Hemodialysis Kidney replacement therapy

Laura Worthington

MICRO-568

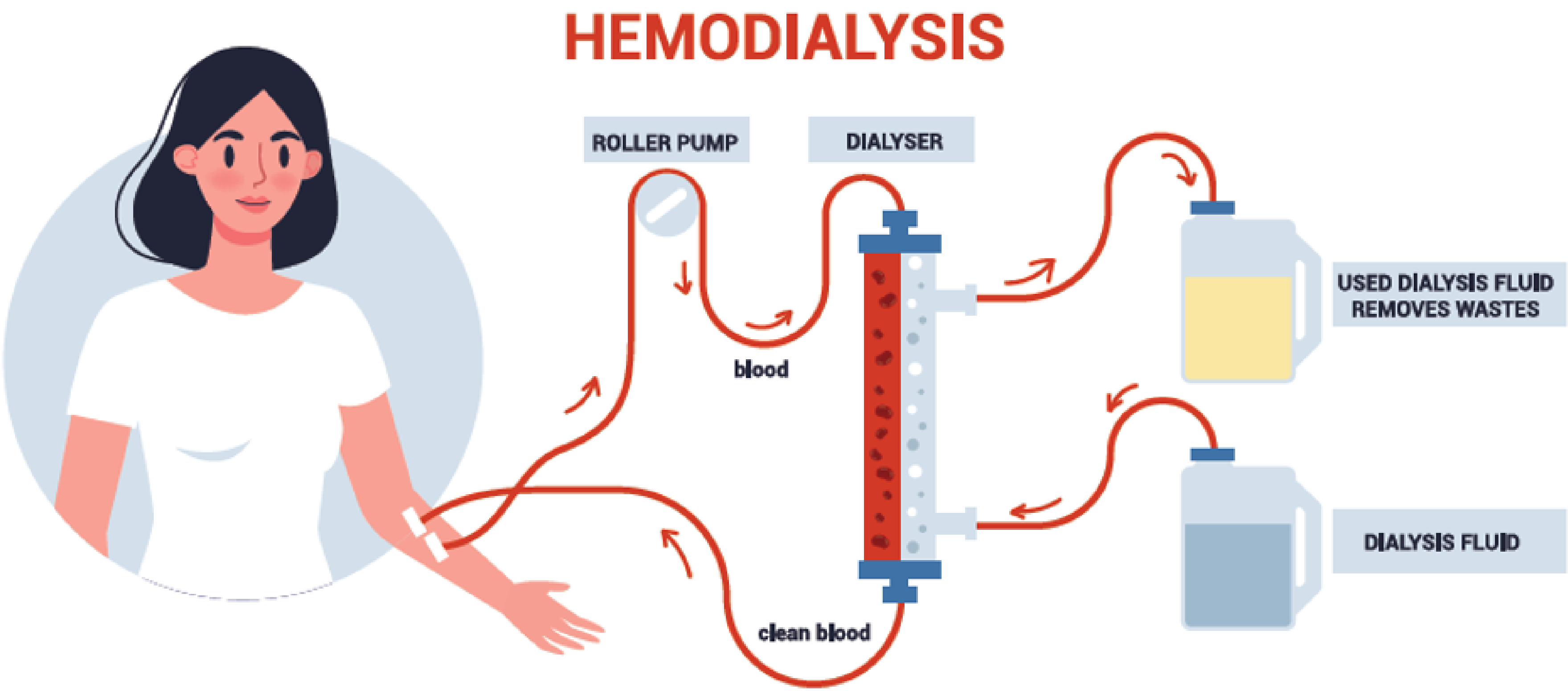
11 December 2025

References

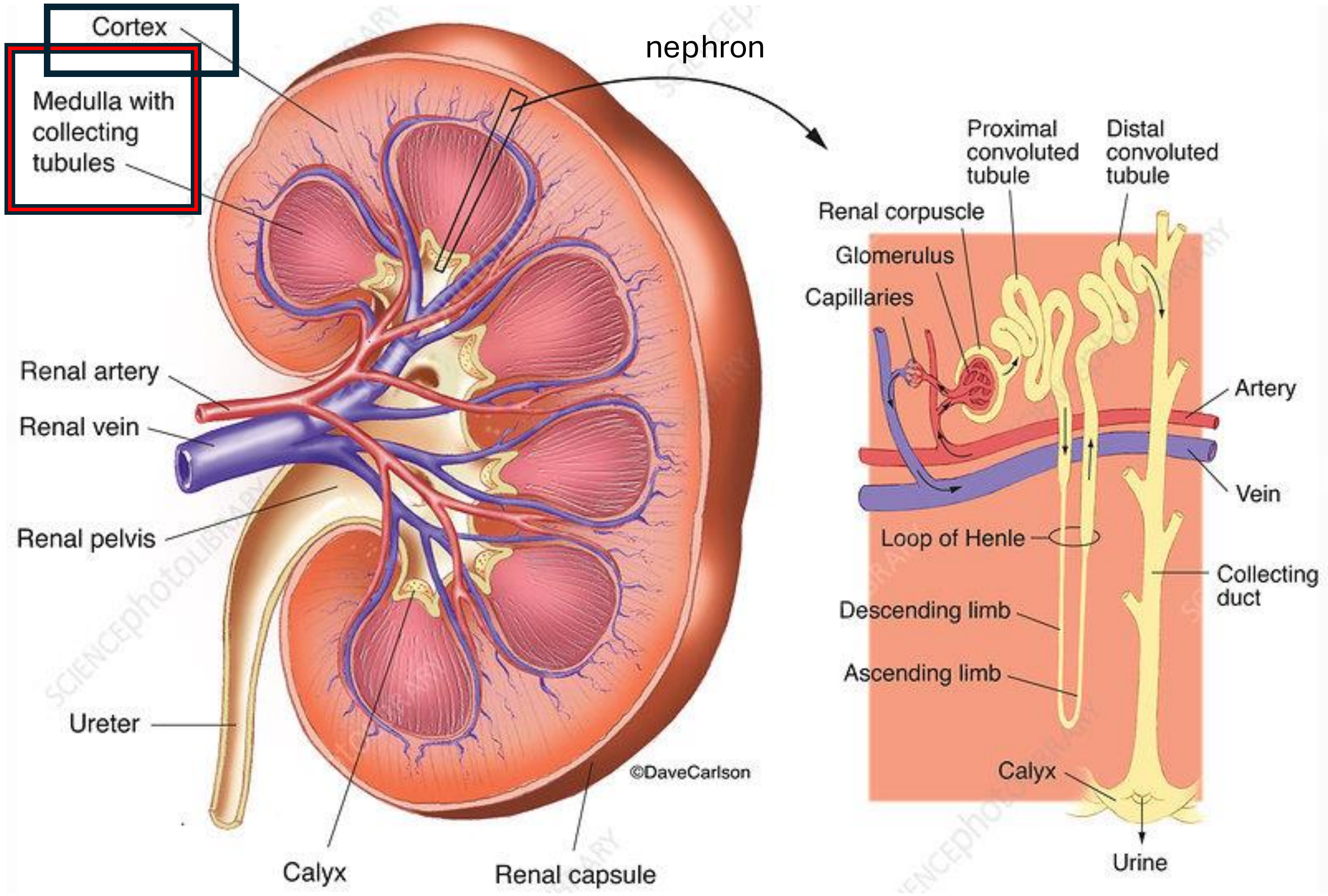
- https://my.clevelandclinic.org/health/treatments/24472-hemodialysis
- https://my.clevelandclinic.org/health/body/21824-kidney
- https://kidneycareuk.org/kidney-disease-information/treatments/dialysis-80-years-of-the-artificial-kidney/
- https://derangedphysiology.com/main/cicm-primary-exam/renal-system/Chapter-1165/physical-and-chemical-characteristics-dialysis-membranes
- https://www.swissinfo.ch/eng/demographics/transplantation-reduces-healthcare-costs-says-swisstransplant/87552883
- https://www.kidney.org/kidney-topics/hemodialysis
- https://onlinelibrary.wiley.com/doi/full/10.1046/j.1525-139X.2002.00065.x
- https://www.intechopen.com/chapters/1175051
- https://myendoconsult.com/learn/nephron/
- https://wecaregolp.com/dialysate/
- https://www.sciencedirect.com/topics/nursing-and-health-professions/dialyzer#:~:text=Dialyzers%20and%20Hemofilters&text=Membranes%20are%20characterized%20by%20their,to%205%20nm%20in%20diameter
- https://my.clevelandclinic.org/health/diseases/5791-polycystic-kidney-disease
- https://www.kidneyhealth.com.sg/peritoneal-dialysis/
- https://www.shutterstock.com/search/dialyzing?image_type=illustration
- https://www.kireports.org/article/S2468-0249%2825%2900003-8/fulltext
- https://www.youtube.com/watch?v=jDDCAF90_6A
- https://www.narayanahealth.org/blog/latest-developments-in-dialysis-technology
- https://nephcure.org/intro-to-rkd/end-stage-kidney-disease/dialysis/hemodialysis/
- https://www.nature.com/articles/s41581-020-0333-2
- https://freseniusmedicalcare.com/en-us/products/treating-with-home-hemodialysis/home-hemodialysis-products/nxstage-system-one/
- https://onlinelibrary.wiley.com/doi/full/10.1046/j.1525-139X.2002.00065.x
- https://link.springer.com/article/10.1186/s12882-023-03271-6
- https://ocrc.net/advancements-in-kidney-dialysis-technology/
- https://www.polarismarketresearch.com/industry-analysis/hemodialysis-market
- https://www.discovery.co.za/corporate/health-insights-effects-of-chronic-kidney-disease
- https://www.kidney.org/global-facts-about-kidney-disease#:~:text=Over%202%20million%20people%20worldwide,actually%20need%20treatment%20to%20live.
- https://www.researchgate.net/publication/324799314_Reconstruction_of_structure_and_function_in_tissue_engineering_of_solid_organs_Toward_simulation_of_natural_development_based_on_decellularization
- https://pharm.ucsf.edu/kidney
- https://www.hug.ch/en/nephrologie/practical-information#:~:text=Reimbursement,insurance%20company%20for%20more%20information.
- Guyton, A. C., & Hall, J. E. (2006). *Textbook of medical physiology* (11th ed.). Elsevier/Saunders

