HYPERTENSION

PHYSIOLOGY OF THE CARDIOVASCULAR SYSTEM

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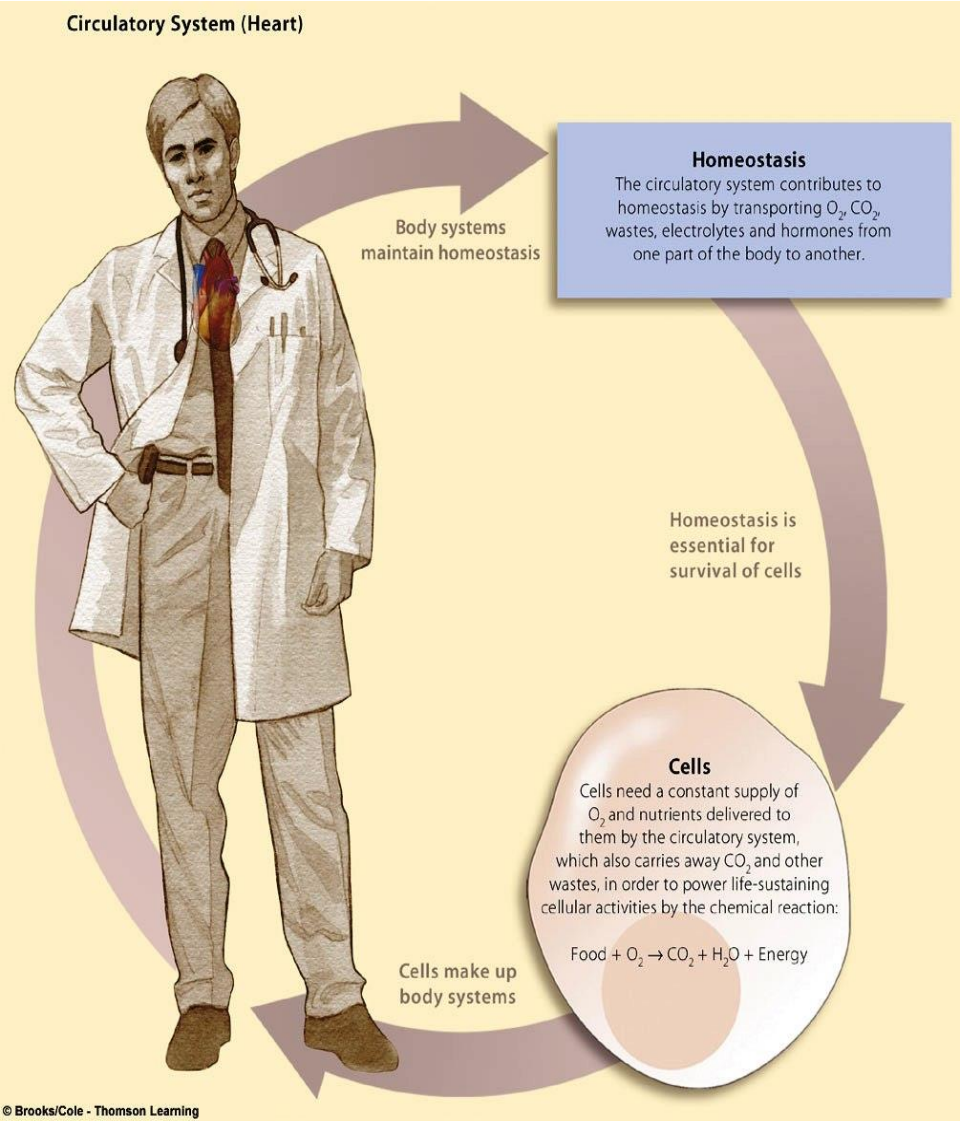
OBJECTIVES

At the end of these lectures you should be knowledgeable on the following aspects:

