commonly used	Widely used (especially home therapy)
Dwell time	4–8 hours	Short cycles (night) + optional long daytime dwell
Frequency	3–5 exchanges/day, daily (7 days/week)	Multiple automated exchanges (usually overnight)
Machine requirement	Not required	Required
Portability	Portable, flexible	Less portable (machine dependent)
Patient suitability	Independent patients	Patients needing assistance / prefer overnight dialysis
Variants	—	Includes CCPD and other automated forms

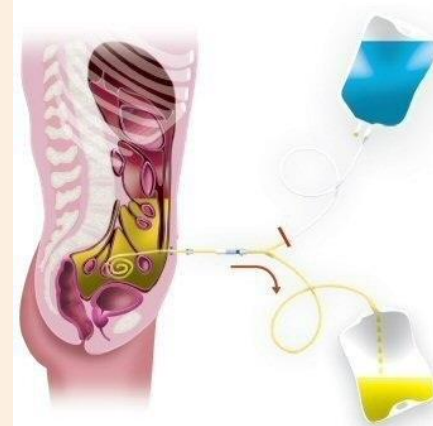
Category	Complications
Infectious	Peritonitis (most important), Catheter-related infections
Mechanical	Catheter malfunction, Dialysate leakage, Hernias, Back pain
Metabolic	Weight gain (glucose absorption), Hyperglycemia, Protein and amino acid loss
Others	Inadequate ultrafiltration, Technique failure, Hemorrhoids

Advantages of Peritoneal Dialysis	Disadvantages of Peritoneal Dialysis
Better hemodynamic stability (no rapid fluid shifts)	Risk of peritonitis
Preserves residual kidney function	Protein loss through peritoneum
No need for vascular access	Continuous glucose absorption → obesity, hyperglycemia
Can be done at home (independence, flexibility)	Reduced appetite
Less blood loss	Mechanical complications: hernias, dialysate leaks, catheter problems
No need for systemic heparinization	Less efficient for rapid toxin removal (vs hemodialysis)
Useful for all age groups	
Allows intraperitoneal drug administration	

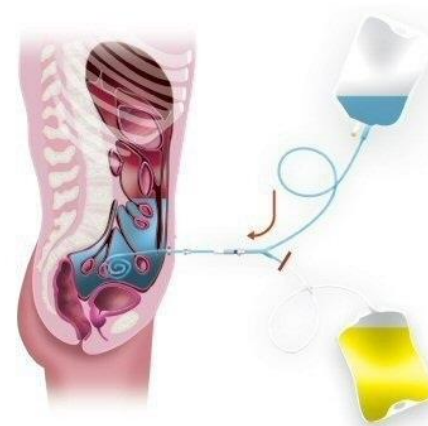
Peritoneal Dialysis



Peritoneal Dialysis "PD" exchanges



DRAIN



FILL



DWELL

Does not require
the use of blood
to leave your body