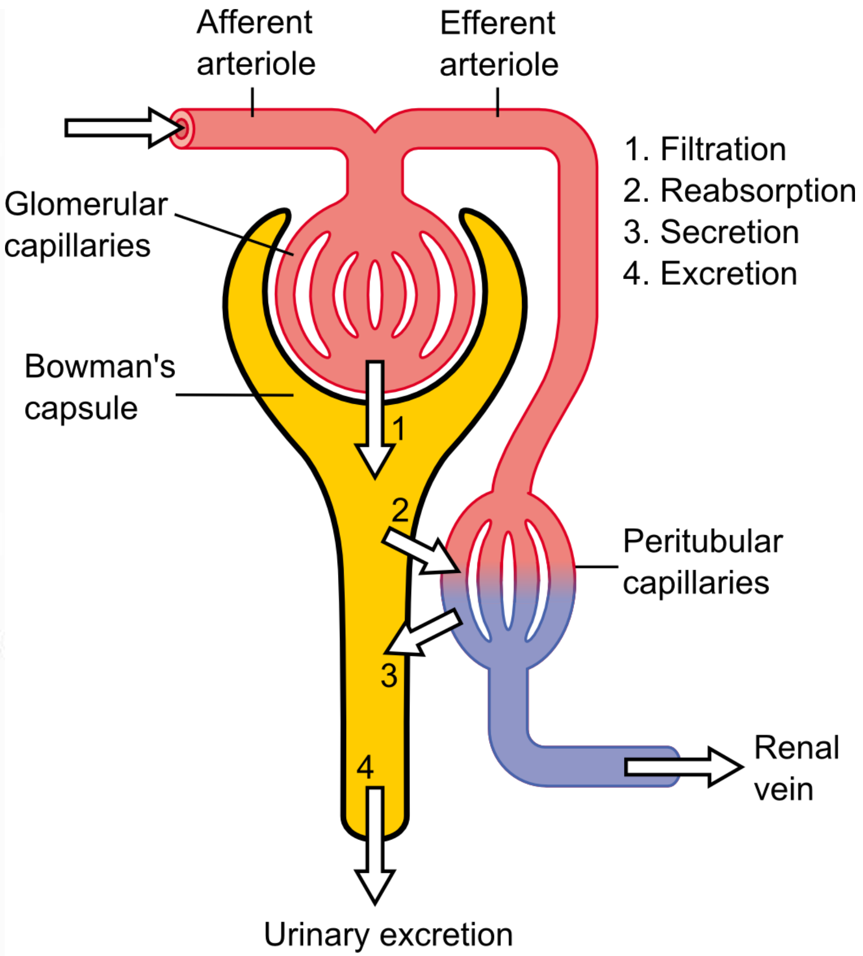
Presentation overview

Introduction



The Kidneys





Excretion = Filtration – Reabsorption + Secretion

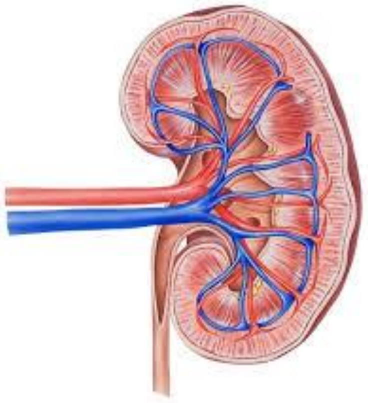
The Kidneys

Vitamin D metabolism

Blood pressure regulation via renin

Blood purification and filtration

- Filter 180 litres a day (all blood every 45 mins)
- Removes waste and toxins as urine
- Waste : urea, creatine, acids and excess sugar



Red blood cell production via erythropoeitin

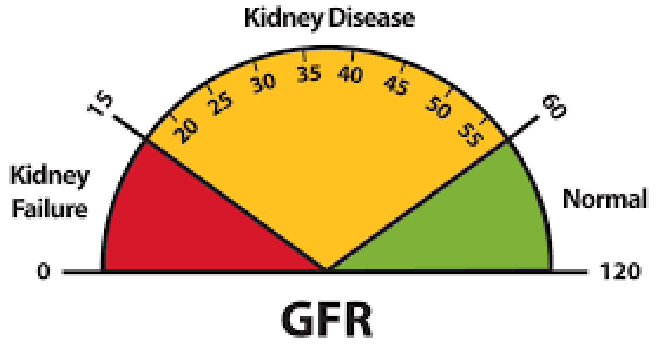
Electrolyte, acid and sugar balance

Evaluate kidney functionality : GFR (Glomerular Filtration rate)

