KIDNEY DIALYSIS

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There are two kidneys in the human body and both are identical in structure and function.

- Located in the abdominal cavity.
- Each kidney is 10 cm long and 6.5 cm wide.
- Weights 125-170 grams in males and 115-155 grams in females.
Regulates the amount of water lost through the body
Removes waste products from the blood
Blood contains waste due to the breakdown of active tissue and unused end products of metabolism
Substances removed from the body:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Amount (per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>1,500 mL</td>
</tr>
<tr>
<td>Urea</td>
<td>30 grams</td>
</tr>
<tr>
<td>Uric Acid</td>
<td>0.7 grams</td>
</tr>
<tr>
<td>Sodium Chloride</td>
<td>15 grams</td>
</tr>
<tr>
<td>Other</td>
<td>13 grams</td>
</tr>
</tbody>
</table>
Removal of waste occurs in tiny functional units of the kidney called nephrons.

Each kidney contains approx. 1 million nephrons.

Inside a nephron, a glomerulus interconnects with a urine collecting tube.

The glomerulus acts as the filtering unit.

<table>
<thead>
<tr>
<th></th>
<th>Liters (per day)</th>
<th>Milliliters (per minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filtration</td>
<td>170.0</td>
<td>120</td>
</tr>
<tr>
<td>Resorption</td>
<td>168.5</td>
<td>119</td>
</tr>
<tr>
<td>Urine Excretion</td>
<td>1.5</td>
<td>1</td>
</tr>
</tbody>
</table>
Kidneys release three important hormones:

1. **Erythropoietin (EPO)** - stimulates bone marrow to make red blood cells
2. **Renin** - regulates blood pressure
3. **Calcitriol** - Active form of Vitamin D, which helps maintain calcium level for bones and for normal chemical balance in the body
Azotaemia is the build-up of waste products that accumulate in the blood and the body when the kidneys fail to function.
- if the kidney failure is severe, symptoms will start to appear.

If the kidney (or renal) failure is of sufficient degree to cause symptoms, it is called uraemia.
1) ACUTE RENAL FAILURE

- Can happen rapidly - over days, weeks or months

CAUSES:
- Illnesses or operations
- Reduced blood supply to the kidneys
- Sudden blockage to the drainage of urine from the kidney (i.e. kidney stone)
- Rare side effect of some medications and other conditions
SYMPTOMS:
- Blood loss → causing a drop in blood pressure
- Vomiting and diarrhoea → causing dehydration
- Crush injuries → release of toxic protein substances
- Sudden blockage of urine drainage
2) CHRONIC RENAL FAILURE

- Can happen slowly over a period of years

CAUSES:

- Long-standing diabetes
  - Inflammatory conditions affecting the kidney tissue
- Inherited conditions (i.e. polycystic kidney disease)
  - Chronic blockage to the drainage of the kidneys
  - Cause cannot be identified
SYMPTOMS:
 The damage to the kidneys is usually 'silent' and not noticed at an early stage. (discovered from blood or urine tests)
 Symptoms are uncommon unless kidney failure is **far advanced**:
  - Tiredness
  - Itching
  - Loss of appetite
  - Nausea and vomiting
  - Breathlessness
  - Fluid retention, shown as ankle swelling (oedema)
  - Weakness
Acute Renal Failure
- Most causes can be treated
- Kidney Dialysis may be necessary until kidney function has returned

Chronic Renal Failure
- Not reversible: the kidneys eventually fail completely
- Affects around 26 million people in the U.S.
- ~550,000 of these patients require dialysis or transplantation
- Medicines to lower blood pressure
- Changes in diet
Thomas Graham (1854)
- Bell-shaped vessel

Based on: Graham T. Philos Trans R Soc Lond 144:117-128, 1854
1800-1913: Dialysis of animal blood against saline solution

1914: Abel et al. developed and tested the first efficient dialysis system at Johns Hopkins University School of Medicine

1924: The first human hemodialysis was performed in a uremic patient by Haas at the University of Giessen in Germany

1937: The first flat hemodialysis membrane made of cellophane was produced

1960: A new phase in clinical hemodialysis started with the introduction of the Quinton and Scribner AV shunt

1960: Cimino and Brescia first described their native arterio-venous fistula for chronic vascular access
CURRENT TREATMENTS

Hemodialysis
- The person’s blood is lead through an ‘artificial kidney’ machine that cleans the blood and returns it by tubing to a vein.
- It can be carried out over a few hours, and needs to be repeated, on average, every couple of days. It is done in a specialised dialysis unit attached to a hospital.
- Short-term dialysis

Peritoneal Dialysis
- Bloodless system that relies on fluid instilled into the peritoneal cavity
- The peritoneum is the clear membrane that covers the internal organs inside the abdomen.
- A plastic tube is placed within the abdomen and led out to the skin surface on the tummy
- Specially made fluid is run into the abdomen, left for a few hours and then run out again to wash out the toxic substances from the body
- Can be carried out at home (with support & guidance)
- Nocturnal Administration increases convenience
Extracorporeal housing

The hemodialysis machine contains a hemodialyzer, this is where the blood is filtered
WASTE PRODUCT REMOVAL

- Hemodialyzer has a thin, porous membrane (cellulose) that separates the blood from the dialysate fluid
- Perforations are invisible to the naked eye
- Perforations have a diameter of approximately 50Å
The dialysate fluid is free of any waste product molecules.

