UNDERSTANDING THE CRRT MACHINE

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RRT options - IHD vs CRRT (1)

	PROS	CONS
Intermittent HaemoDialysis e.g. 4hrs daily or on alternate days using on-line dialysis fluid	▪ Less labour-intensive ▪ Cheaper fluid (on-line supply) ▪ Fewer machines needed ▪ Dialysis fluid tailored to patient's needs ▪ Shorter periods of anticoagulation ▪ Allows patient to mobilise between treatment sessions	▪ Fast fluid removal may not be well tolerated -> intradialytic hypotension ▪ May not be able to give optimal nutrition due to volume restriction ▪ Usually operated by specialised dialysis nurses, not ICU staff ▪ Water plant installation-expensive ▪ Uses 1 circuit/day ▪ Some blood loss each day

RRT options - IHD vs CRRT (2)

	PROS	CONS
Continuous Renal Replacement Therapy 24h/24h if no interruptions due to circuits clotting or off-unit procedures	▪ Fluid removed gradually – easier to remove large volumes of fluid ▪ No restrictions on fluid input so full nutrition always possible ▪ ICU staff operate the machines ▪ Use of bagged fluid makes it possible to use machines anywhere ▪ 1 circuit may last several days	▪ More labour-intensive ▪ Need 1 machine /patient ▪ Uses bagged fluid - more expensive than on-line supply ▪ No choice of fluid composition ('one size fits all') ▪ Long periods of anticoagulation usually required ▪ Patient 'tied' to machine – difficult to mobilise

RRT options – hybrid therapies

	PROS	CONS
SLE(D)D **= SLow Extended (Daily) Dialysis** or **Sustained Low Efficiency (Daily) Dialysis** = IHD run at slower rate for 8-12h daily or on alternate days	▪ Fluid removed more gradually than in IHD so easier to remove large volumes of fluid without hypotension	▪ May still not be as good as 24h/24h CRRT if pt. cardiovascularly unstable
'Intermittent CRRT' = CRRT run at higher rate for 8-12h daily or on alternate days	▪ Allows easier patient mobilisation than CRRT ▪ Less labour-intensive than CRRT	▪ Patient needs to be sufficiently stable ▪ Uses 1 circuit/day ▪ Some blood loss each day

CRRT machines

CRRT machines

Fresenius Multifiltrate

CRRT machines

Fresenius Multifiltrate

Gambro Prismaflex

CRRT machines

Fresenius Multifiltrate

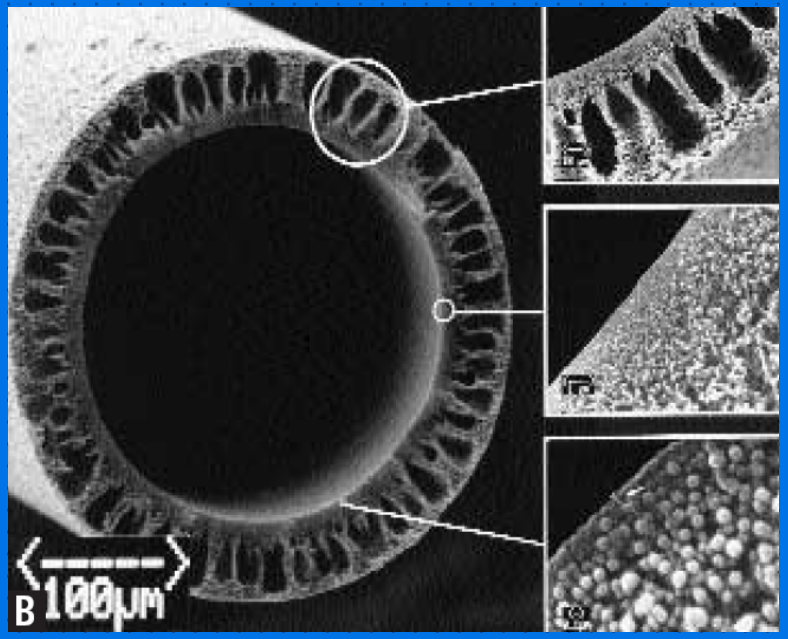
Gambro Prismaflex

Nikkiso Aquarius

Structure of haemofilter/dialyser

Bundle of hollow fibres, made of biocompatible synthetic material, in clear plastic cylinder.

Fibre material is semi-permeable, allowing water and molecules up to ~30,000 Daltons to pass, but not the larger molecules and blood components, e.g. plasma proteins and blood cells



Internal diameter ~200µm

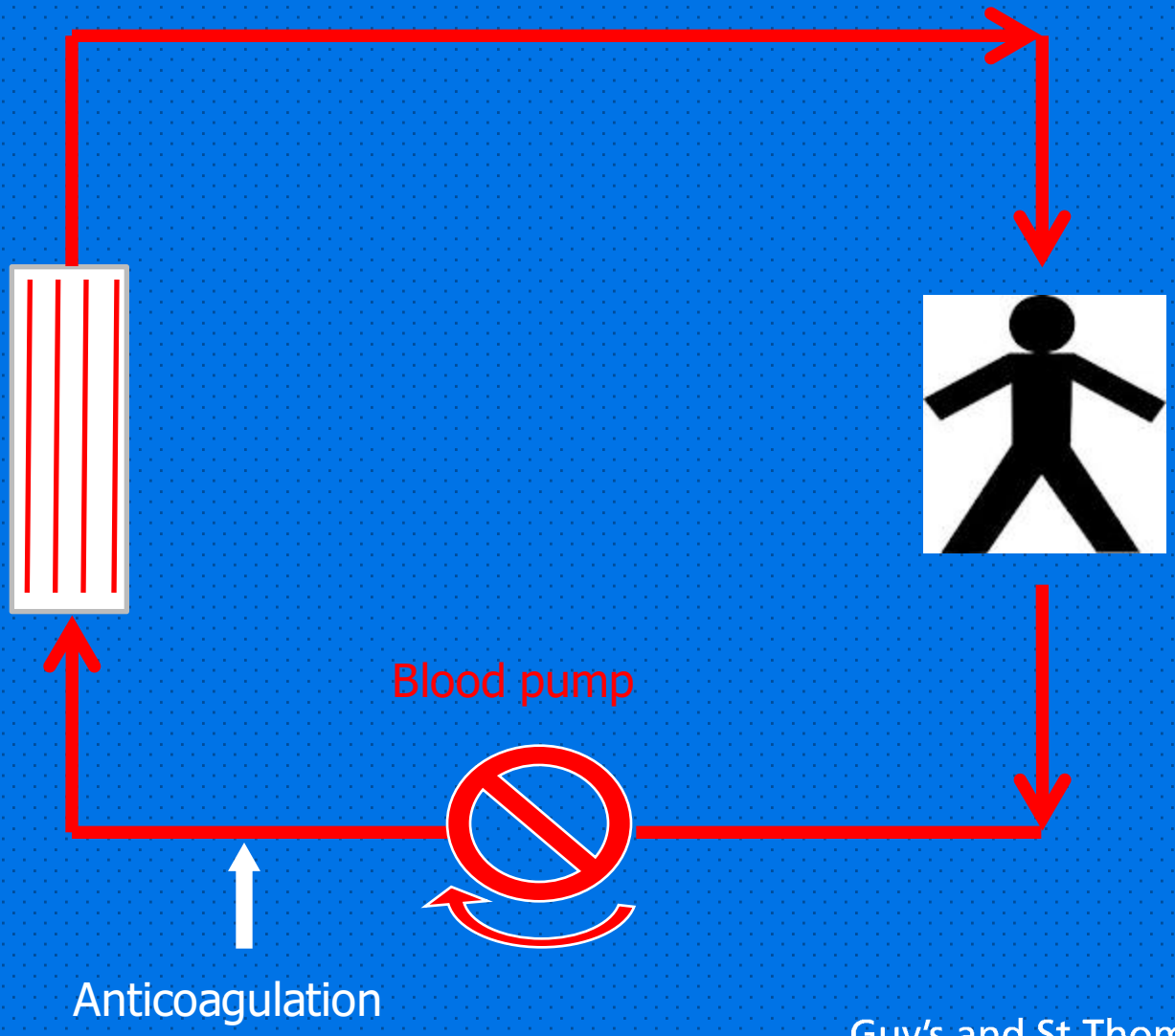
c.f. 8µm for a capillary

Possible modes of CRRT

- **SCUF** - Slow continuous Ultrafiltration
- **CVVH** -Continuous Veno-Venous Haemofiltration
- **CVVHD** - Continuous Veno-Venous Haemodialysis
- **CVVHDF** - Continuous Veno-Venous Haemodiafiltration