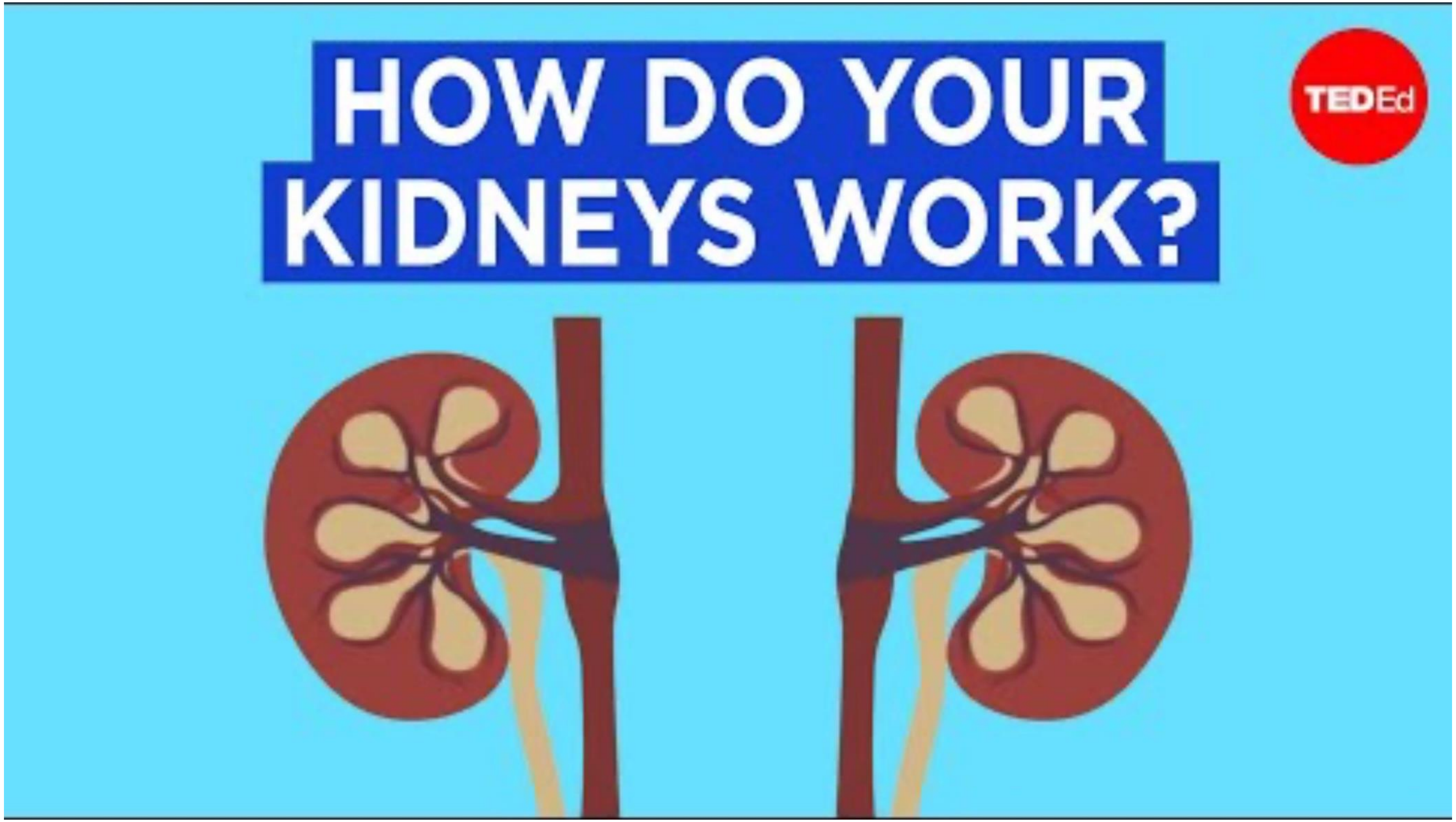
→ Rate blood is filtered

→ Calculated indirectly using creatine clearance

$$C_{cr} = \frac{U_{cr} \times V}{P_{cr}}$$

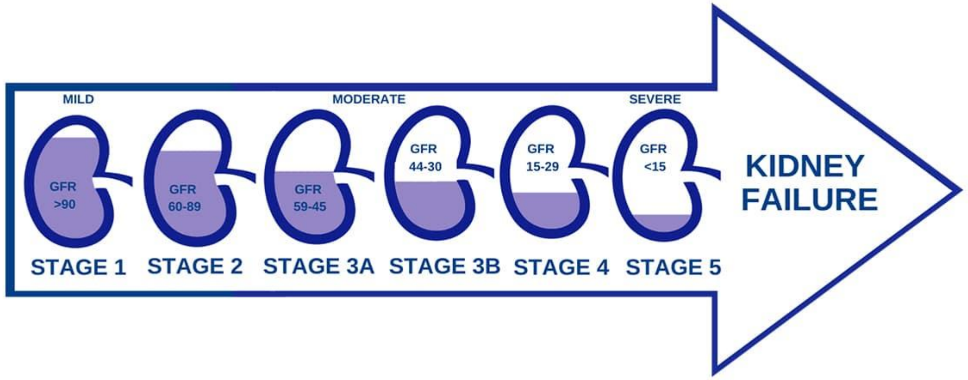


Kidney Physiology



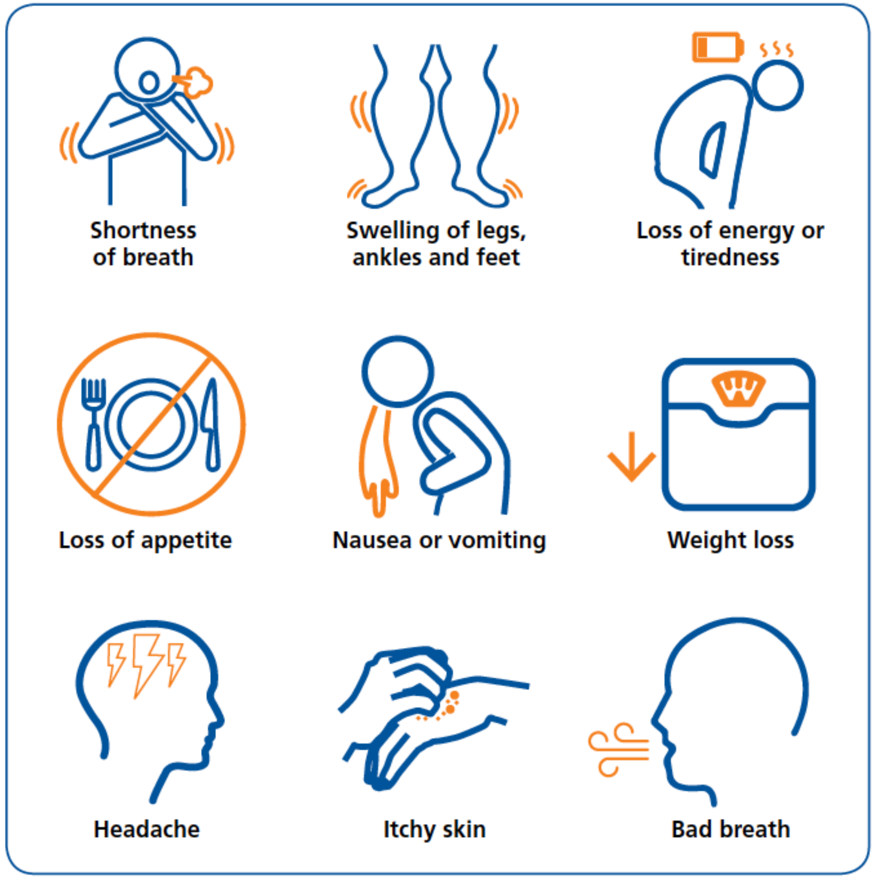
Kidney pathology

Type	What	Duration	Causes
AKF (Acute Kidney Failure)	Sudden loss of function (hours/days)	Days/Weeks Temporary with treatement	Severe dehydration, infections, medication, blockage, heart failure
CKD (Chronic Kidney Disease)	Gradual damage over time (> 3 months)	Permanent damage, progression can be halted, can lead to End Stage Kindey Failure (ESKF)	Diabetes, high blood pressure, genetic conditions (e.g. PKD), autoimmune diseases (lupus) , long-term blockages
PKD (Polycystic Kidney Disease)	Fluid like cysts grow in kidney, impairing function	Lifelong condition, can lead to ESKF	Genetic condition, PKD1 or PKD2 mutation



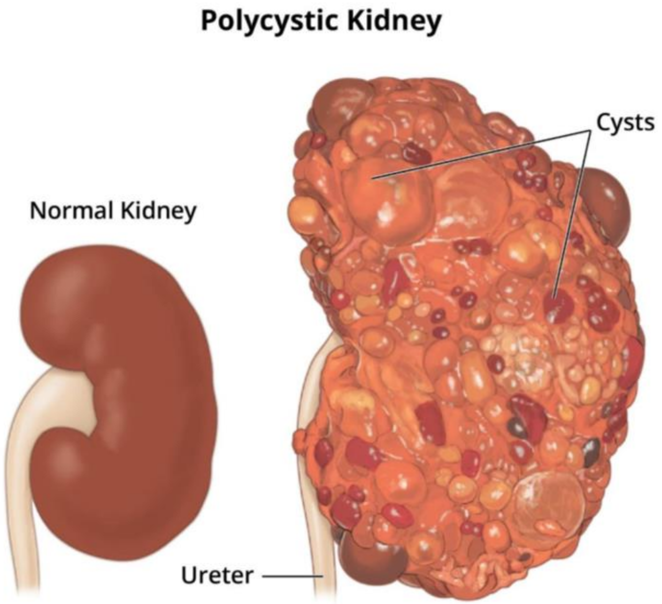
Kidney pathological symptoms

Kidney failure symptoms



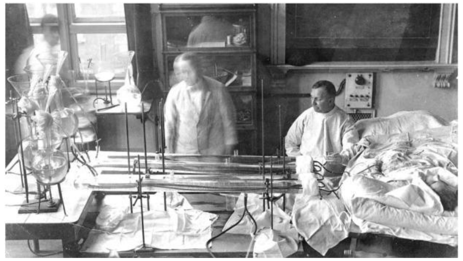
PKD symptoms

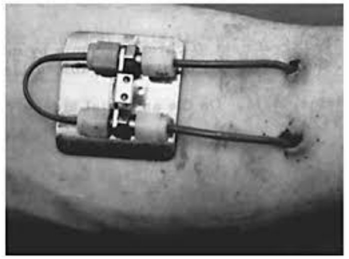
- Blood in urine
- Side and back pain
- Abdominal swelling
- High blood pressure
- Frequent UTIs
- Headaches



