Lecture 11: Blood Pressure (Part 2)

0. Review
1. Oscillometric Method
2. Extravascular Sensors
3. Cardiac Output

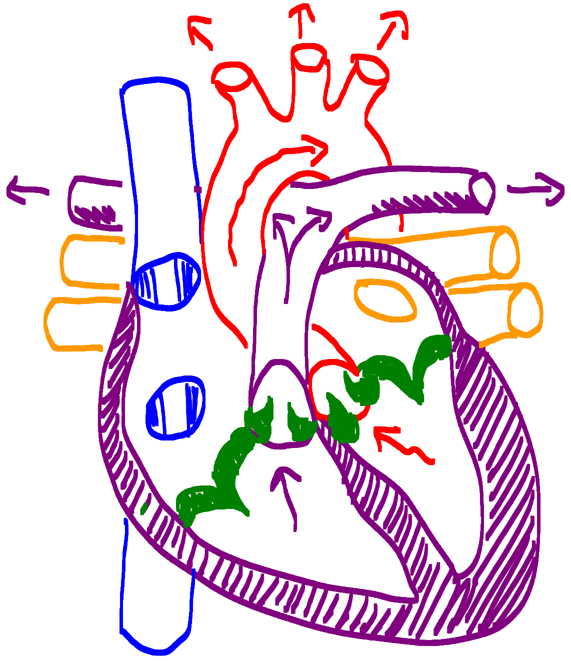
- Fri (2/14): Lab3 report due
- Mon (2/17): Exam #1 problems
  → Counts as HW
  Re-do all 4 problems
- PreLab5 due at lab session
- Thu (2/20): HW5
- Fri (2/21): Lab4 report due

★ Student presentations (Mar 10+12)
→ Teams of 2-3 students
→ 20 min powerpoint
[• Disease or medical condition
• Electronic instrumentation]
e.g. ablation catheter

① Physiology

SYSTOLE

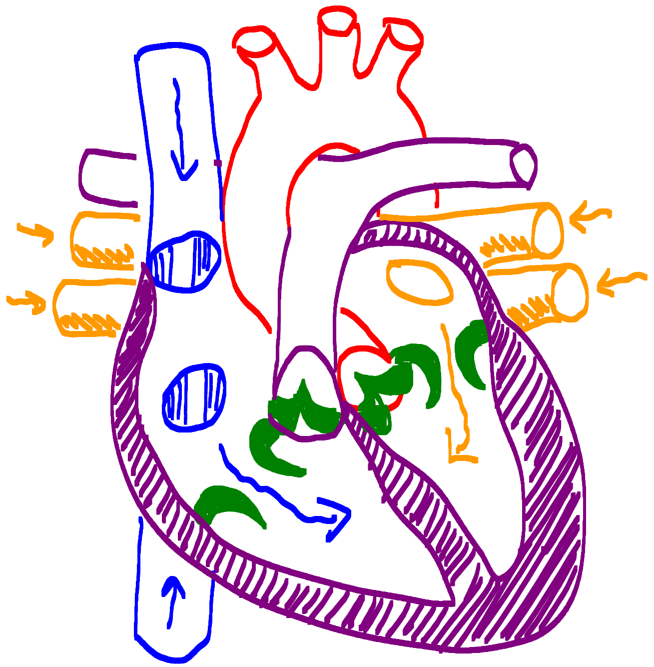
"Pumping Phase"
"LUB"



~~Tricuspid Valve~~	Pulmonary Valve	Aortic Valve	~~Mitral Valve~~

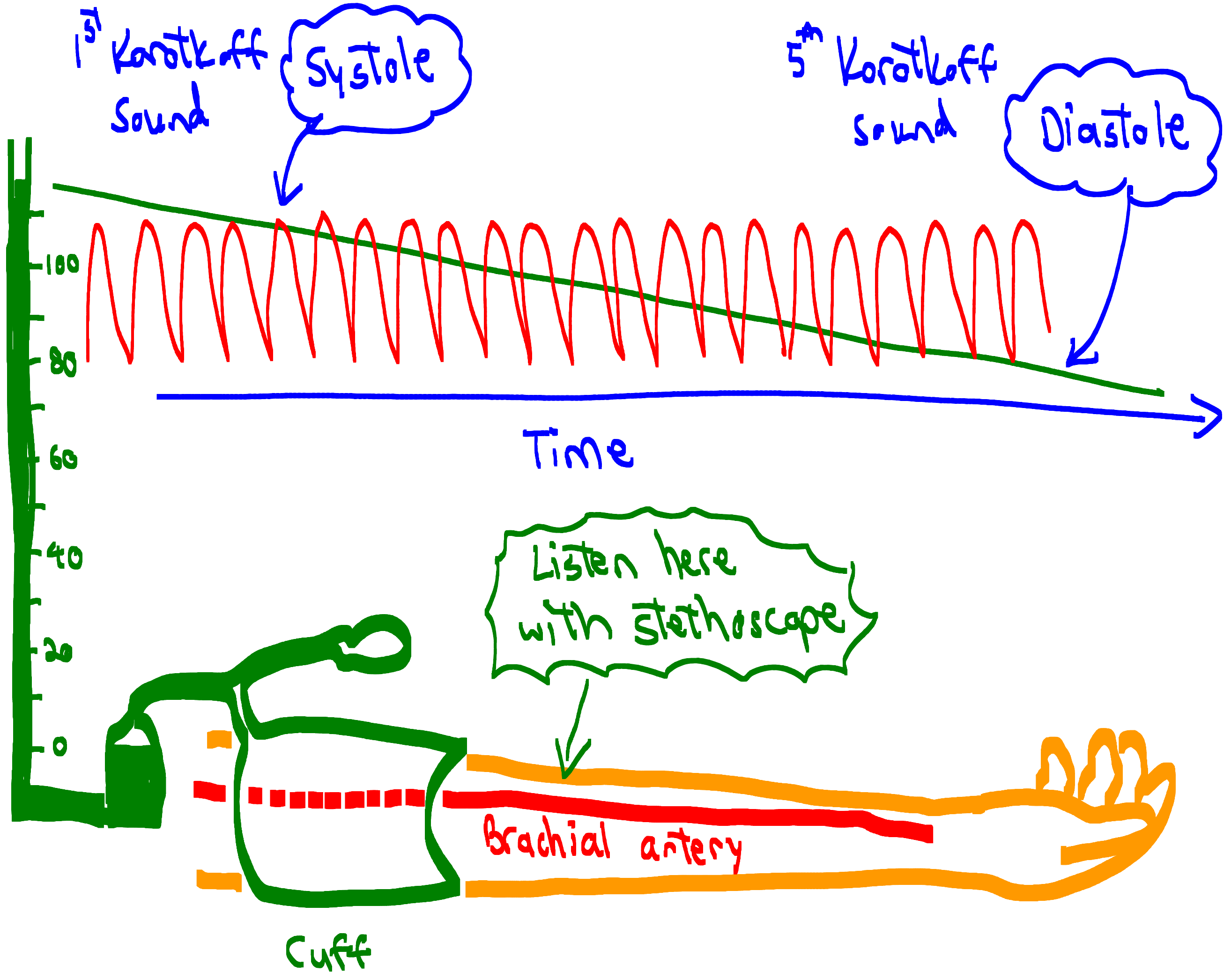
DIASTOLE

"Resting Phase"
"DUB"