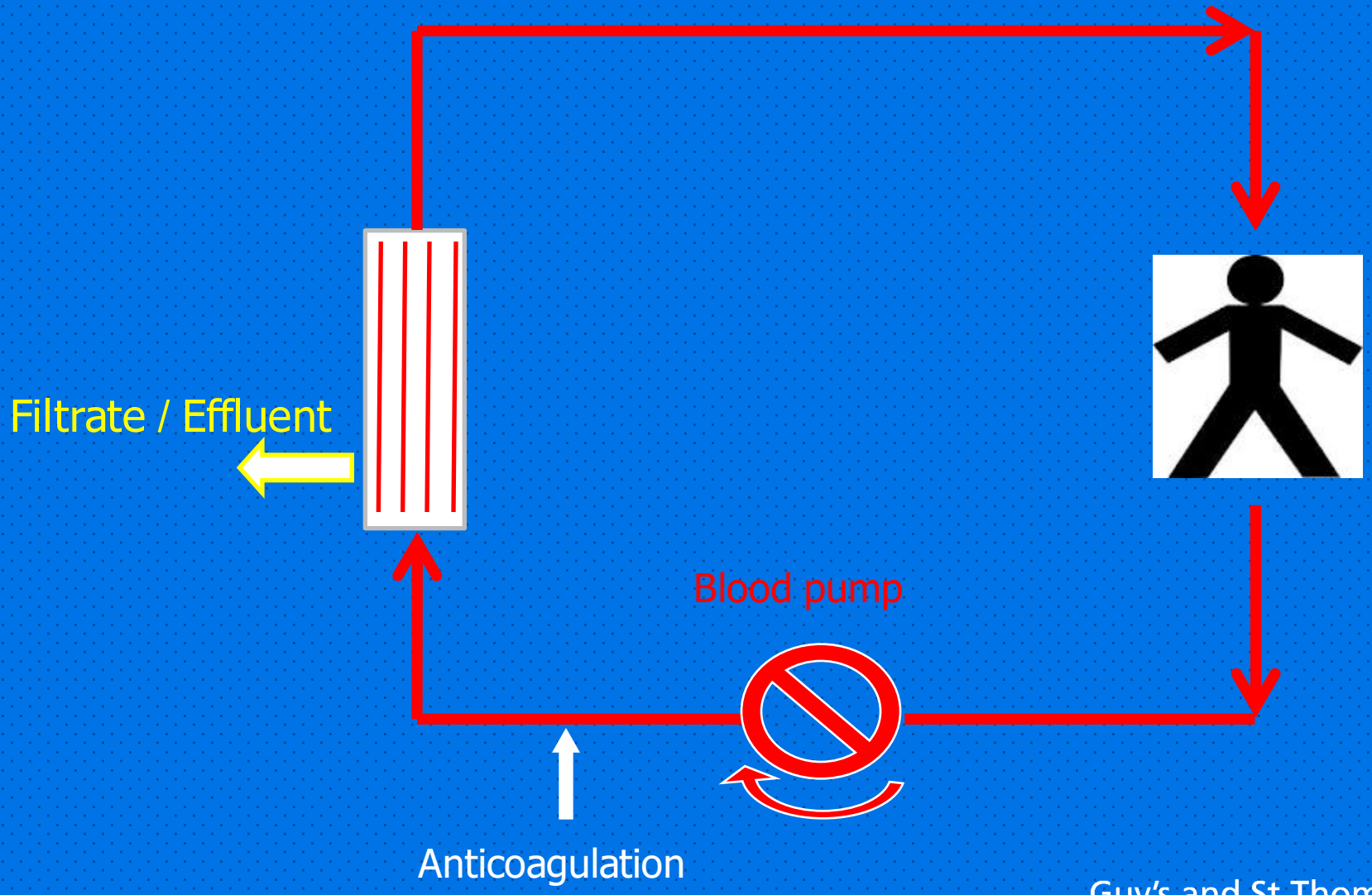
Haemofiltration – 1

the circuit



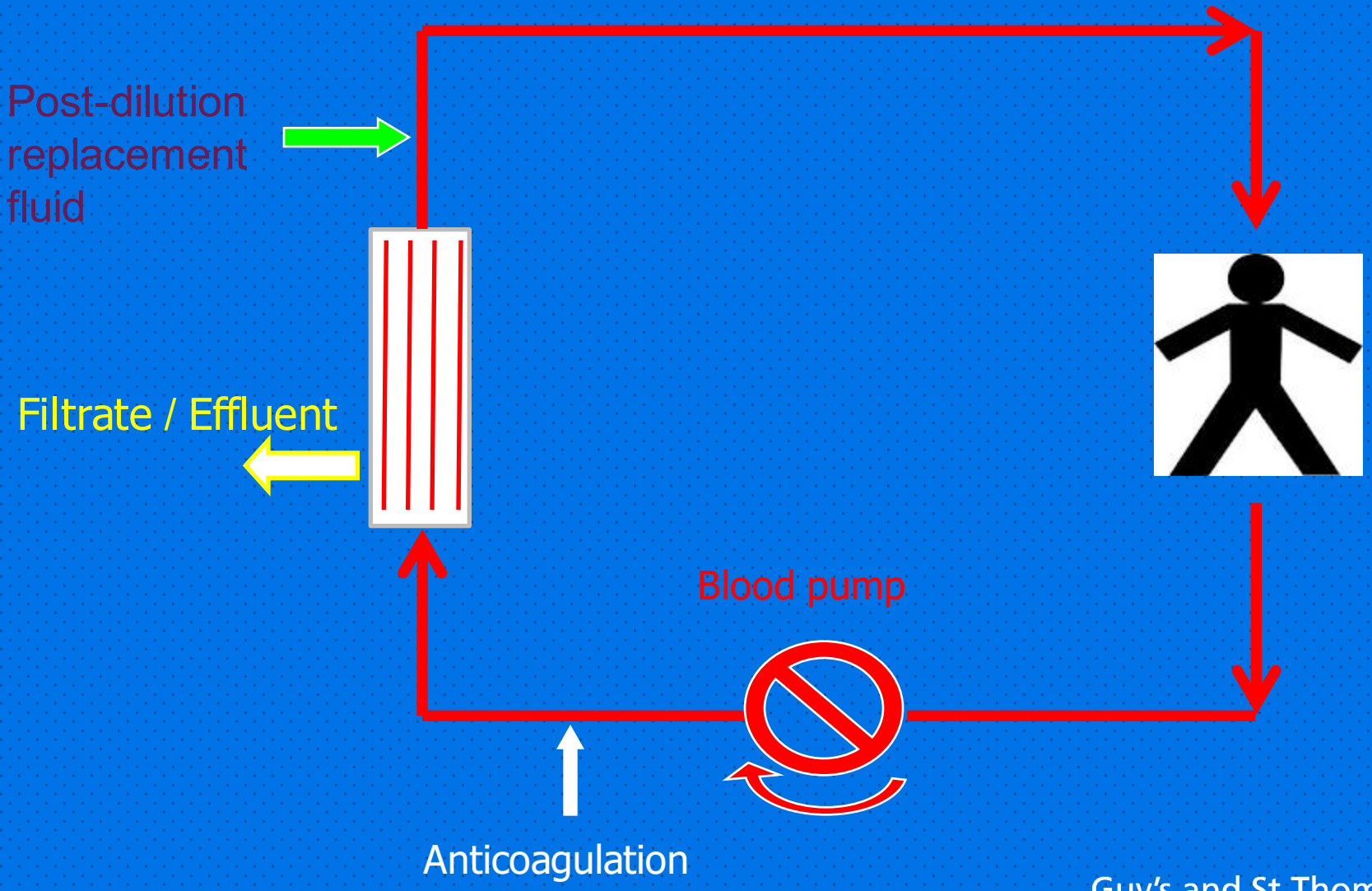
Haemofiltration – 1

the circuit



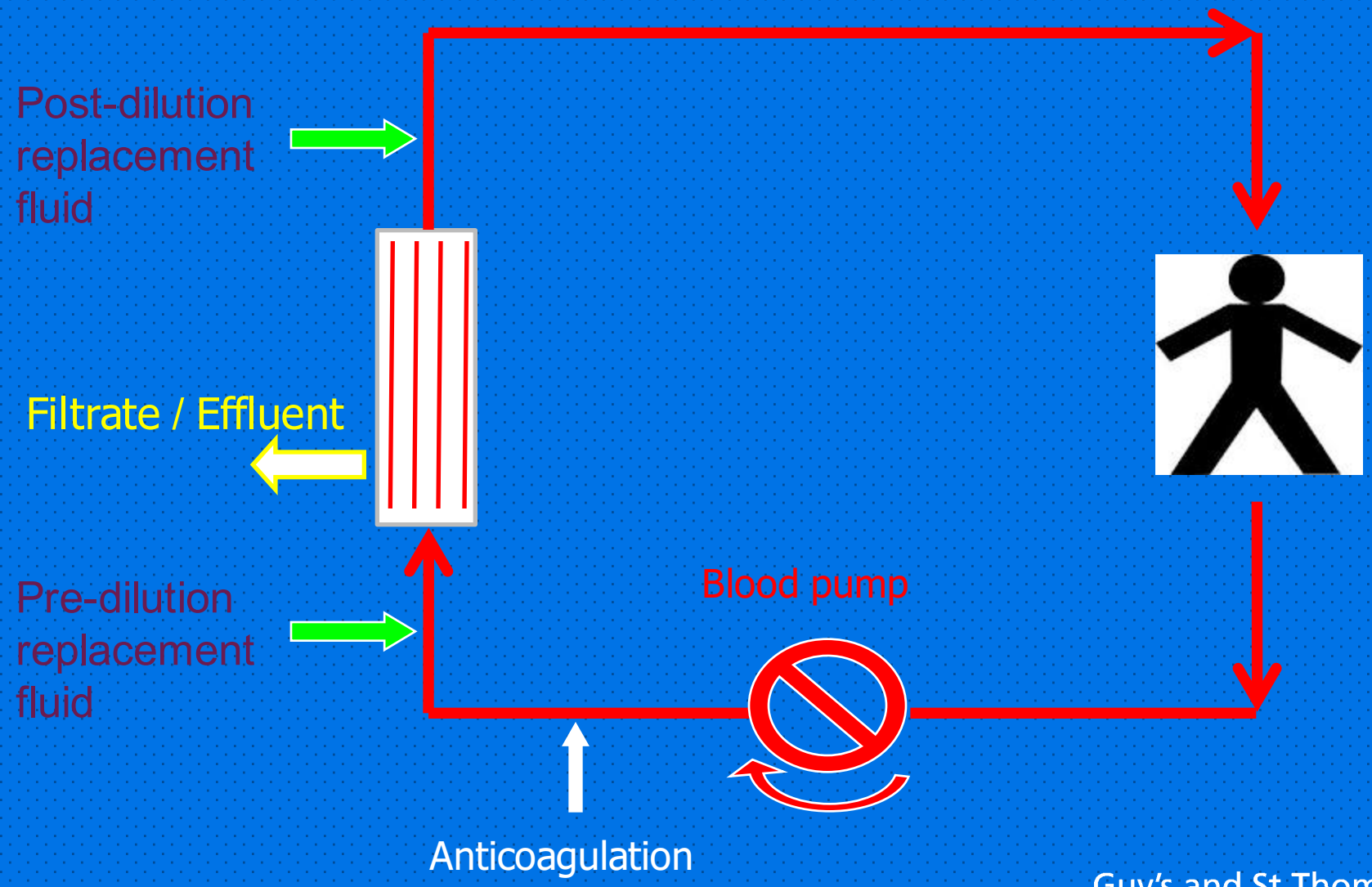
Haemofiltration – 1

the circuit



Haemofiltration – 1

the circuit



Haemofiltration - 2

Ultrafiltration with Convective solute clearance

- Water removed from the blood due to hydrostatic pressure difference
- Solutes carried over with the water by convection
- High volumes of ultrafiltrate are required to ensure adequate clearance of waste products of metabolism
- Loss of large volumes of ultrafiltrate from the blood requires simultaneous and continuous fluid replacement (substitution).

  If net loss is required, this replacement volume is less than the ultrafiltrate volume.

Haemofiltration - 3

- Solute clearance depends on :
  - ultrafiltration flow rate
  - sieving coefficient of the solute in question
  - concentration of the solute in the plasma water (serum)
  - concentration of the solute in the replacement fluid
- Filtration rate = Net fluid loss rate + Replacement fluid rate
- Solute clearance can be achieved independently of changes in total body water.

Haemofiltration - 4

Pre-dilution = replacement fluid enters blood circuit *before* the filter
Post-dilution = replacement fluid enters blood circuit *after* the filter