→ Toxin buildup, dialysis or transplant required

Historical timeline





1828

First notion of osmosis (Dutrochet)

1840s

Discovery of urea and creatine

Description of glomerulus (Bowman)

1854

Fundamentals of dialysis (Graham)

1913

First dialysis done on animals (Abel)

- Collodion as membrane and hirudin as anticoagulant

1924

First dialysis on humans (Haas)

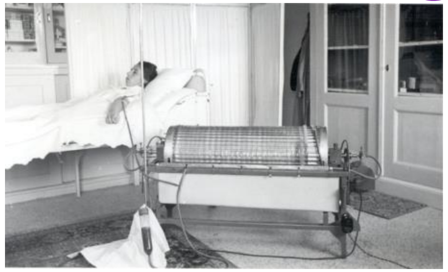
- Collodion and heparin (1916)

1943-45

Start of the modern era of dialysis by Kolf

Development of the first artificial kidney

- Rotating drum with cellophane tubing in pool of pool of rinsing fluid



1954

First renal transplant (Murray)

1956

First commercially available dialyzer, sold by Baxter Labs based on Kolf's design

1964

Hollow fiber dialyzer

Scribner shunt

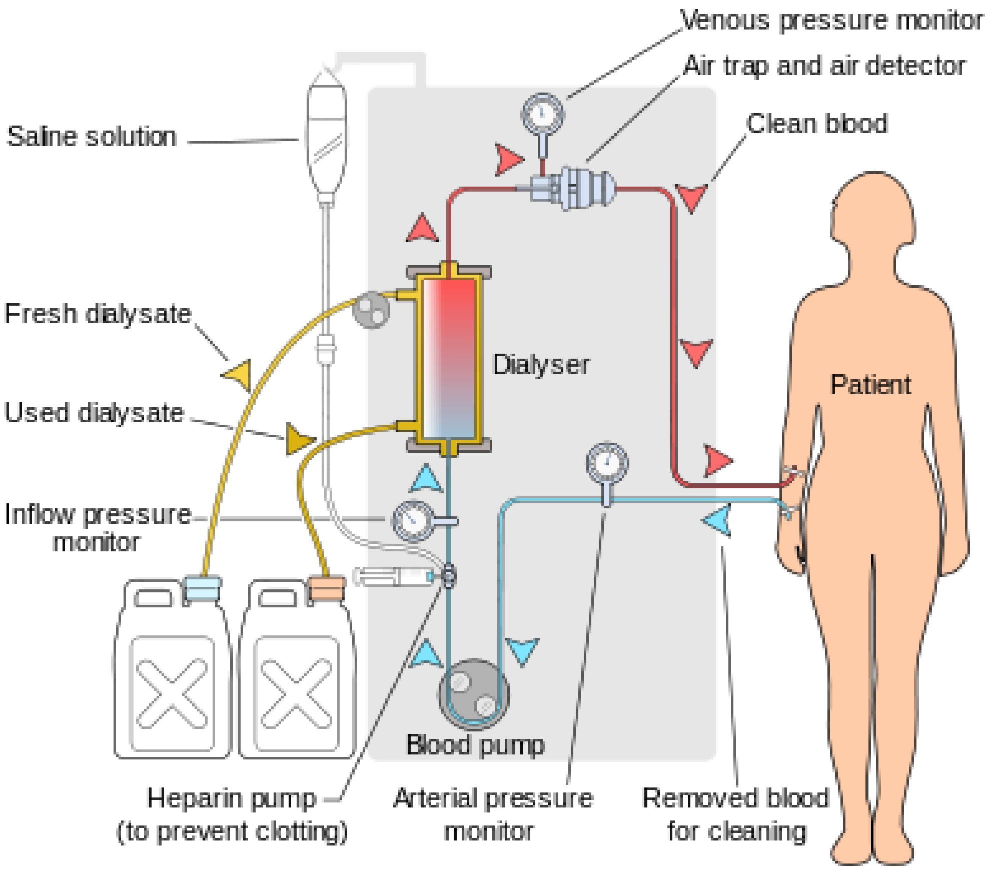
- Teflon loop connecting artery and vein
- Allowed long term access for blood filtering

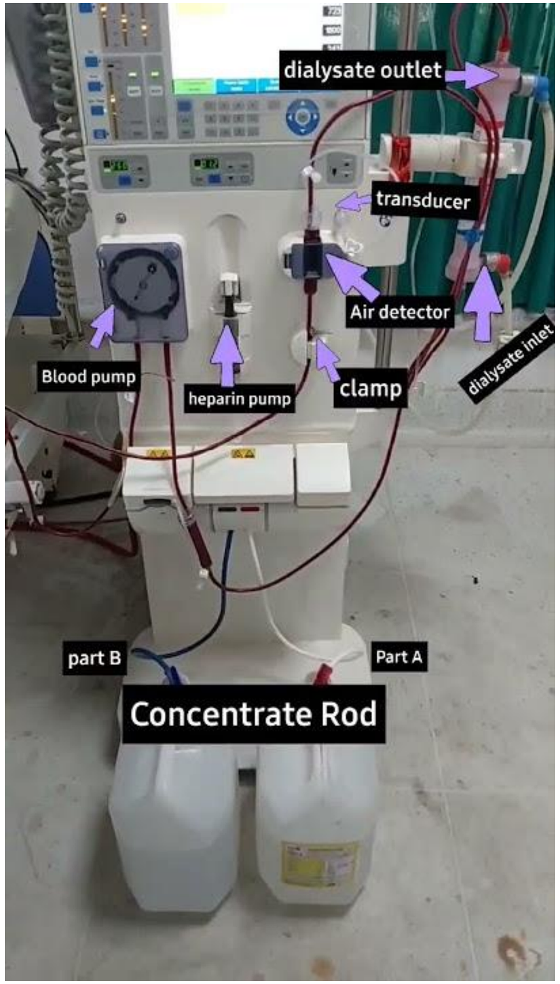
1966

AV fistula (Appel)

Gold standard for long term access

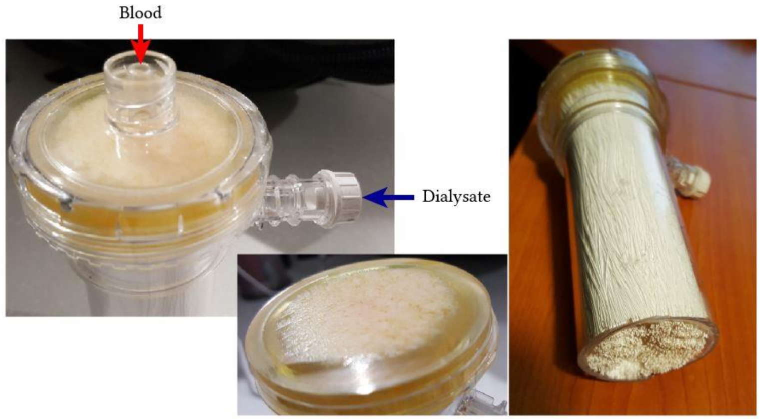
Technical presentation – general components