1. Differences between pulmonary & systemic circulations
2. Determinants of mean arterial blood pressure (MAP)
   a. Cardiac output (CO)
   b. Total peripheral resistance (TPR)
3. Determinants of cardiac output (CO)
   a. Heart rate (HR)
   b. Stroke volume (SV)
4. Control of heart rate & stroke volume

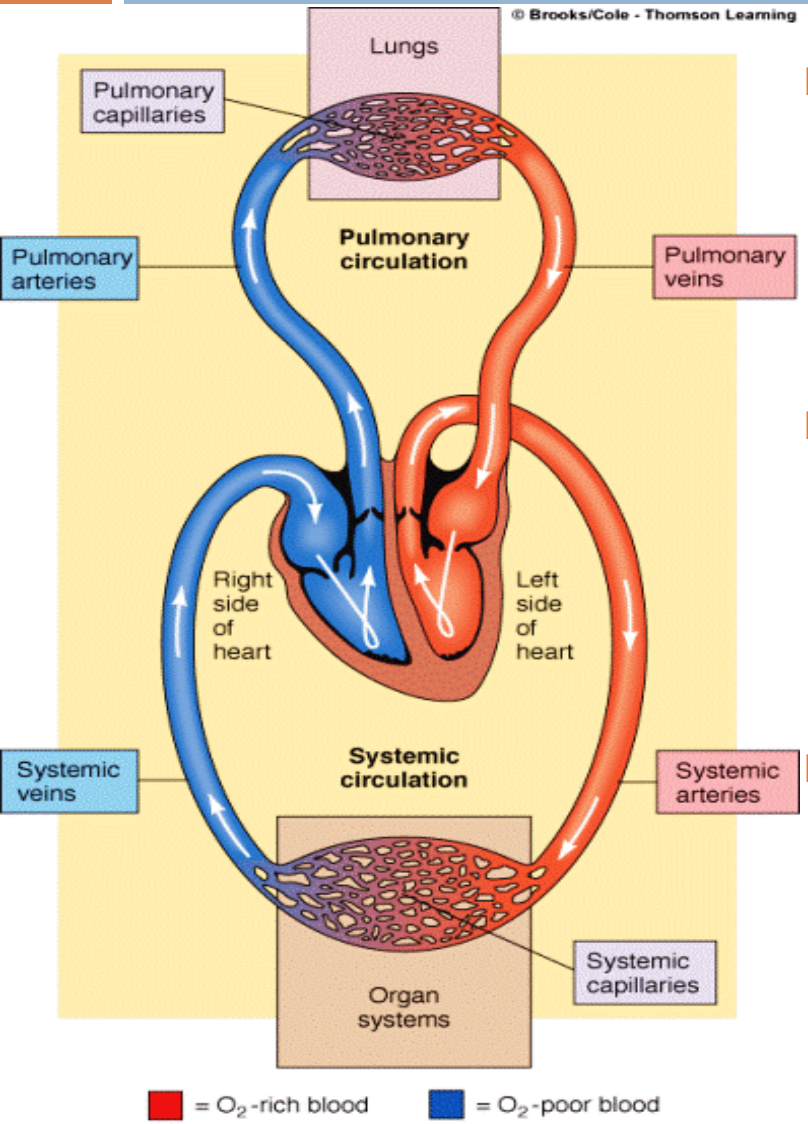
5. Vascular system
   a) Types of blood vessels
   b) Relationship between blood flow, pressure & resistance
6. Role of arteries in BP
   a) Elastic walls with little resistance
   b) Measurement of BP
   c) Calculation of MAP
7. Role of arterioles in peripheral resistance
   a. Control of arteriolar resistance
      i. Sympathetic nerve control
      ii. Blood chemicals
      iii. Hormones