Advantages of pre-dilution

- Does not cause haemoconcentration
  ⇨ Reduced chance of clotting
- Reduced build-up of protein layer at blood-membrane interface
  ⇨ Increased membrane efficiency

Disadvantage of pre-dilution

- Ultrafiltrate is diluted
  ⇨ decreased clearance of solutes

Filtration Fraction (FF) - 1

- When plasma water removed by ultrafiltration, and only replaced after the filter (post-dilution), the blood becomes more viscous, or haemoconcentrated.
- Filtration Fraction refers to the fraction of plasma volume removed by ultrafiltration and is a measure of this haemoconcentration

Filtration Fraction (FF) - 2

Correct formula:

$$\frac{\textit{Post-dilution rate (L/h) + Net fluid loss (L/h)}}{\textit{Blood flow rate (L/h)}\ \textbf{x (1-Hct)}} \times 100\ \%$$

Example :

Post-dilution rate 2000mL/h = 2.0L/h

Net fluid loss rate 100mL/h = 0.1L/h

Blood pump speed **200mL/min** = 1200mL/h = **12.0L/h**

Haematocrit 0.30

$$\textbf{FF} = \frac{2.0 + 0.1}{12.0 \times 0.70} \times 100\% = \frac{2.1}{8.4} \times 100\ \% = \textbf{25.0\%}$$

Filtration Fraction (FF) - 3

In practice **whole blood flow** is used to calculate FF:

$$\sim \frac{\textit{Post-dilution rate (L/h)} + \textit{Net fluid loss (L/h)}}{\textit{Blood flow rate (L/h)}} \times 100\ \%$$