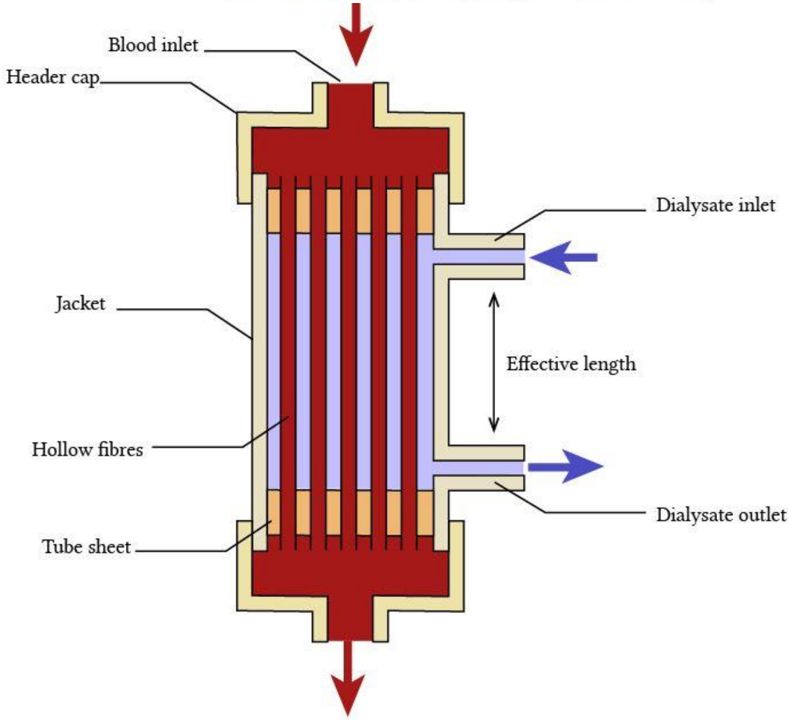




- Blood pump : ~300ml/min
- Heparin pump : Prevents blood clotting
- Dialyser: filtration membrane
- Dialysate : regulates gradients
- Air trap + detector : Removes bubbles and insures safety
- Pressure monitors (Pa/Pv) : acces and function monitoring

Technical presentation – Dialyser





- “artificial kidney”
- ~ 10k hollow tubes/fibres, 10-15 cm in length
- Surface area of 0.8-2.1m^2
- Synthethics materials
  - Chemically inert and non-thrombogenic
  - Thin but strong
  - Sulfones are as good choice (ex. Polyarylethersulfones (PAES) and polyethersulfones (PES))
- Permeability via small holes :
  - 1-2nm for low-flux membranes (diffusion, intermittent dialysis)
  - 3-5nm for high flux membranes (convection, hemofiltration or high flux hemodialysis)

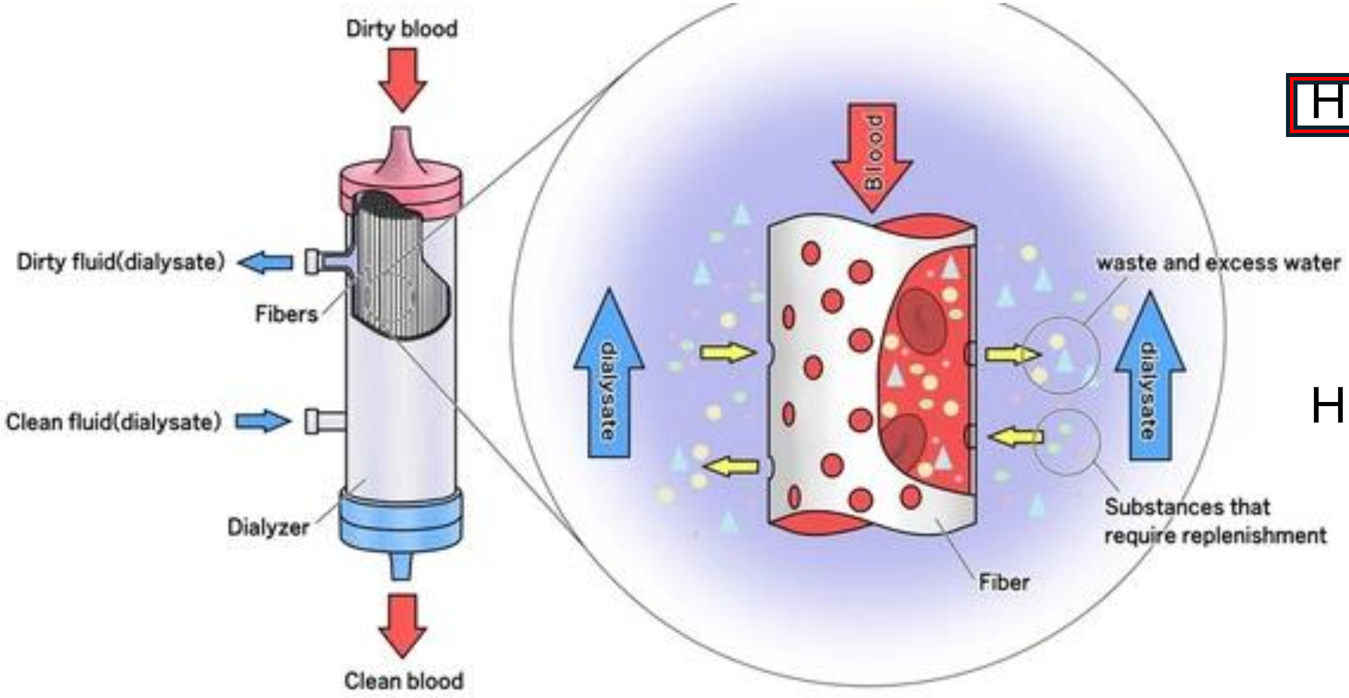
Technical presentation – Dialysate

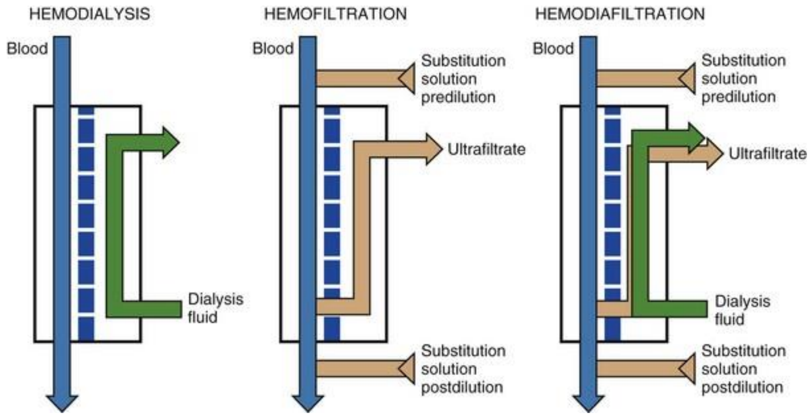
Electrolyte	Normal plasma range*	Typical dialysate range	Key notes
Sodium Na+	135–145 mmol/L	135–145 mmol/L	**=**, Major determinant of fluid balance and blood pressure
Potassium K+	3.5–5.5 mmol/L	1–4 mmol/L	**High**, low levels can cause arrhythmias
Calcium Ca+	2.2–2.7 mmol/L	1-1.75 mmol/L	**Low**, Diffuses mainly into blood; supports myocardial and bone stability
Magnesium Mg+	0.7-1.1 mmol/L	0.5-1 mmol/L	**High,** Helps reduce neuromuscular symptoms and supports RBC lifespan.
Glucose	1 g/L	0-2 g/L	Prevents hypoglycemia, especially in diabetics
Chloride Cl- (acid)	96-106 mmol/L	100-115 mmol/L	Adjusts inversely with bicarbonate; helps maintain acid–base balance.
Bicarbonate (base)	24 mmol/L	30-36 mmol/L	**Corrects metabolic acidosis** and restores acid–base balance. Main buffer used today.

- Should be at BT, 37°c
- Allows convection and diffusion across the membrane → correct imbalances and remove waste
- Contains :
  - Ultrapure water
  - Acid concentrate → adapted for the patient's needs
  - Base components

* Desired range after filtration

Technical presentation – Working principle





Hemodialysis (HD)

- Ultrafiltration (pressure gradients) to remove only excess fluids
- **Diffusion** along concentration gradient
- Better for small solutes
- Long term, intermittent treatement

Hemofiltration (HF)