Cardiovascular system essential for survival of cells



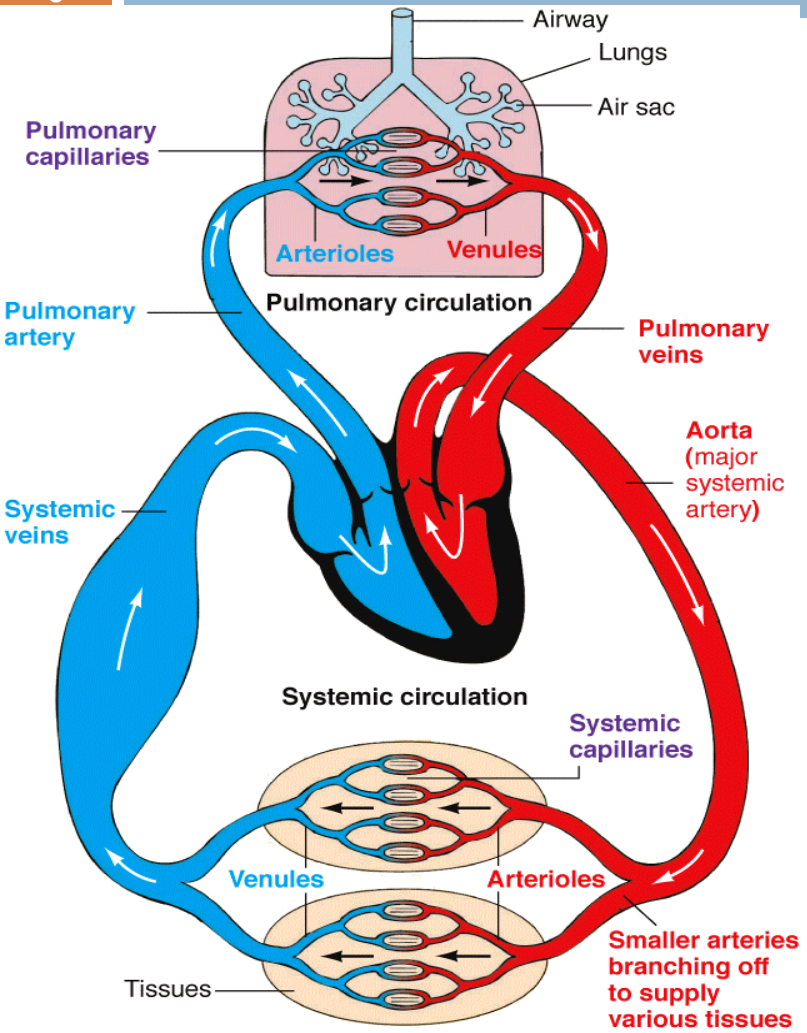
- *Transports O_2 and nutrients to cells*
- *Transports CO_2 and waste products away from cells*

Cardiovascular system consists of:



- ***Heart***
  - *Contracts*
    - *Generates pressure*
      - *Allows blood to flow through the vessels*
- ***Blood vessels***
  - *Transport blood to all parts of body*
  - *Offer resistance to create pressure gradient for blood flow*
- ***Blood***
  - *Transport medium for dissolved nutrients and waste products*