Example 1:

Post-dilution rate 2000mL/h = 2.0L/h

Net fluid loss rate 100mL/h = 0.1L/h

Blood pump speed **200mL/min** = 1200mL/h = **12.0L/h**

$$\textbf{FF} = \frac{2.0 + 0.1}{\textbf{12.0}} \times 100\% = \frac{2.1}{\textbf{12.0}} \times 100\ \% = \textbf{17.5\%}$$

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Filtration Fraction (FF) - 4

Increasing blood flow reduces FF:

$$\sim \frac{\textit{Post-dilution rate (L/h)} + \textit{Net fluid loss (L/h)}}{\textit{Blood flow rate (L/h)}} \times 100\ \%$$

Example 2:
Post-dilution rate 2000mL/h = 2.0L/h
Net fluid loss rate 100mL/h = 0.1L/h
Blood pump speed **300mL/min** =1800mL/h = **18.0L/h**

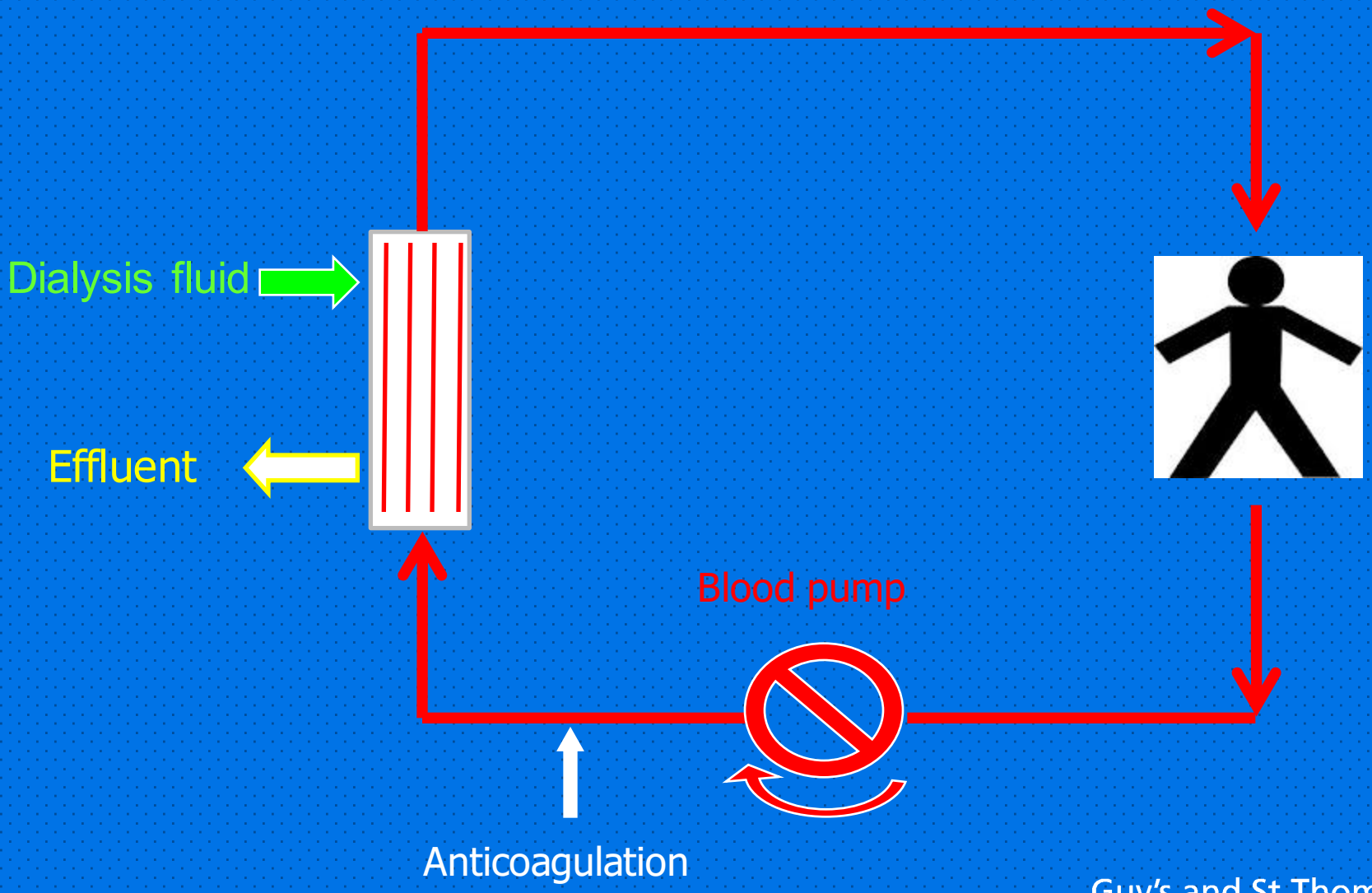
$$\textbf{FR} = \frac{2.0 + 0.1}{\textbf{18.0}} \times 100\% = \frac{2.1}{\textbf{18.0}} \times 100\ \% = \textbf{11.7\%}$$

Filtration Fraction (FF) - 5

- The higher the FF, the more haemoconcentrated the blood
- ↑ haemoconcentration → ↑ tendency to clot
- Risk of filter clotting reduced by keeping FF <20%
- Pre-dilution does not contribute to haemoconcn, so pre-dilution rate does not affect FF
- In dialysis, only net fluid loss causes haemoconcn.