Tricuspid Valve	~~Pulmonary Valve~~	~~Aortic Valve~~	Mitral Valve

② Auscultatory Method = Sphygmomanometer + Stethoscope



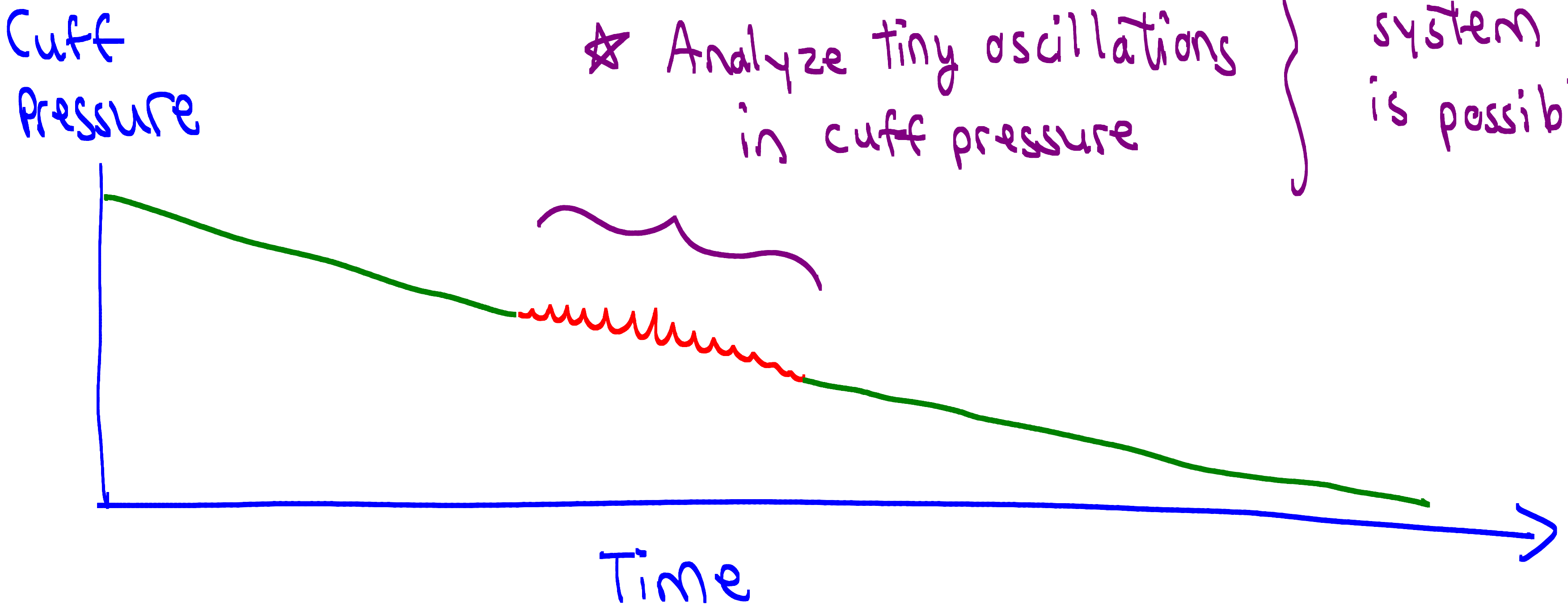
1. Oscillometric Method

A. Intro

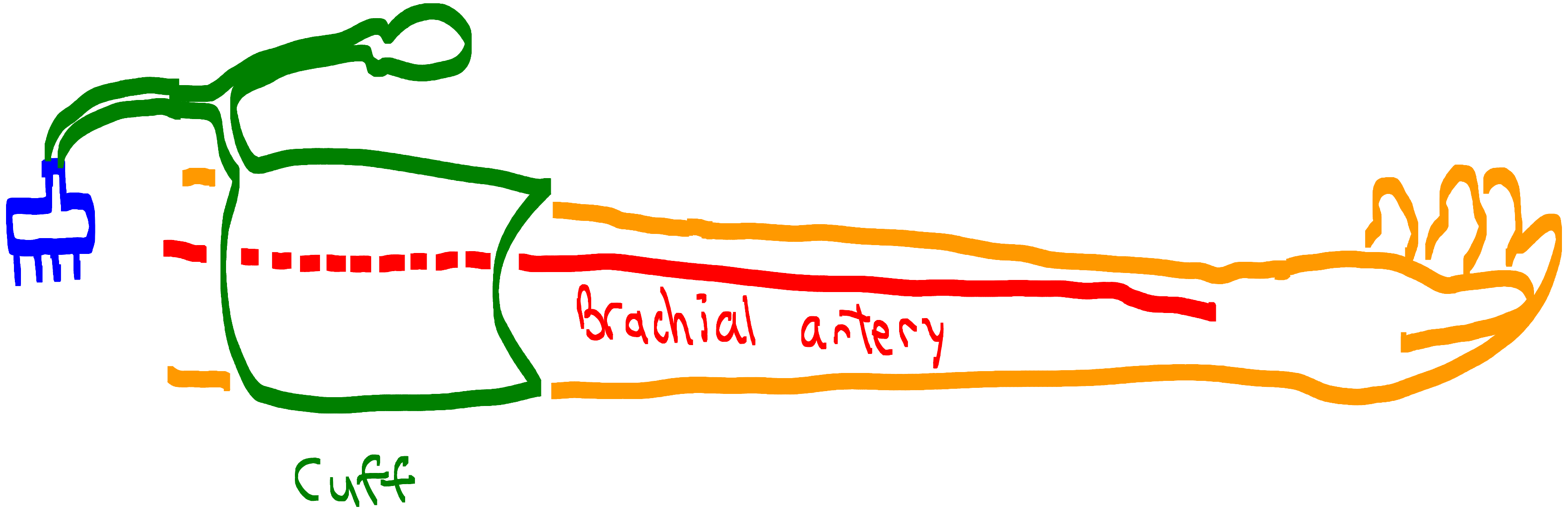
Sphygmomanometer
without stethoscope

* No stethoscope