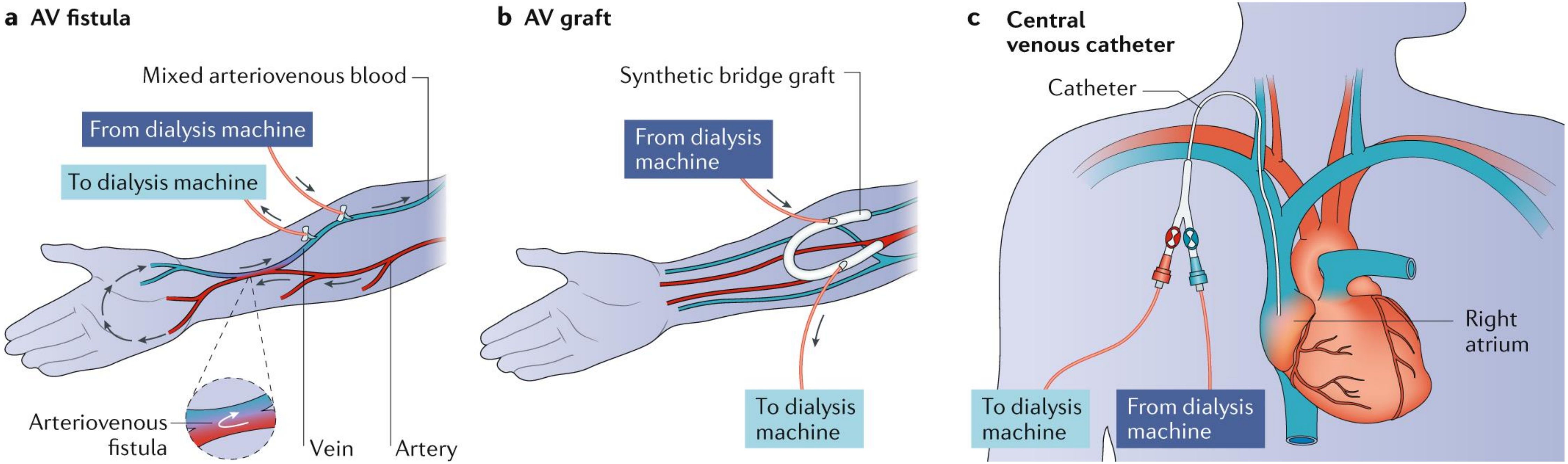
- Very high ultrafiltration to remove lots of fluids and larger solutes
- No dialysate
- Transmemebrane pressure ~ 150 mmHg
- Ultrafiltration coefficient (membrane's permeability to water) ~ 10-25 ml/h/mmHg/m^2
- Solutes get "dragged" by fluid : **convection**
- Substitution fluid
- Intensive care for acute KF, continuous treatement

Hemodiafiltration (HDF)

- Relies on convection and diffusion
- Substitution fluid
- Long term, intermittent treatement

Clinical application

Before hemodialysis : surgical creation of vascular acces



Lowest infection risk → Highest infection risk

Clinical application

- Wait time after surgery before dialysis :
  - AV fistula : 6 weeks to 3 months
  - AV graft : 2-6 weeks
  - Central venous catheter : none
- Treatment schedule:
  - In center: 3-5h, >3x a week
  - At home : >3h, 5-7x a week
- Life expectancy : average 5-10 years, up to 30 years
- Expected outcome : symptoms improve after weeks

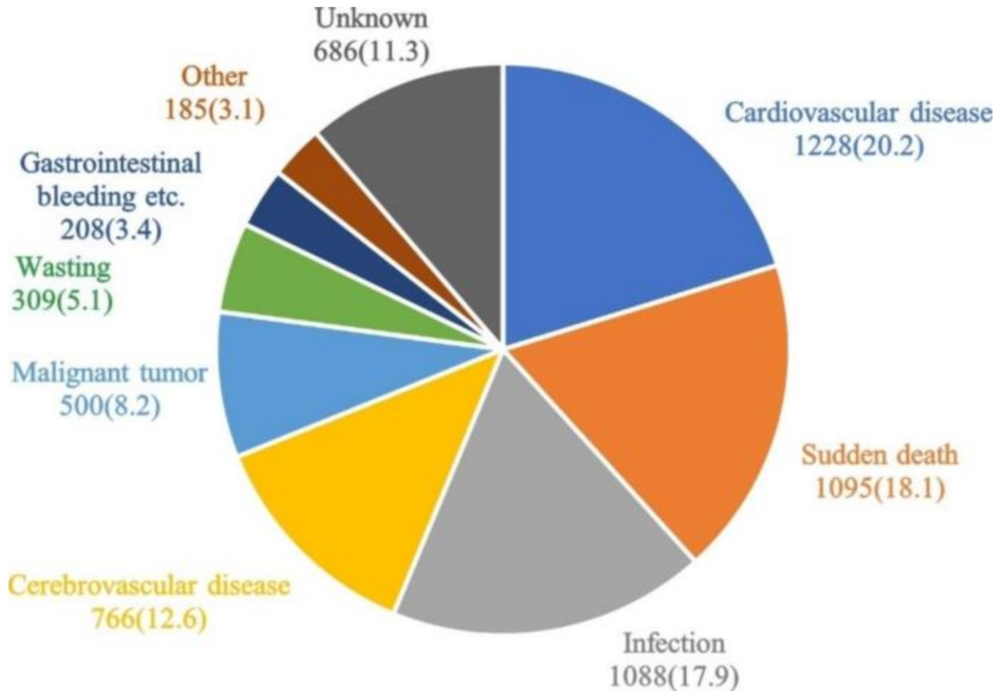
Required lifestyle changes

- Diet change
  - Low potassium and phosphate intake
  - Controlled sodium and sugar intake
  - Enough protein to counter catabolism
  - Limited fluids
- Exercice
- Blood pressure medication

→ **But still not as functional as 24/7 physiological filtering**

Clinical application- potential complications

- **Hematological** : anemia, aluminium toxicity
- **Cardiovascular** : Low BP, arrythmias
- **Long-term** : amyloidosis, adynamic bone disease (ABD), aquired cystic kidney disease (ACKD), kidney cancer
- **Acces-related** : infection, stenosis or thrombosis



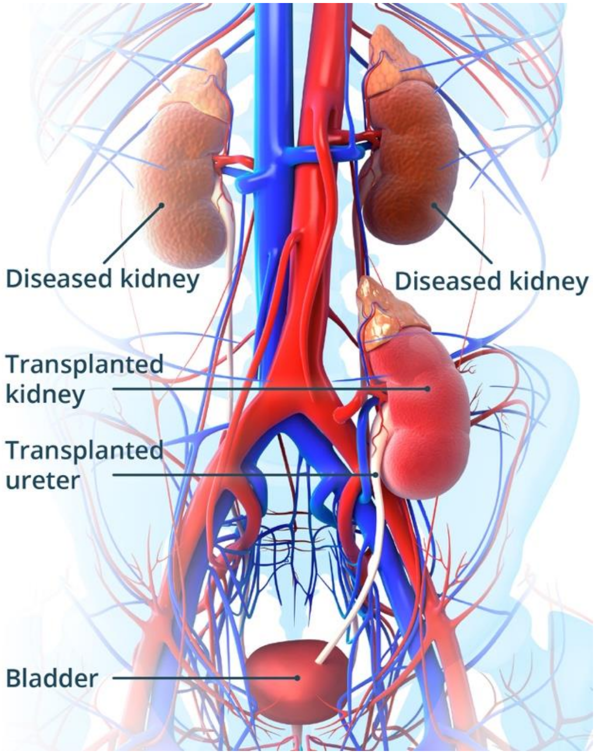
Chinese study, 25k patients, 6k died from 2014-2020, annual rate 8%

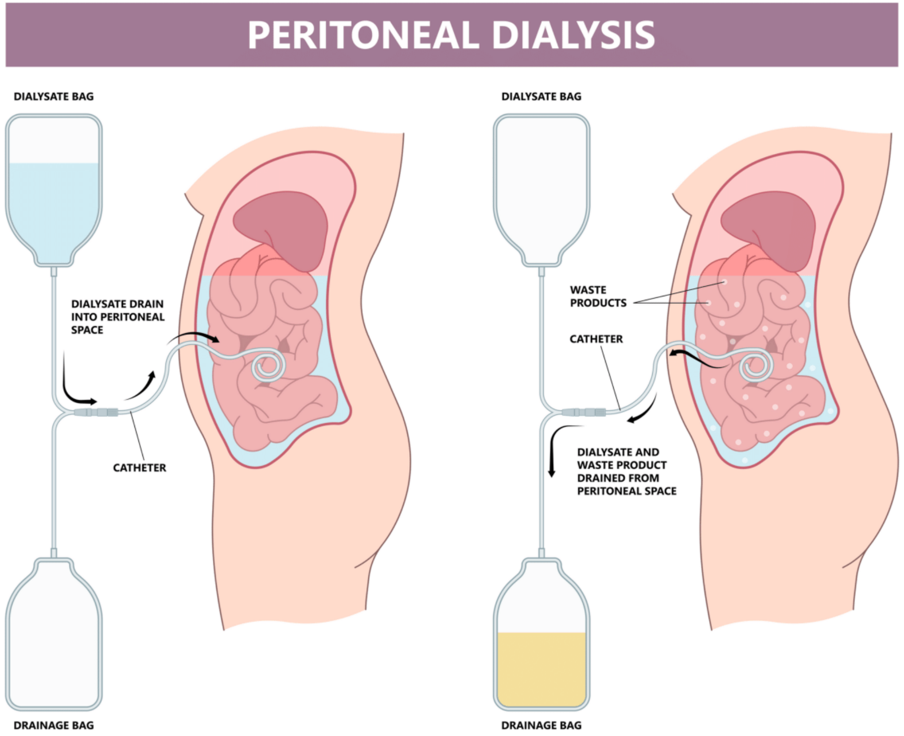
Alternatives

- **Kidney transplant**
  - ESKD (<10% function)
  - Better quality of life after
  - 3 types of donors (living related, living non-related, cadaveric)
  - Risk of rejection