Haemodialysis – 1

the circuit



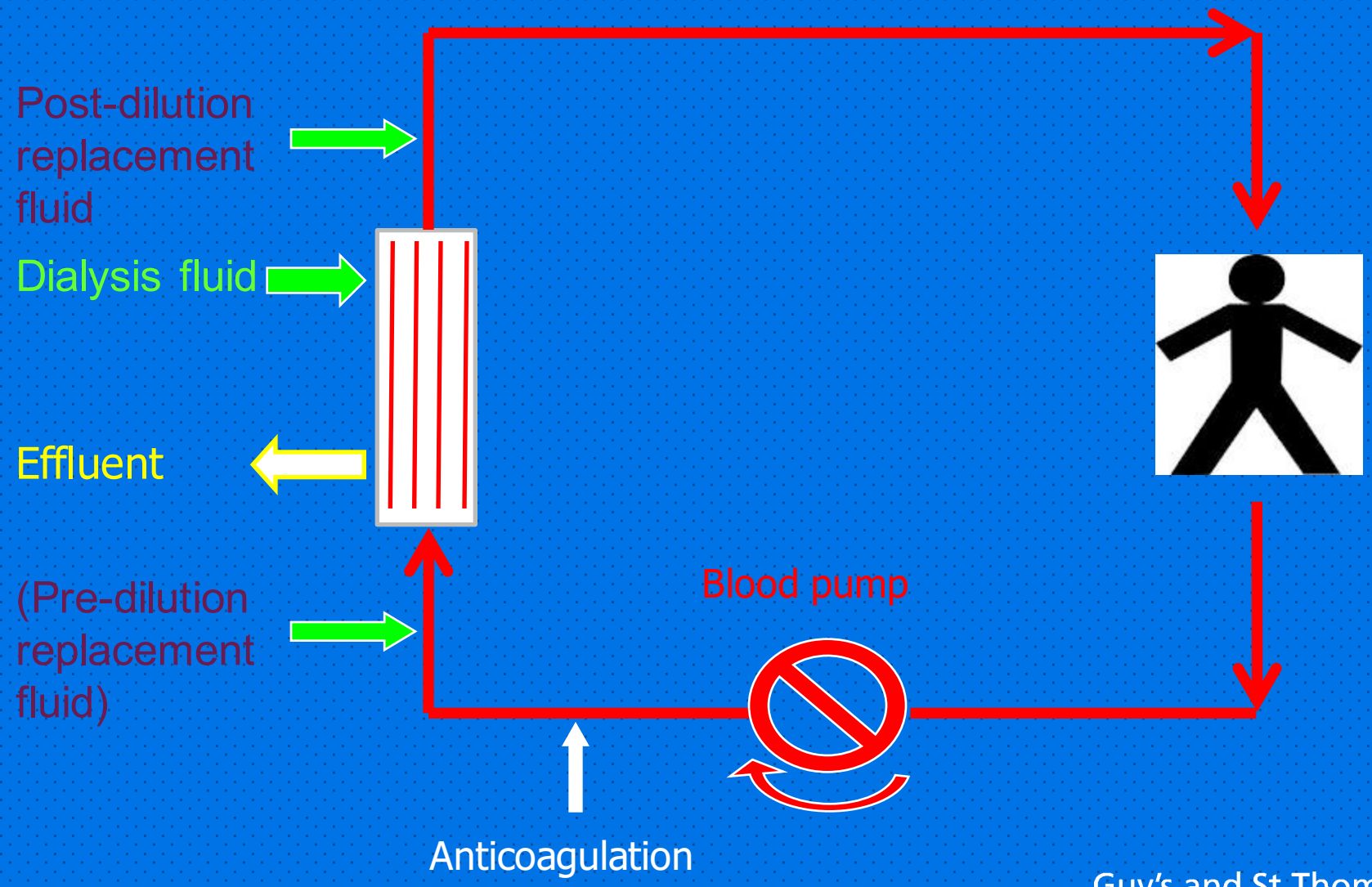
Haemodialysis - 2

- Based on principle of DIFFUSION of solutes across the membrane due to a concentration gradient.
- Dialysis fluid runs through the filter (dialyser) counter-current to the blood, which is flowing through the hollow fibres
- The semi-permeable hollow fibres allow the diffusion of solutes from the blood to the dialysis fluid if the concentration there is less than in the blood
- The greater this concentration gradient between the blood and the dialysis fluid, the greater the clearance

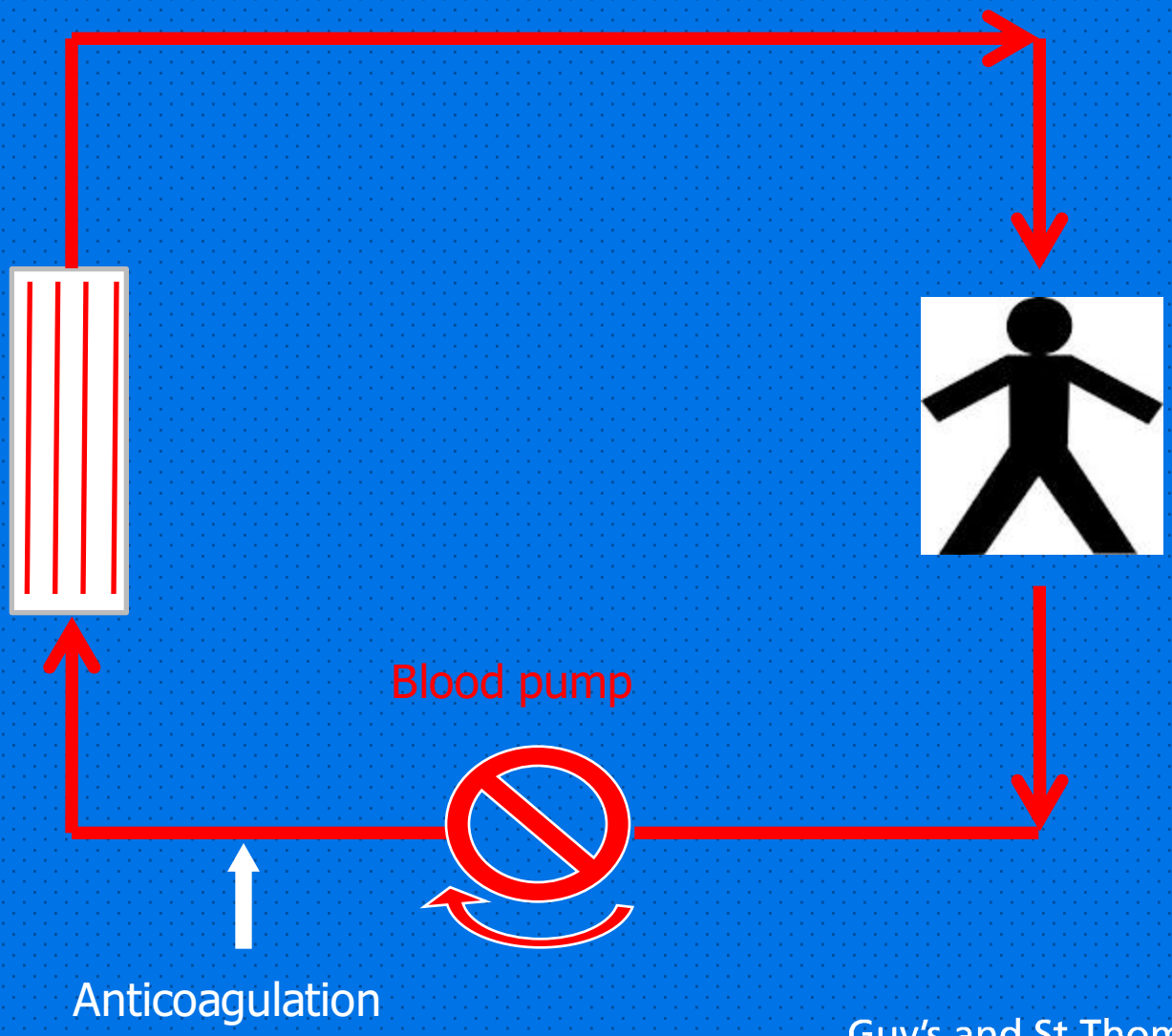
Haemodialysis - 3

- Solute clearance depends on :
  - concentration of the solute in the dialysis fluid
  - concentration of the solute in the plasma water (serum)
  - dialysis fluid flow rate
  - blood flow rate
  - surface area of the filter (dialyser)
  - size of solute (smaller solutes cleared better)
- For water removal:
  - effluent pump runs at a higher rate than dialysate pump, so pulling the programmed amt. of water (net loss) from the blood through the semi-permeable membrane by ultrafiltration
  - Effluent rate = Net fluid loss rate + Dialysis rate
- Solute clearance can be achieved independently of changes in total body water.