* Analyze tiny oscillations in cuff pressure

Automated system is possible



* Cuff pressure is measured with an electronic sensor



B. Mean Arterial Pressure (MAP)

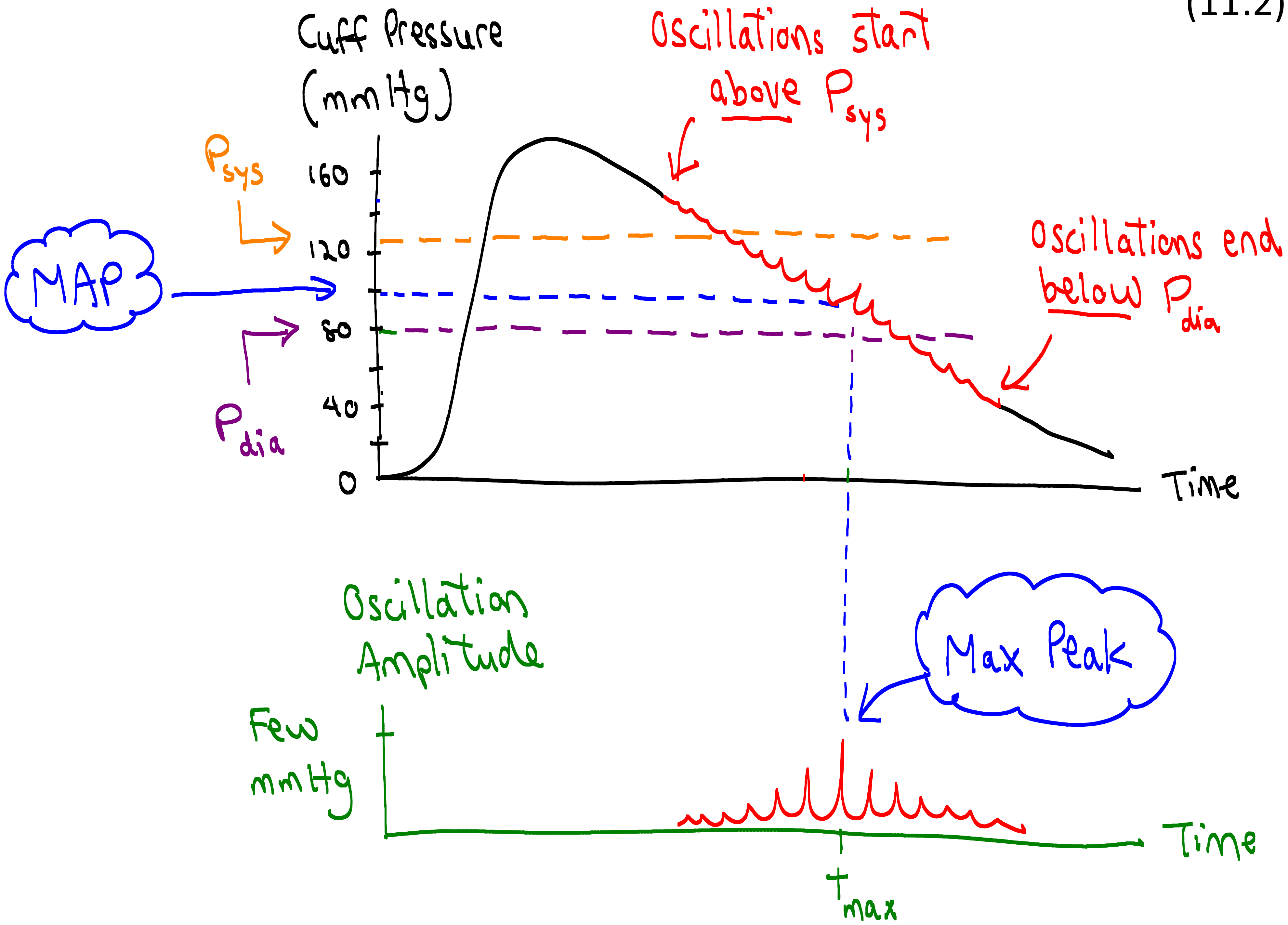
The maximum oscillation occurs at the MAP!

NOTE:

Oscillation Amplitude ≠ Cuff Pressure!