- **Peritoneal dialysis**
  - Uses peritoneum (lining of the abdomen) as membrane for osmosis
  - CAPD (continuous ambulatory) or APD (automated)
  - Can be done at home, daily
  - Risk of peritonitis

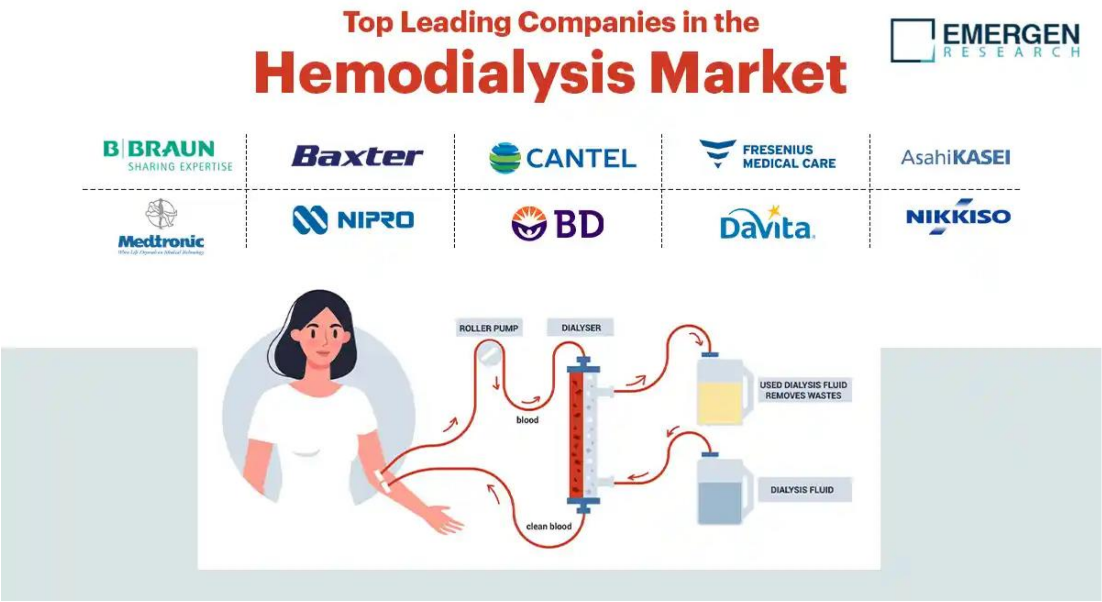
- **Supportive medical management**

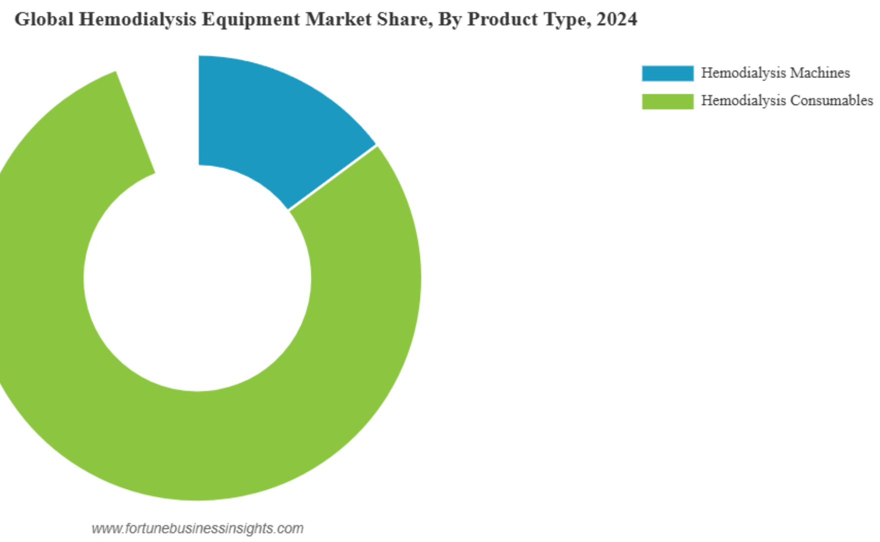




Product aspects

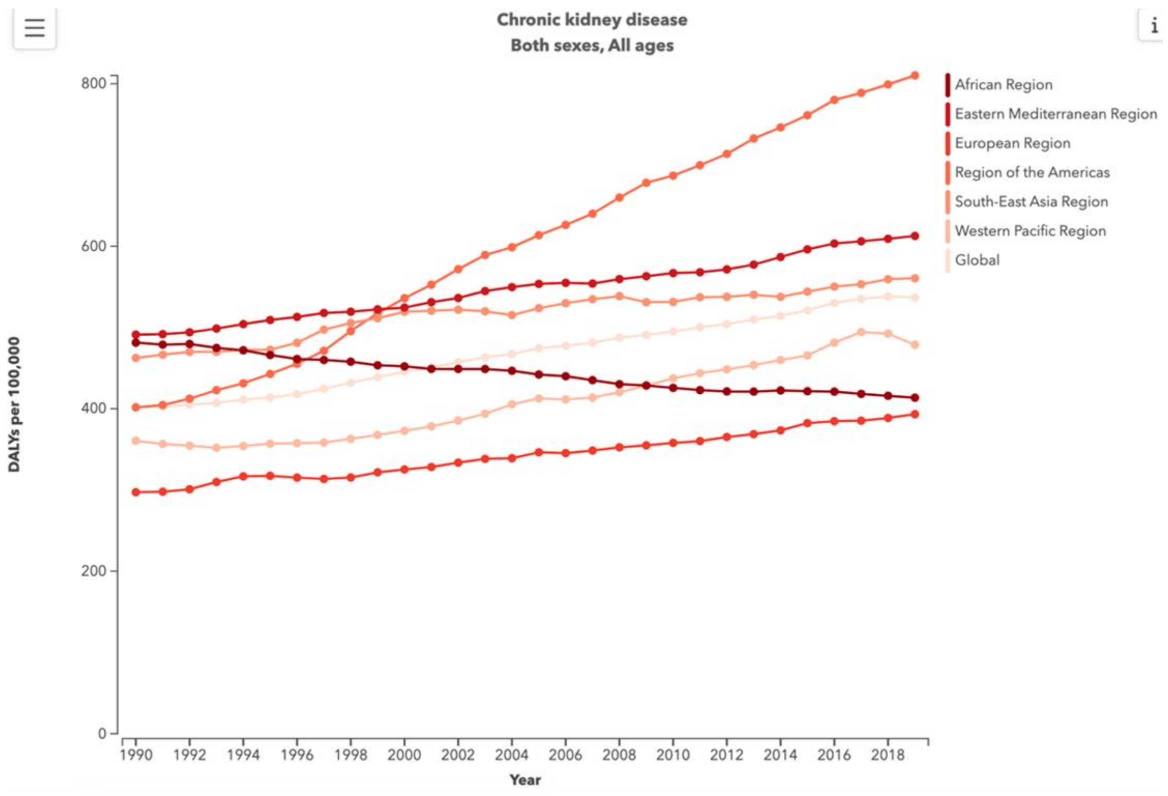
- Consult with doctor to determine care plan
- At home is more cost effective
- At home machine costs 26k-47k USD (owned by hospital)
- In switzerland :
  - 100K CHF a year in center
  - Covered by basic insurance