Waste product molecules flow from the blood to the dialysate fluid due to a concentration gradient.

Blood components (i.e., erythrocytes and leukocytes) are not removed since they are too large to fit through the perforations.

No bacteria/viruses can be introduced to the blood.

To keep important chemicals in the blood, the dialysate fluid concentration is made equal to the blood concentration for that chemical → no concentration gradient.
Actual size of molecules

- Albumin
- γ-globulin
- Hemoglobin
- Virus (small)

Holes in the membrane

Salts
- Urea
- Creatinine
- Uric acid

100 Å
**WATER REMOVAL**

- Water molecules are small enough to pass through the pores of the hemodialyzer.
- There are two ways of removing water from the blood:
  1. Addition of a substance to the dialysate fluid
  2. Ultrafiltration

![Osmosis](image1)

**Osmosis**

(Water moves by concentration gradient)

![Ultrafiltration](image2)

**Ultrafiltration**

(Solution moves by pressure gradient)
A large amount of a harmless substance (ie. Dextrose) is added to the dialysate fluid
This decreases the water concentration
Blood has a higher water concentration compared to the dialysate fluid
Concentration gradient is set up
Water moves from the blood to the dialysate fluid

Osmosis
(Water moves by concentration gradient)
At points in the membrane length when the pressure in the blood is greater than the opposite pressure in the dialysate fluid, water flows from the blood into the dialysate fluid.

Pressure difference in the dialysate fluid is adjusted to remove water from the blood.

More effective process than the addition of dextrose to the dialysate.
DIALYZER EFFECTIVENESS

- The metabolite clearance (MC) is a measure of removal rate of waste products.

- The mathematical equation is: 
  \[ MC = \frac{(C1 - C2)}{C2} \times Qb, \text{ ml./min} \]

  - C1 = blood inlet concentration of waste product to the dialyzer.
  - C2 = blood outlet concentration of waste product from the dialyzer.
  - Qb = blood flow rate.

- Depends on the functional change in waste product as the blood flows through the dialyzer.

- Often compromises have to be made in order to achieve the optimum efficiency of the dialyzer.

- Ultrafiltration often has to be traded off with the waste product removal.
The dialysate fluid has two functions:
1) Serves as a reservoir for the waste material and fluids removed.
2) Prevents loss of several body chemicals.
Contains five salts or electrolyte compounds:
1) Calcium Chloride
2) Magnesium Chloride
3) Potassium Chloride
4) Sodium Acetate
5) Sodium Chloride
DIALYSATE FLUID CONT’D

- Concentrations of the electrolytes are equal to or less than the concentrations in the blood
- Sodium acetate controls the pH of water
- Supplied in two forms: concentrated water solution and dry chemicals

<table>
<thead>
<tr>
<th></th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concentrated Water</strong></td>
<td>Easy to mix accurately</td>
<td>Heavy and bulky</td>
</tr>
<tr>
<td><strong>Solution</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dry Chemicals</strong></td>
<td>Easy to handle and transport</td>
<td>Difficult to mix properly</td>
</tr>
</tbody>
</table>

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1) Conventional Hemodialysis
   - 3 times/week
   - Each treatment is 3-4 hours
   - Blood is drawn at a rate of 300 mL/min
   - Entire blood volume circulates every 15 minutes

2) Daily Hemodialysis
   - Performed at home
   - 6 times/week
   - Each treatment is 2 hours

3) Nocturnal Hemodialysis
   - Performed while the patient is asleep
   - Each treatment is 8 hours
   - Improved blood pressure control
   - Associated with fewer dietary restrictions/medications
PROCESS OF INSTALLATION

- **Vascular Access:** A site in the body where blood is removed and returned to during dialysis.
- Vascular access should allow continuous high volumes of blood flow.
- Should be prepared weeks or months before starting dialysis.
- Three basic kinds of vascular access are:
  1. Fistula
  2. Graft
  3. Venous Catheter
FISTULA

- Requires surgery
- Takes a long time to develop (24 months in some cases)
- Usually in the forearm or arm
- An artery is directly connected to a vein
- Properly formed fistulas last many years
Graft