What matters is the cuff pressure at time t_{max}

when max oscillation occurs



- Accuracy of oscillometric method

→ Good for direct measurement of MAP

→ Not as good for P_{sys} and P_{dia}

✲ Device manufacturers have {secret} algorithms to compute P_{sys} and P_{dia}

Ex: $A_s = 0.7\,A_m$ → Determines t_{sys}

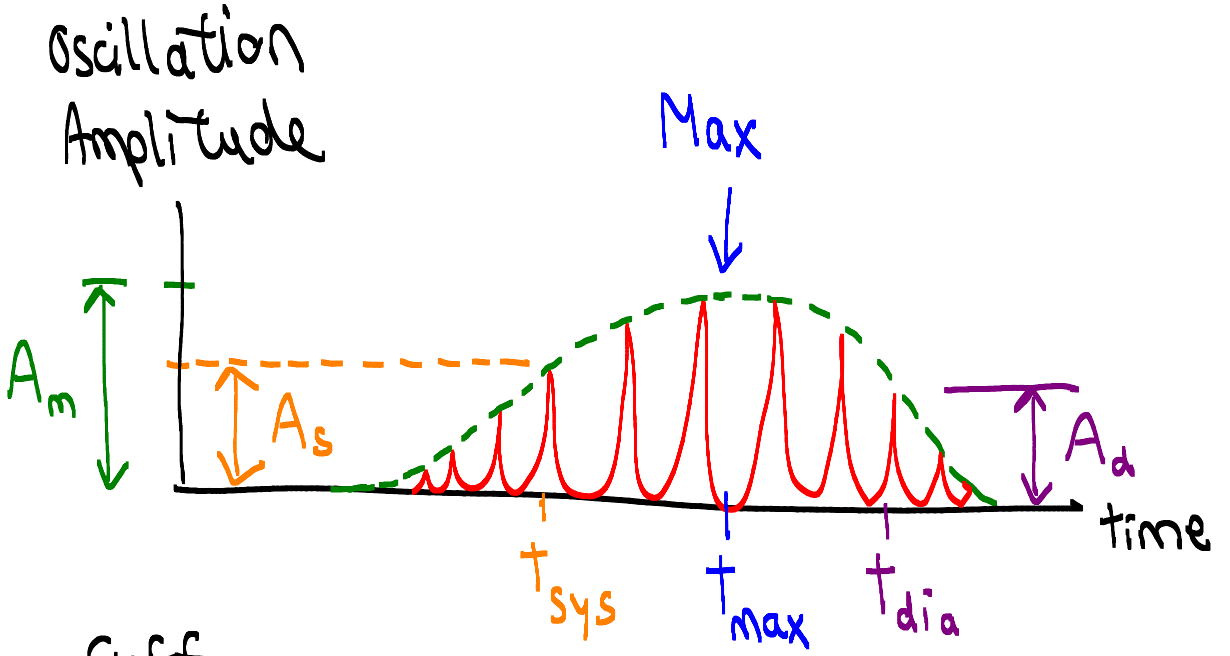
⇓

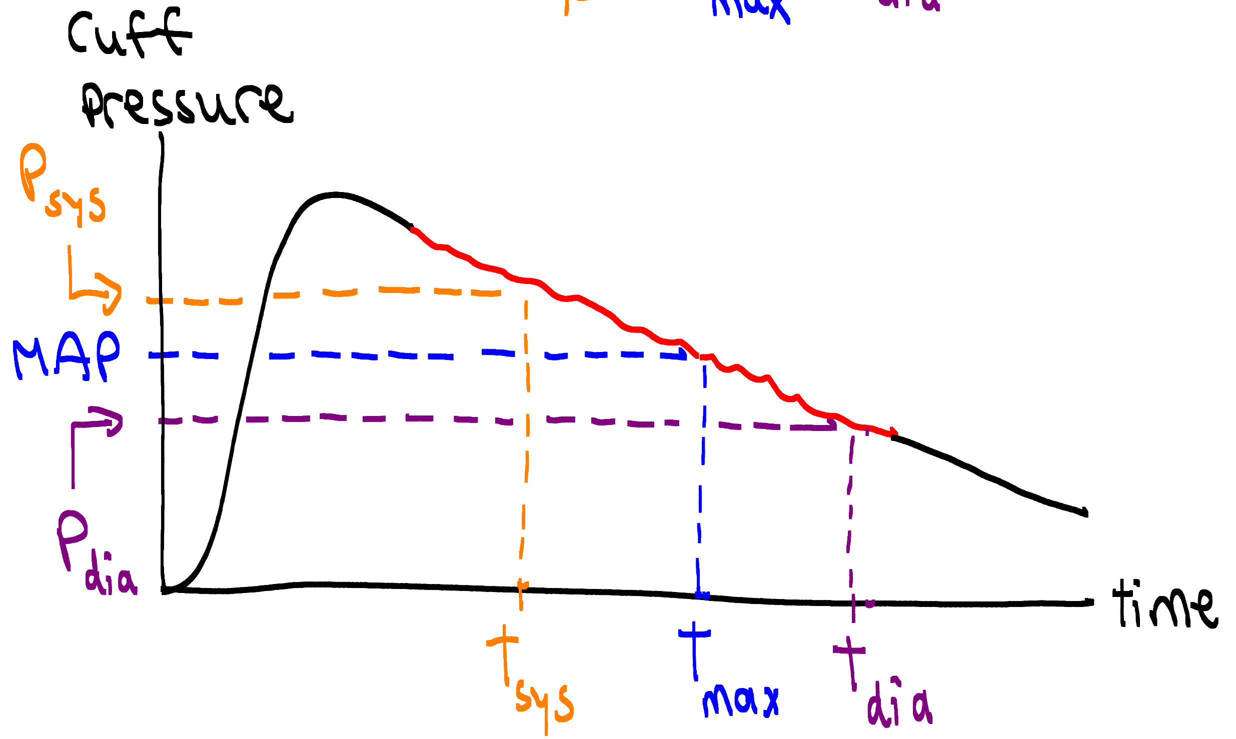
Determines P_{sys}

$A_d = 0.6\,A_m$ → Determines t_{dia}

⇓

Determines P_{dia}





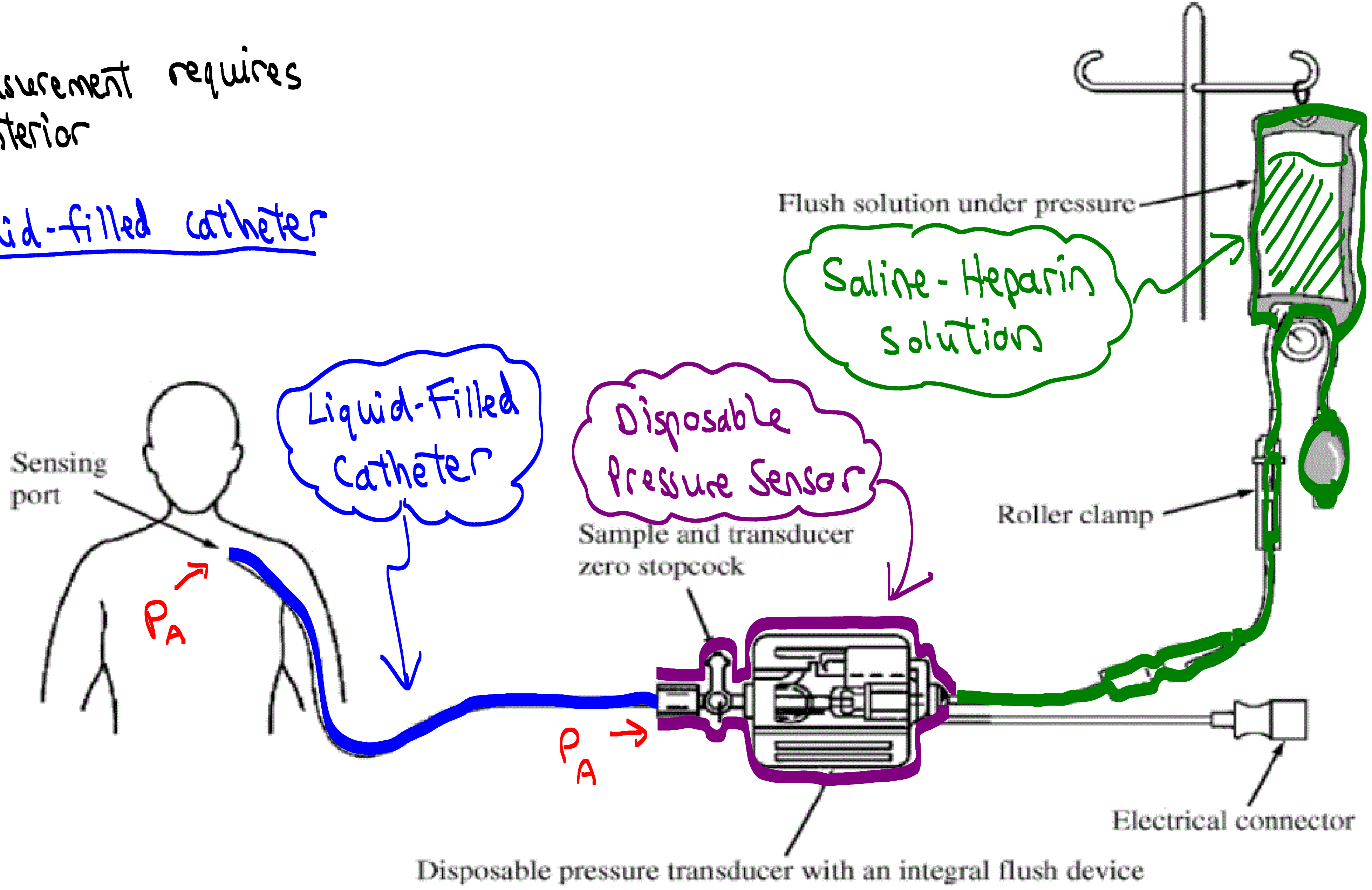