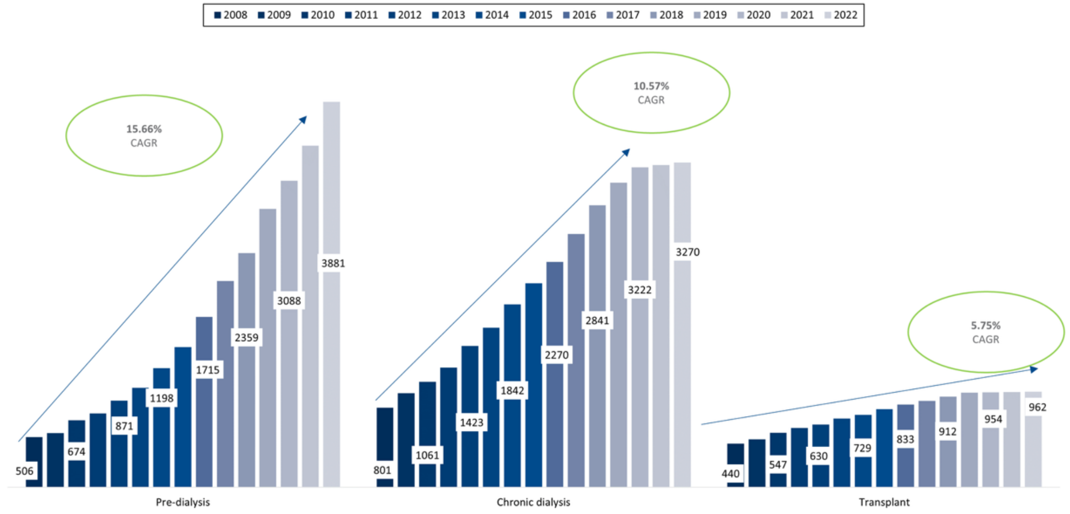


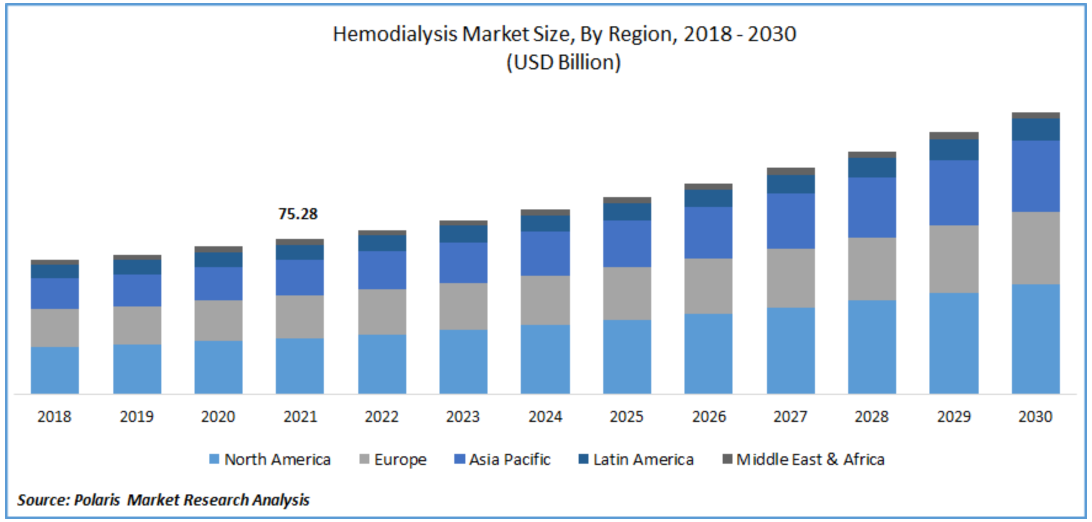


Current trends

Global CKD rising → HD demand increasing → market growth







DALY per 100,000 = number of disability adjusted years lost
CAGR = coumpound annual growth rate

Medical significance

- Life saving treatement
- 90% of medical dialysis is HD (otherwise perinatal dialysis)
- Estimated >2 million patients used HD in 2025
- 10% of those need it have access to HD globally
- Rising prevalence of CKD

Clinical advances

Portable filtration device : e.g. NxStage System One (Fresenius Medical Care)

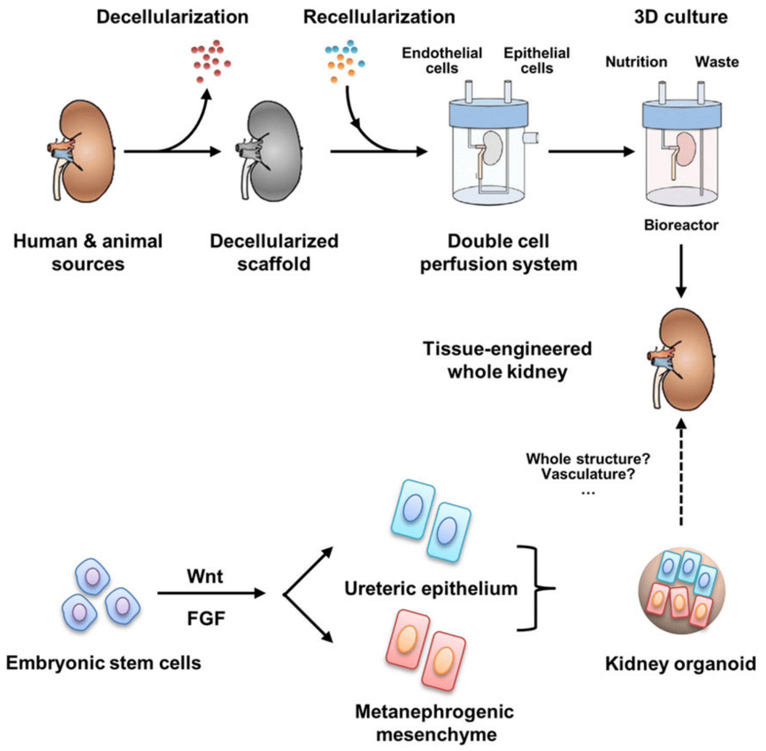
- Easy at home, can be taken to travel, weighs 30 kg
- Better quality of life
- 5 sessions, total of 30h a week
- Company offers 24/7 helpline + supplies delivered 1x/month
- 26 k USD + supplies

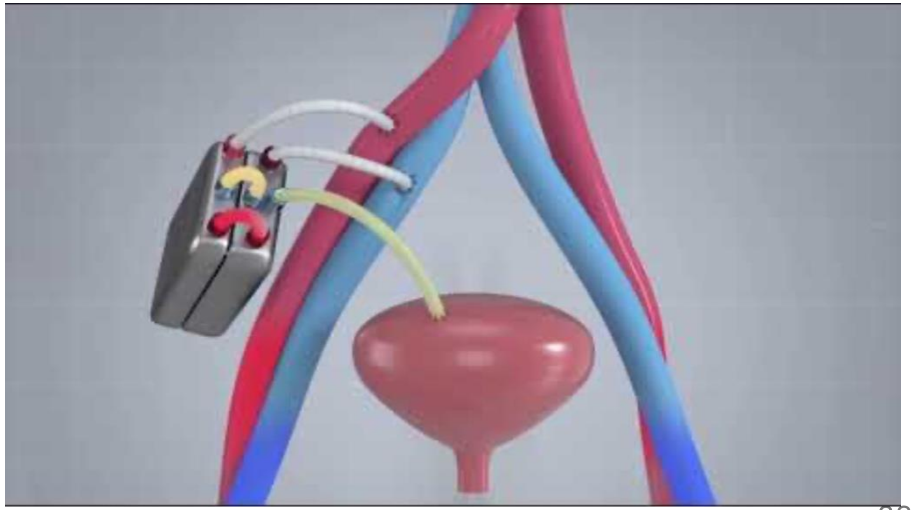
Integration of AI

- Predict dangerous drop in BP
- Adapt prescriptions

Clinical advances

- Artificial kidneys
  - Human nephron using stem cells in mice (2018)
  - Stem cell-based approaches for kidney tissue regeneration
  - Bioartificial kidney : the kidney project
    - Combination of synthetic filters and a bioreactor with engineered kidney cells
    - Powered by BP
    - Potential for 2030





Conclusion and future perspectives

- Hemodialisys replicates key kidney functions
- Uses pressure gradient, diffusion and convection
- Time consuming and high prevalence of side effects
- Global rise in CKD → prevention
- Affordability and accessibility challenge
- Technology improving safety and quality of life

Thank you for you attention

Questions?