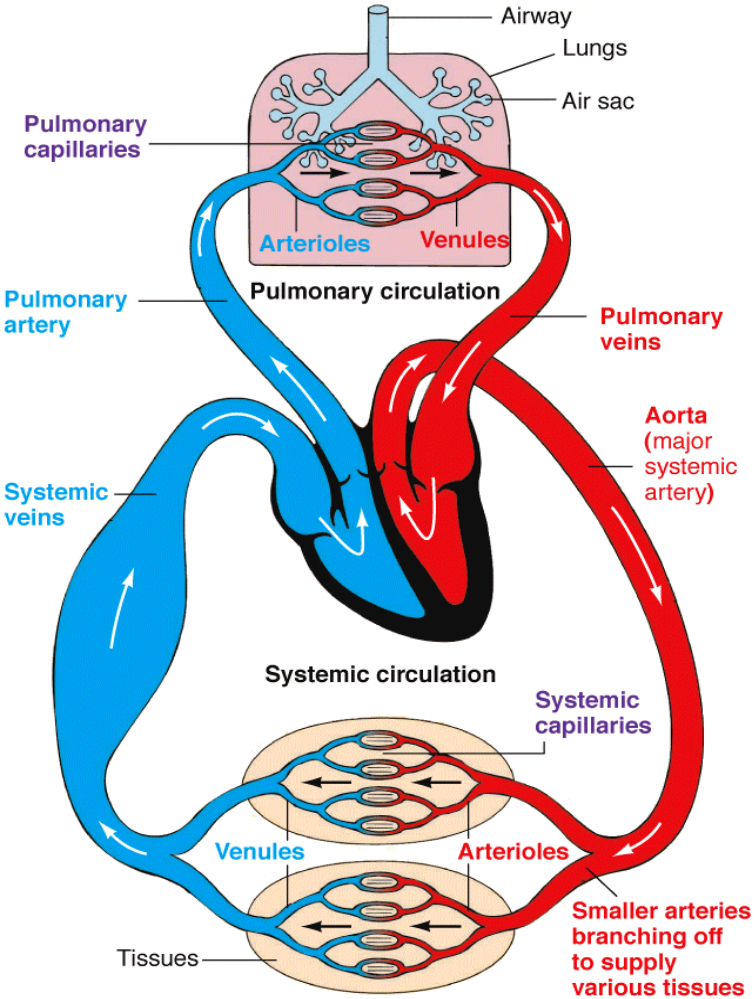
Two separate circulations supply blood to lungs and systemic organs



For simplicity, only two capillary beds within two organs are illustrated.

- ***Pulmonary circulation***
  - *Carries blood to and from lungs*
    - *Low pressure system*
- ***Systemic circulation***
  - *Carries blood to and from organ tissues*
    - *High pressure system*

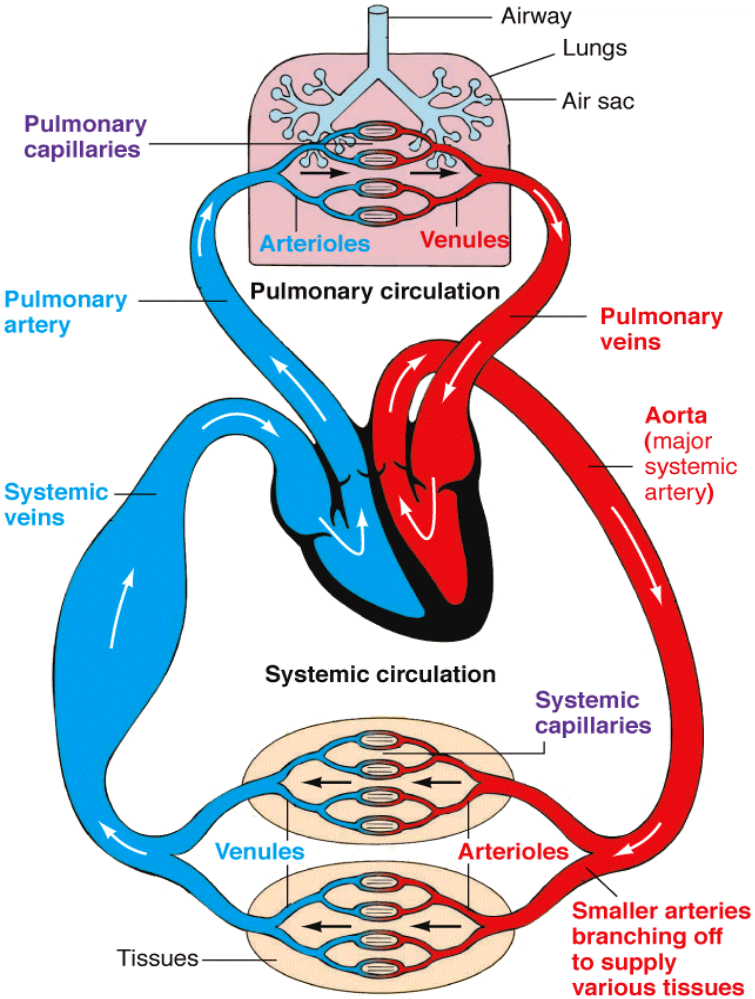
A pressure gradient is needed for blood to flow through circulation