2. Extravascular Sensors

- The most accurate blood pressure measurement requires direct access to the blood vessel interior

- Most common technique uses a liquid-filled catheter with a disposable pressure sensor

- Blood pressure is transmitted to the sensor via the catheter liquid

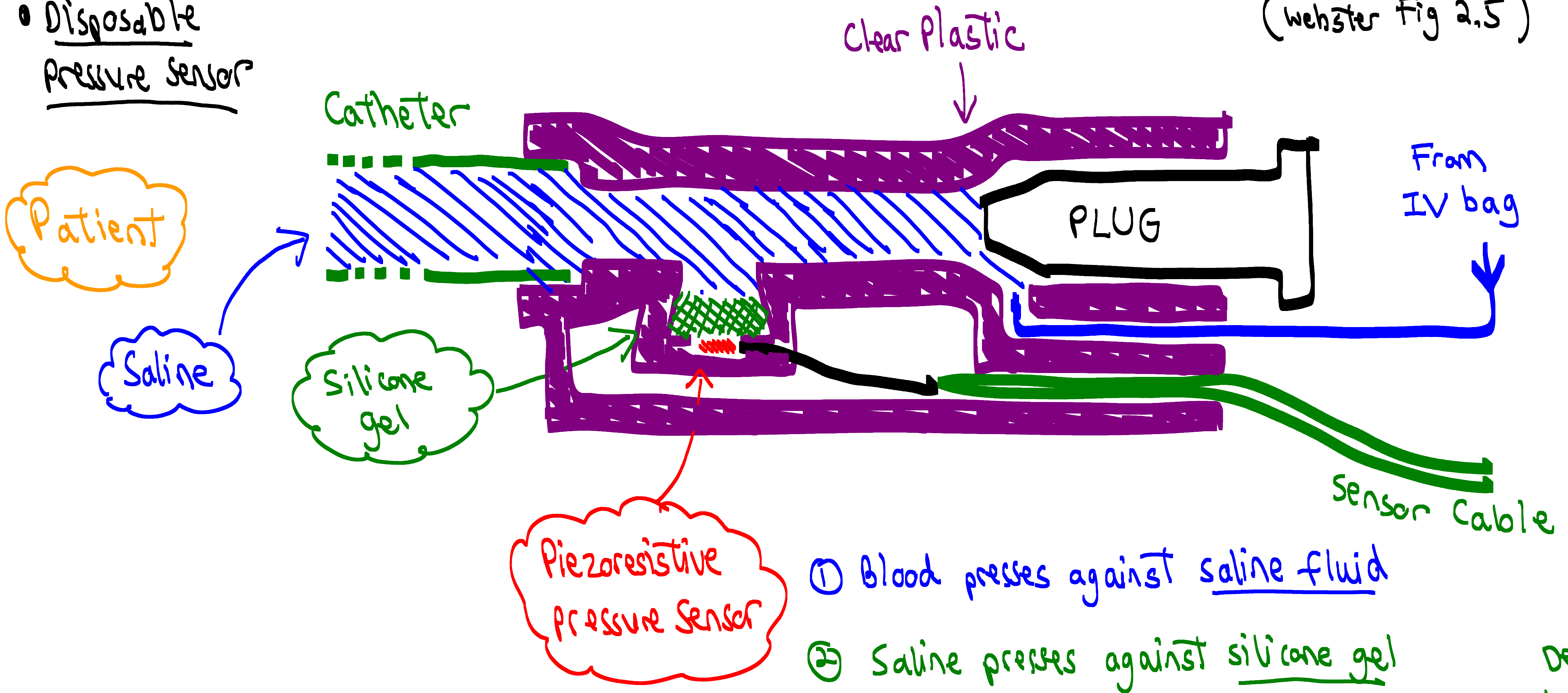
- Frequent flushing required to prevent blood clots at catheter tip



Webster Fig 7.3

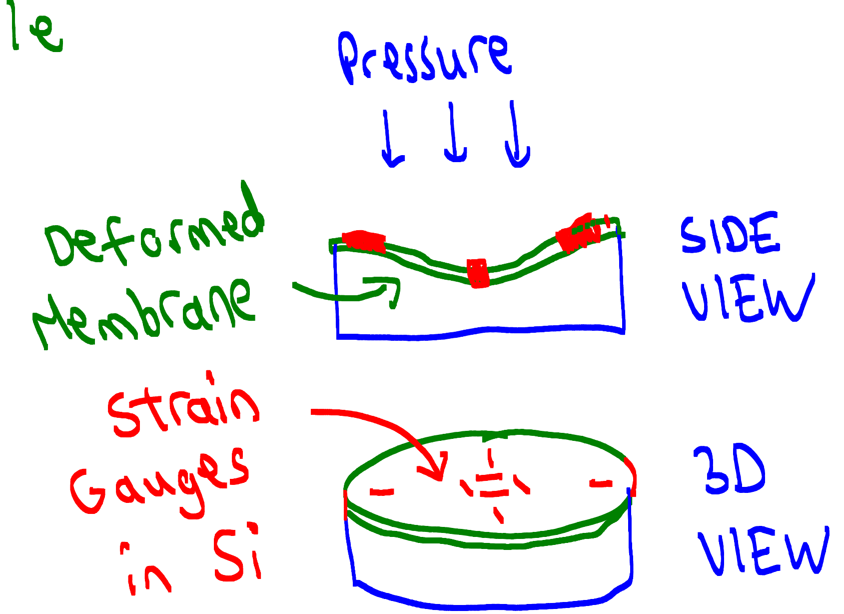
- Disposable Pressure Sensor

(webster Fig 2.5)