- Connects an artery to a vein using a synthetic tube
- Implanted under the skin
- Doesn’t need to develop (like a fistula does), therefore, it can be used immediately after placement
- Tends to have problems with clotting and infection
- A polytetrafluoroethylene (PTFE or Gore-Tex) graft is the most common type used for hemodialysis.
VENOUS CATHETER

- Used as a temporary access
- A catheter is a tube that is inserted into the patient’s vein near the neck, chest, or groin
- Has two chambers to allow a two-way flow of blood
- Needle insertion is not necessary
- Can easily clog or become infected
HEMODIALYSIS
PERITONEAL DIALYSIS

- Uses the peritoneal membrane as a filter
- Used for patients who have a tendency to bleed easily
- Vascular access is a catheter placed in the stomach
- Placement is usually done 10-14 days before dialysis starts
- In theory similar to hemodialysis

Process:
1) Dialysis fluid enters the peritoneal cavity
2) Extra fluid and waste travel across the peritoneal membrane into the dialysis fluid
3) The dialysis fluid is drained and replaced with new fluid
There are two types of peritoneal dialysis techniques:

1) **Continuous ambulatory peritoneal dialysis (CAPD)**
   - Dialysate stays in the belly for 4-6 hours
   - After this time the solution is drained out and the patient’s belly is refilled with fresh solution
   - Solution needs to be changed four times a day

1) **Continuous cycling peritoneal dialysis (CCPD)**
   - A machine automatically fills and drains the dialysate from the patient’s belly
Before starting the procedure the patient’s bladder should be emptied

Most recommended puncture site is the midline about two inches below the umbilicus

A repeated puncture technique with a multipuncture catheter is the simplest and safest way of performing peritoneal dialysis

The skin and subcutaneous tissue are infiltrated with a 1% procain (local anesthesia)

A 2 cm long and 4 cm wide stab wound is made

A catheter is placed in the patient
INSERTION OF THE CATHETER
Wound is closed with one or two band-aids, a single suture, or a metal clip
Before the wound is closed, the abdomen should be completely empty
Recovering all the dialysate fluid from the abdomen is very important
PERITONEAL DIALYSIS PROCEDURE
PATIENT SUCCESS STORIES
FUTURE: NEW DIALYZERS

1. Schemes that use various accordion type of cellulose based tubing
2. The hollow fiber artificial kidney
The object of both of these developments is to:
- reduce the size of the present dialyzer units
- to allow the development of low-cost, disposable dialyzers

The end package has featured some type of external clamping and/or capsulation of the dialysis tubing.

Several such dialyzers are presently under development; the sizes that have been shown to date have generally been cubes 6 inches on each side. Packaged within this small volume is a membrane surface area comparable to that presently incorporated in today’s large dialyzers.
A significant amount of effort is now being applied toward the development of blood purification that perform their function through ultrafiltration.

- Blood flows in the unit on one side of a membrane. The chamber on the other side of the membrane, rather than containing the conventional dialyzing fluid, is evacuated.
- The unwanted metabolites are filtered from the blood to the evacuated side of the unit. (Hemodiafilter and Ultrafilter)
- These units are being proposed as alternatives to dialysis for extracorporeal blood purification.
- A device of this type operates in a manner similar to the human kidney glomerulus.
- The development of this equipment is currently in its embryonic stage.

**Problem:**
- the ability to provide low-cost units that are easily handled and disposable
- the decision as to the degree of patient monitoring and safety equipment that is to be provided
Fig. 9-5
Artificial kidneys that can be worn by the patients

Problem: The ability to provide sufficient dialysate and membrane area within reasonable weight and volume constraints and yet perform the necessary blood purification.

- Use of activated carbon for filtering metabolites either out of the bloodstream or from dialysate, should it be required. Incorporation of absorption materials encapsulated within spherical membranes has also been proposed.

Microencapsulation: The metabolites would transfer through the outer shell of the sphere to the inner portion that provides the absorption material.

- Capsules could either be taken internally or used in a reduced volume dialysate system.

Development of Closed loop ultrafilter

- Blood is filtered with the filtrate correctly processed to permit the unwanted portions to be drained off and the desirable elements to be reintroduced into the body.
University College Hospital Medical School, London, is reporting very encouraging results in safety and efficacy of a portable, wearable dialysis system from LA-based Xcorporeal, Inc. Dubbed a Wearable Artificial Kidney (WAK)

- Battery-powered device
- Weighs less than 5 lbs
- Based on a hollow fiber dialyzer with a surface area of 0.2 sqm
1. Showing up to class
2. Not falling asleep
3. Listening to our presentation!

Questions?
REFERENCES