Haemodiafiltration – 1
the circuit



Haemodiafiltration – 1
the circuit



Haemodiafiltration – 1
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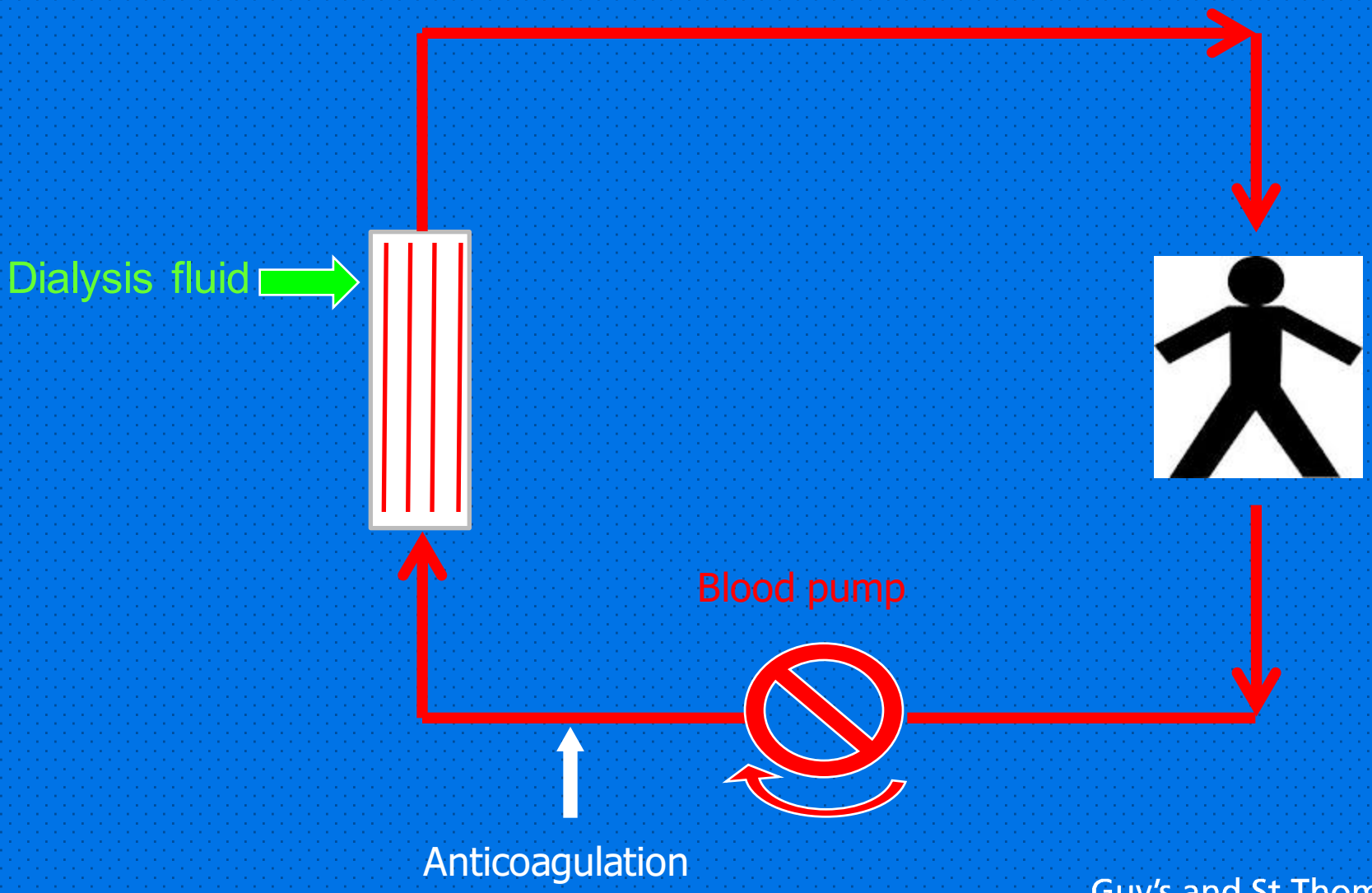
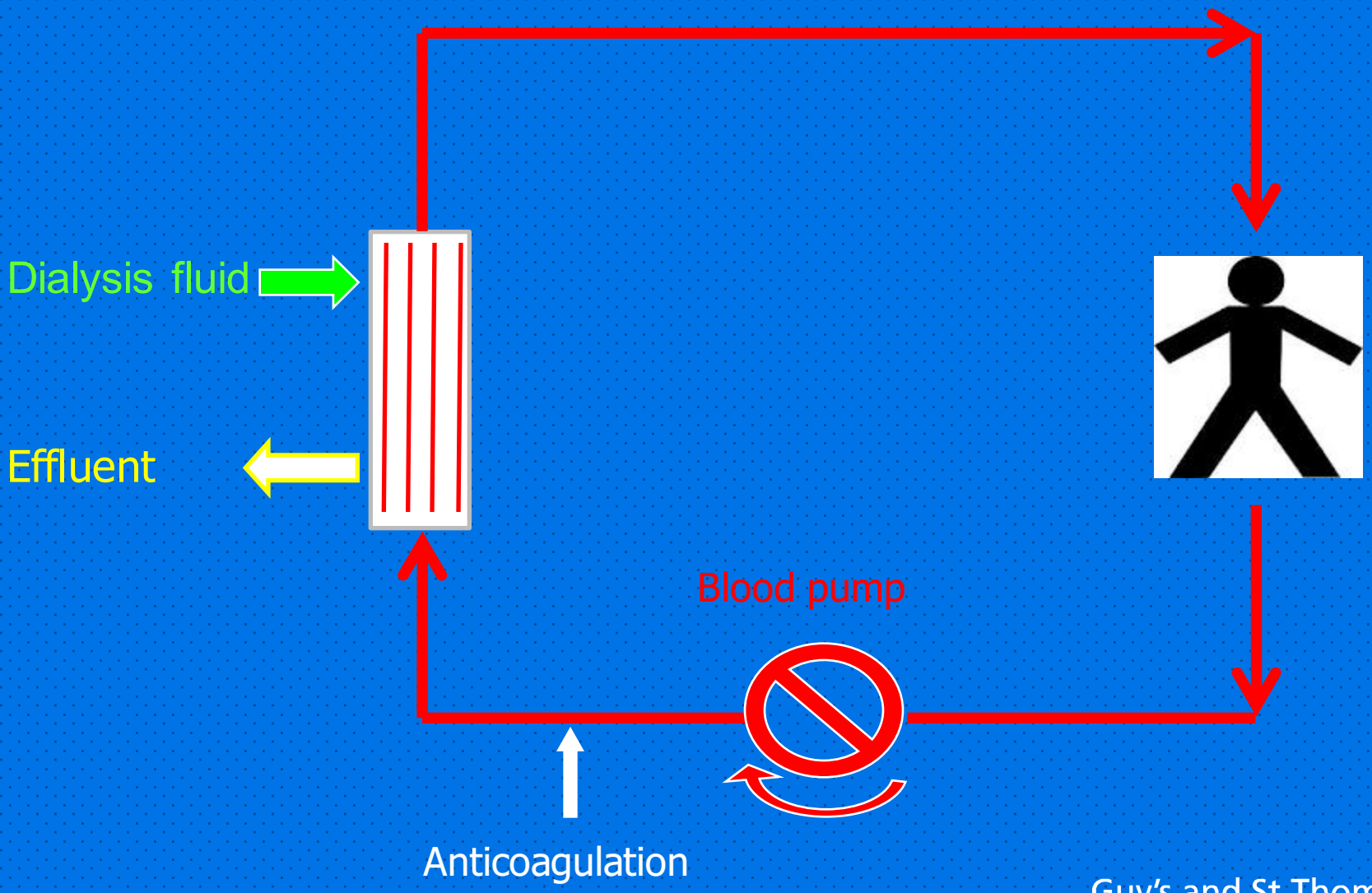
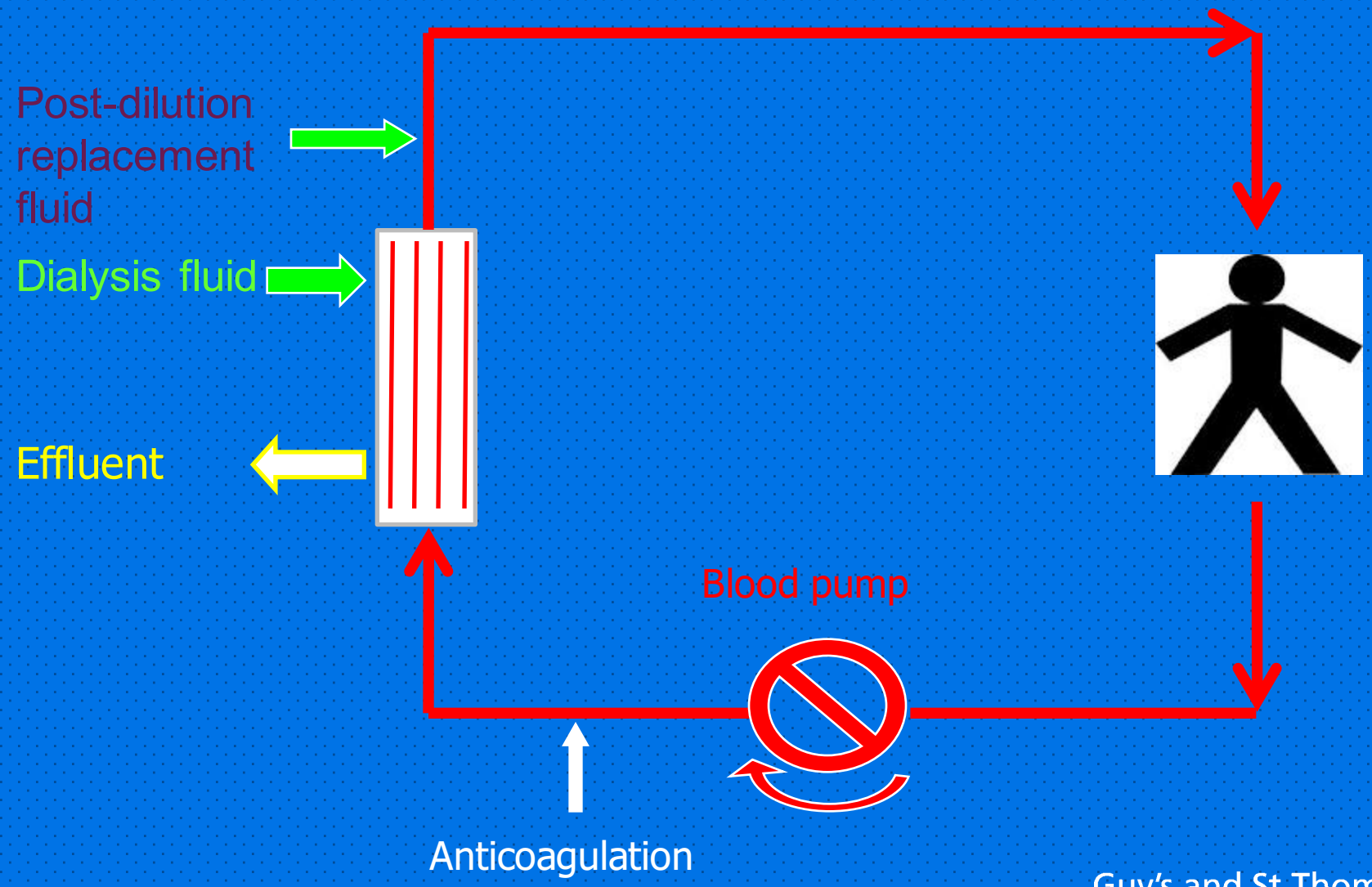