1. Blood presses against saline fluid
2. Saline presses against silicone gel
3. Gel deforms the silicon diaphragm

mV/kPa



3. Cardiac Output

A. Intro

Delivered by blood

- Cells need $\boxed{O_2 \text{ and nutrients}}$

- The delivery rate of O_2 + nutrients is determined by blood flow

Cardiac Output

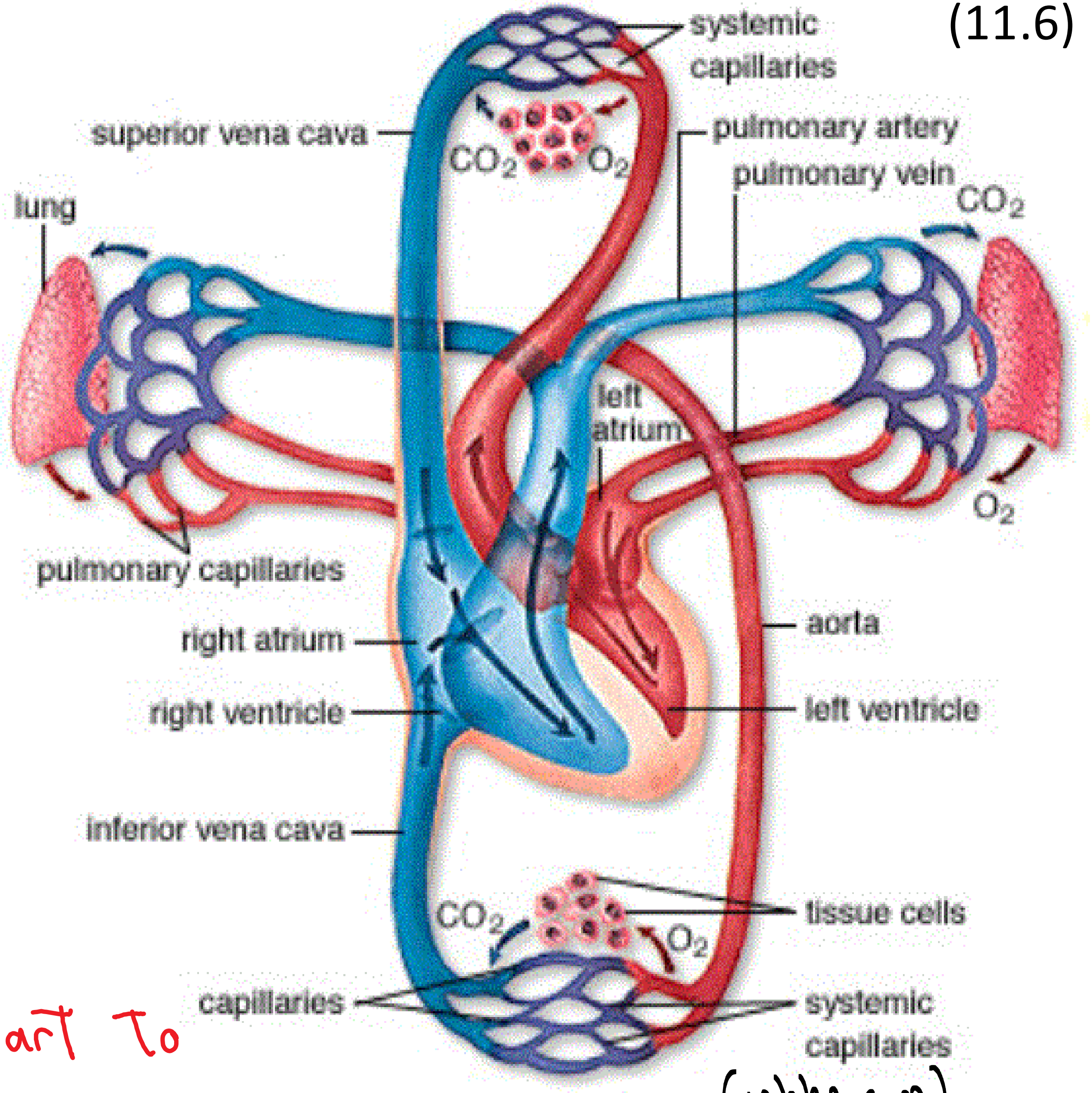
- Cardiac output = Liters/min

= [Heart Rate] × [Stroke Volume]

Person at rest { = [70 beats/min] × [80 mL/beat]

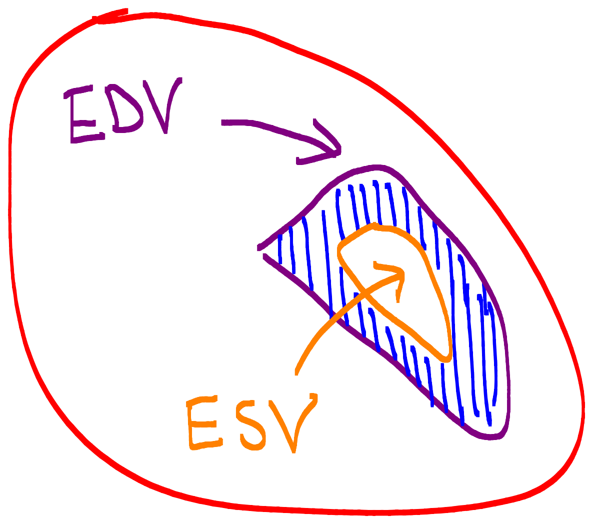
= 5600 mL/min = 5.6 L/min

~5 L of blood in human body → ~1 minute for heart to pump blood volume of entire body.