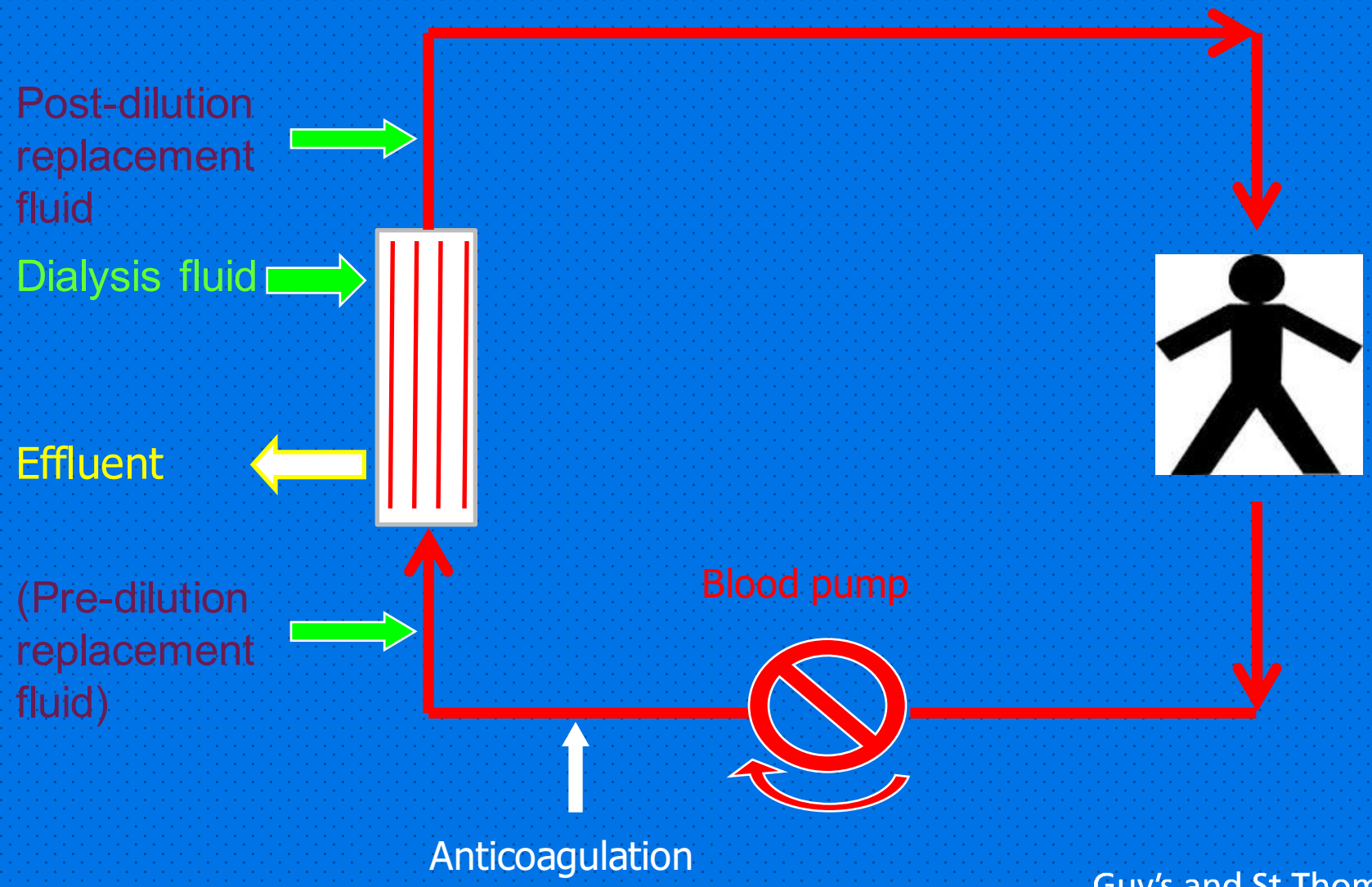
Haemodiafiltration – 1
the circuit



Haemodiafiltration – 1
the circuit



Haemodiafiltration – 1
the circuit



Haemodiafiltration - 2

- Both diffusion and ultrafiltration+convection are used.
- Diffusion takes place from the patient's blood to the dialysis fluid, which runs countercurrent to the blood flow.
- HF occurs simultaneously, so replacement fluid must be given to the patient to compensate for the volume of ultrafiltrate removed less the volume of net loss desired.

Dialysis / Replacement Fluid

- The same fluid is used, whether RRT method is HF, HD or HDF.
- The fluid contains physiological levels of sodium, calcium, magnesium, glucose and a buffer (usually bicarbonate). It may also contain phosphate.
- The concentration of potassium used depends on the patient's serum potassium level.

Typical composition of a bicarbonate-buffered dial/repl fluid

Composition once the 2 compartments mixed :

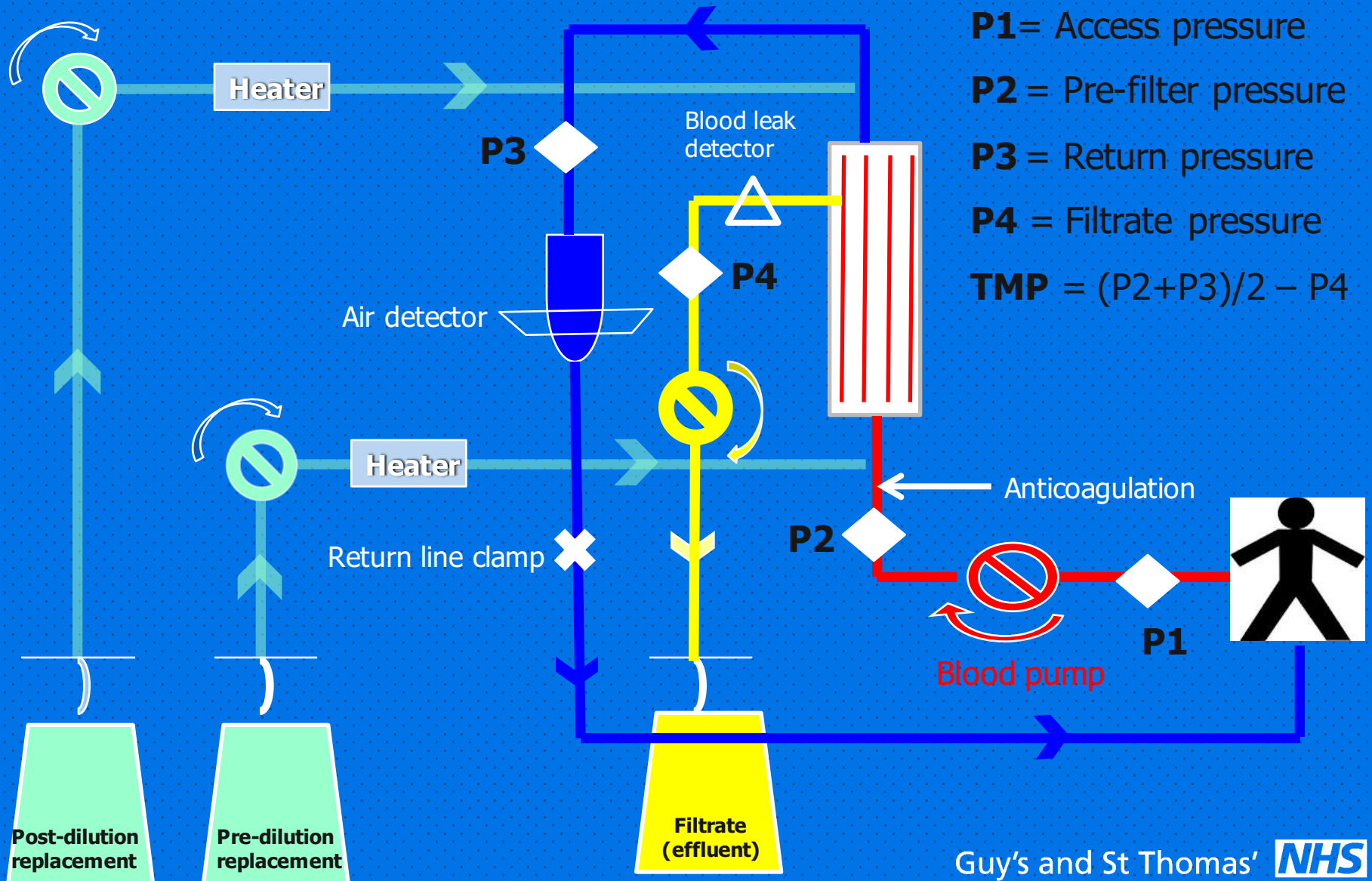
- Na^+ 140 mmol/L
- K^+ **0, 2.0** or **4.0** mmol/L
- Ca^{2+} 1.5 mmol/L
- Mg^{2+} 0.5 mmol/L
- Cl^- 113 mmol/L
- HCO_3^- 35 mmol/L
- Glucose 5.55 mmol/L (1g/L)
- (Phosphate 1 mmol/L)

pH 7.4 Total Volume 5L

Safety features of CRRT machines

- Bubble trap, air detector & return line clamp
- (Degassing chamber)
- Blood leak detector
- Pressure monitoring
- Scales sensitive to 1g weight change – Machine constantly monitors that rates of weight loss from treatment fluid bags and weight gain in effluent bags match the rates programmed
- Heating system for treatment fluids or blood lines

Main features of CRRT circuit (CVVH)



P1= Access pressure

P2 = Pre-filter pressure

P3 = Return pressure

P4 = Filtrate pressure

TMP = (P2+P3)/2 – P4

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Blood Pump speed

- Aim for at least 200mL/min (12L/h) for non-citrate anticoagulation
- Higher PBS required for high filtration rates to avoid haemoconcentration /reduced clearance effects
- Higher PBS can increase clearance in dialysis
- Faster blood flow tends to reduce risk of clotting

Need optimal vascular access to achieve good blood flow

RRT Rate and Dose

Total RRT Rate (mL/h) =

RRT Dose (mL/kg/h) x Body Weight (kg)

Pre-dilution replacement rate
Post-dilution replacement rate
Dialysis rate

} Total RRT rate

Circuit pressures

Access pressure

- is negative in a venovenous circuit
- more negative if
  - increased resistance to blood flow into the circuit
  - increased blood pump speed

Return and Pre-filter pressures

- are positive
- more positive if
  - increased resistance to post-blood pump flow
  - increased blood pump speed

Circuit pressures

Transmembrane pressure (TMP)

$$= \frac{\text{(Pre-filter pressure + Return pressure)}}{2} - \text{Filtrate pressure}$$

i.e. pressure difference across the membrane

- is usually zero or positive
- more positive if
  - high rate of filtration (so TMP always much higher in CVVH than in CVVHD)
  - membrane pores are clogged causing resistance to flow
  - if low flux filter used
  - the blood compartment pressure is high

Circuit pressure alarms

Access pressure

Limit usually set at ~ - 300mmHg

Risk of damage to vein wall and haemolysis

Return pressure

Limit usually set at ~ + 500mmHg

Risk of pushing clot forward / circuit blood leaks

Pre-filter pressure

Limit usually set at ~ + 500mmHg

Risk of pushing clot forward / circuit blood leaks

TMP

Limit usually set at ~ + 300mmHg

Risk of membrane rupture ⟶ blood loss into effluent

When these alarms are triggered, the blood pump and the treatment pumps stop ⟶ ↑ risk of clotting & ↓ solute clearance

Circuit pressures

- If no alarms, the machine is removing fluid and delivering filtration/dialysis precisely as programmed
- Increasingly –ve access pressure or +ve pre-filter, return or TMP pressures indicate machine having difficulty running as programmed.

  (Patient movement will then cause pressures to hit their alarm limit more easily.)
- **Good access & effective anticoagulation is critical to RRT success !!**

Staff training and responsibilities

- Understand principles of CRRT
- Set up & connect circuit correctly
- Program treatment (incl.fluid loss) appropriately
- Monitor patient's response
  (cardiovascular status, acid-base balance, electrolytes, urea / creatinine)
- Manage anticoagulation
- Troubleshoot - prompt & correct response to alarms
  - to facilitate smooth running → optimising circuit life & clearance
  - to avoid fluid balance errors
- Recognise when circuit is clotting & should be washed back
- Recognise access failure