(mhhe.com)

- Example values for 70 kg male



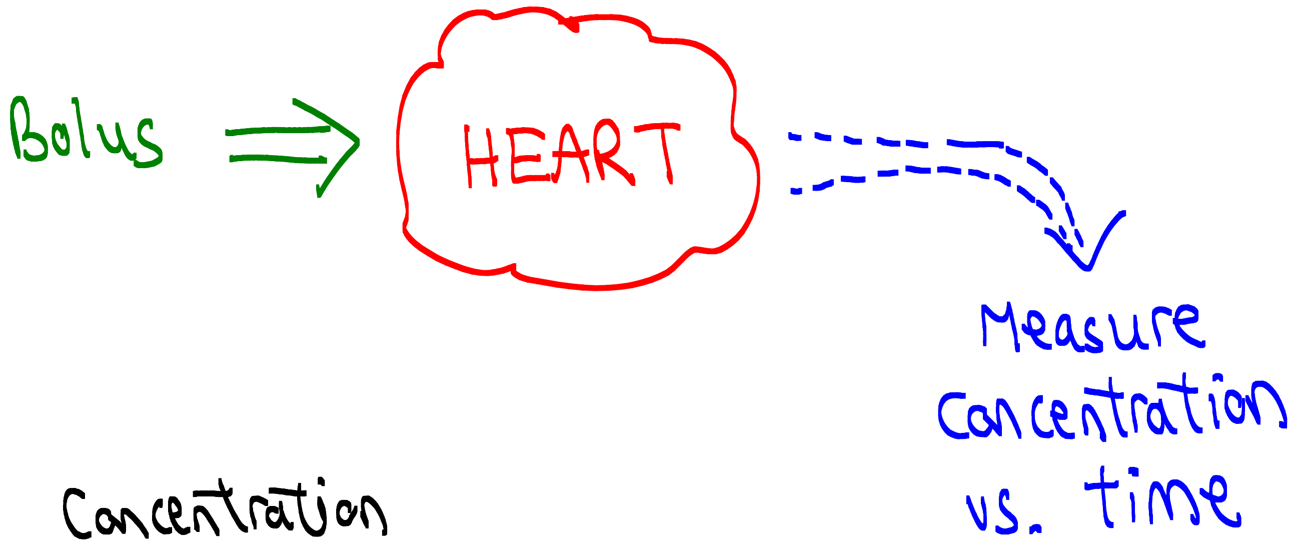
$SV = EDV - ESV$

$CO = SV \times HR$

	Typical Value
End-diastolic Volume (EDV)	120 mL
End-systolic Volume (ESV)	50 mL
Stroke Volume (SV)	70 mL
Heart Rate (HR)	75 beats/min
Cardiac Output (CO)	5.25 L/min

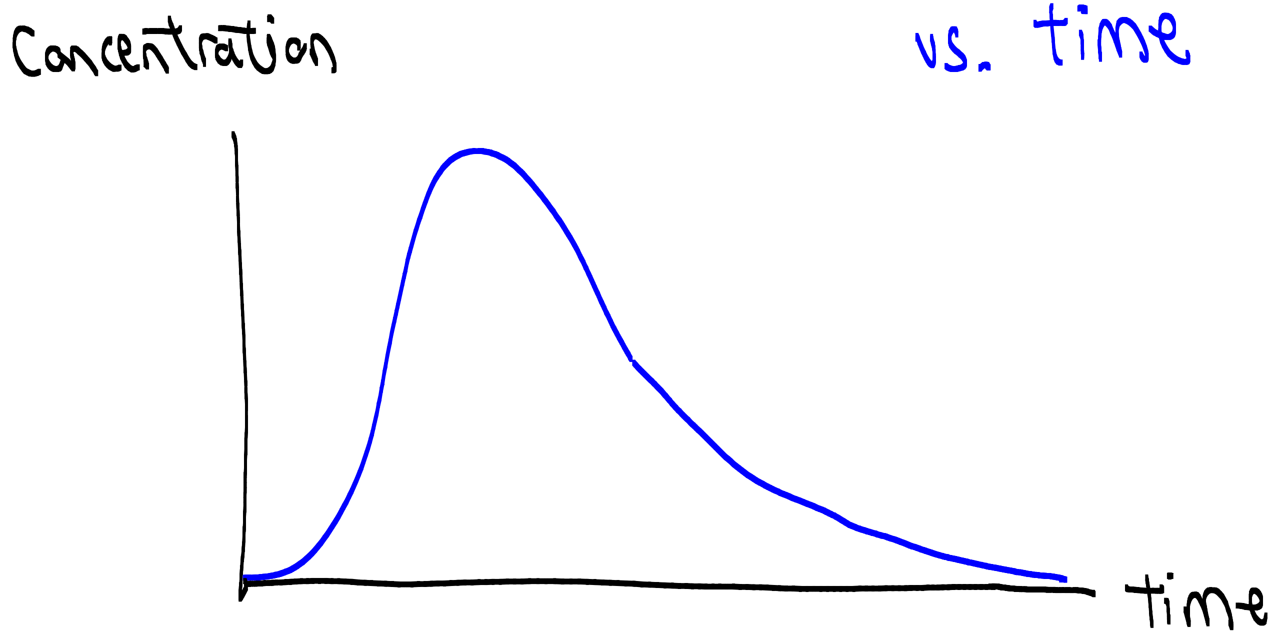
B. Indicator-Dilution Method

Step 1: Inject a bolus of indicator into a vessel



Step 2: Measure the downstream concentration vs. time

Step 3: Compute flow rate F

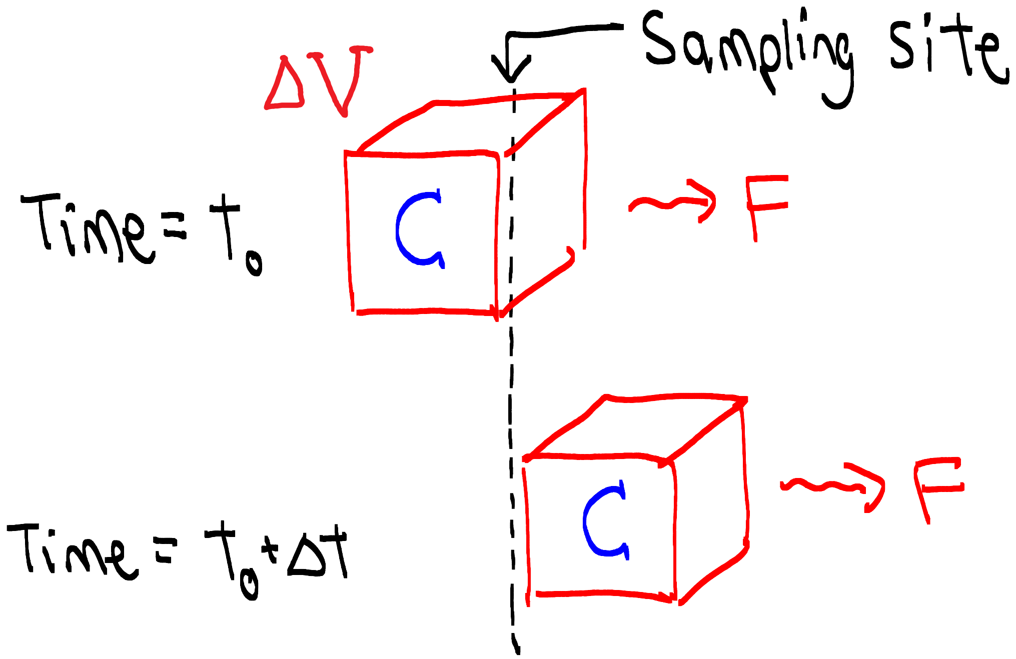


$$\therefore \quad F = \frac{\text{Quantity of Indicator}}{\int [\text{concentration}]\, dt}$$

NOTE: These methods do NOT measure instantaneous flow!

Derivation:

- Consider an increment of blood ΔV passing a sampling site during ΔT
- Amount of indicator is given by:



$$\Delta Q = C \cdot \Delta V = C \cdot F \Delta T$$

Concentration = $\frac{\text{Amount}}{\text{Volume}}$

★ flow = $\frac{\text{Volume}}{\text{Time}}$

$\therefore$ $\underbrace{\text{Total quantity of indicator}}_{\text{Bolus}} = \int dQ$

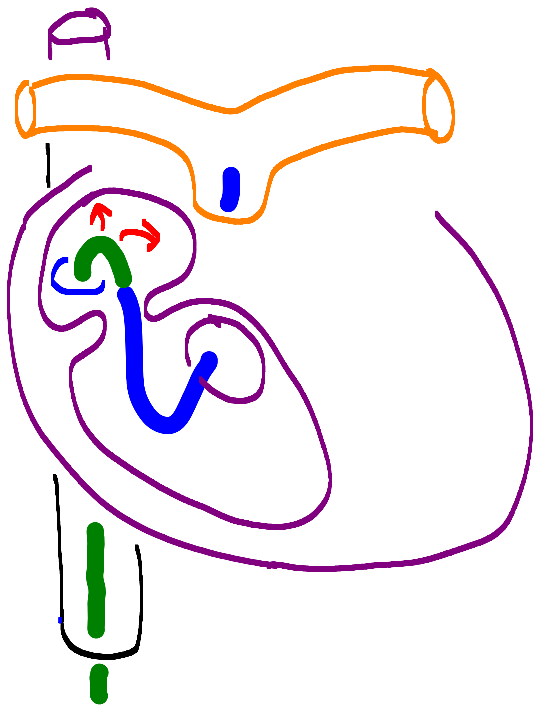
$$= \int_0^T C(t) \cdot F \, dt = F \cdot \int_0^T C(t)\, dt \implies \boxed{F = \frac{\text{Quantity of indicator}}{\int C(t)\, dt}}$$

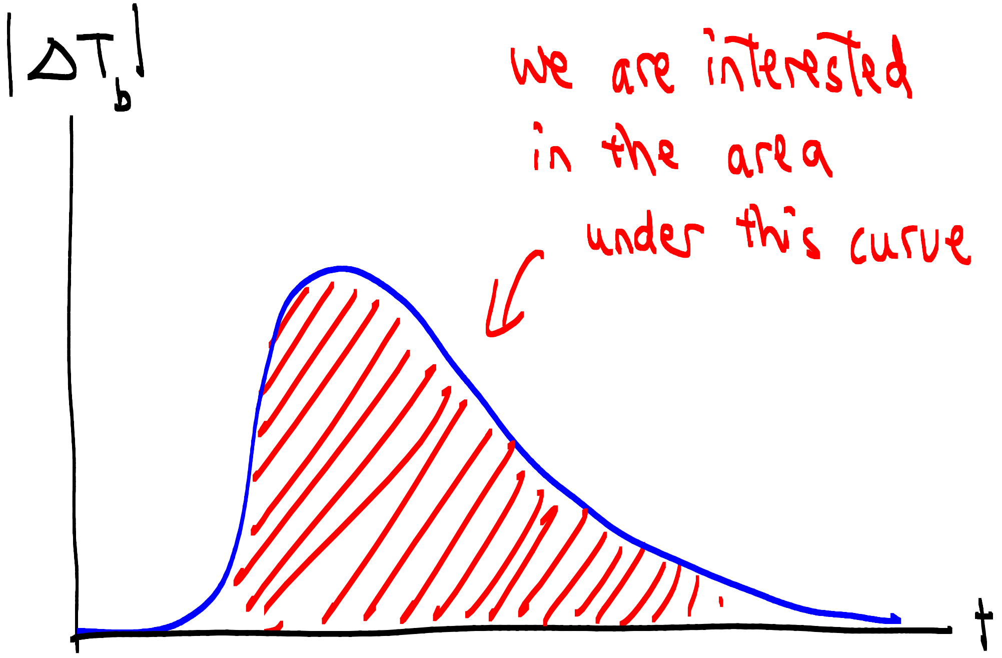
This is what we measure!

Thermodilution ← Most common method!

$\boxed{\text{Step 1}}$ Rapidly inject a bolus of cold saline into the right atrium

$\boxed{\text{Step 2}}$ Temperature of cooled blood in pulmonary artery is measured with a thermistor

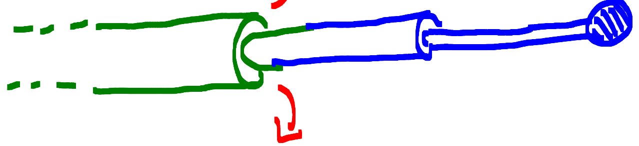




We are interested in the area under this curve

Quantity of indicator is total thermal energy

☆ Both the saline injection and thermistor are performed with "Swan-Ganz" catheter!



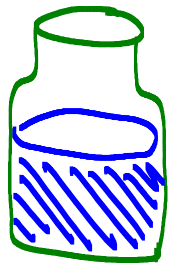
$$Q = mc\Delta T$$

$$= \rho c V \Delta T$$

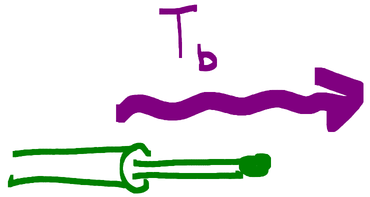
specific heat

$$F = \frac{\text{Total injected amount}}{\text{Integrated concentration}}$$

← Total thermal energy $\quad Q_i = \rho_i c_i V_i \Delta T_i$



← Thermal energy density $\quad \frac{\Delta Q_b}{\Delta V_b} = \rho_b c_b \Delta T_b$



$$= \frac{\rho_i c_i V_i \Delta T_i}{\int_0^{t_0} \rho_b c_b \underbrace{\Delta T_b}_{} \, dt} = \frac{\rho_i c_i}{\rho_b c_b}\left[\frac{\Delta T_i}{\int_0^{t_0} \Delta T_b \, dt}\right] \times V_i$$

Measure this?

units? $\left[\frac{°C}{°C \times sec}\right] \times \text{Liters} = \frac{\text{Liters}}{sec}$ ✓