For simplicity, only two capillary beds within two organs are illustrated.

- ***Systemic circulation***
  - ***Left ventricular contraction*** *generates arterial pressure*
  - ***Arterioles offer resistance***
    - *Contribute to pressure in arteries*
    - *Allow pressure to drop in veins*
  - *Pressure gradient develops*
    - *Allows blood to flow from left ventricle to right atrium*

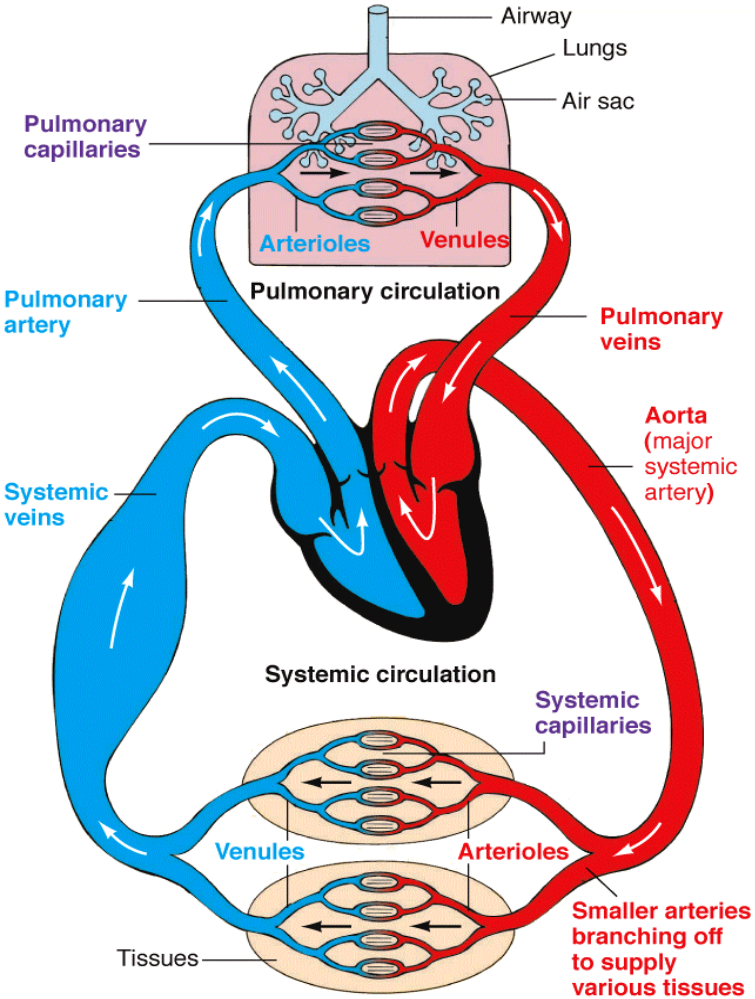
ARTERIAL BLOOD PRESSURE (BP)



For simplicity, only two capillary beds within two organs are illustrated.

- *BP defined as force applied by blood against a blood vessel wall*
  - ***Arterial BP depends on:***
    - ***Force of left ventricular contraction***
      - ***Regulated***
    - *Blood volume*
      - *Kept constant by kidneys*
    - *Elasticity of arterial walls*
      - *Constant*
    - ***Total peripheral resistance***
      - ***Depends on radii of arterioles***
        - ***Regulated***

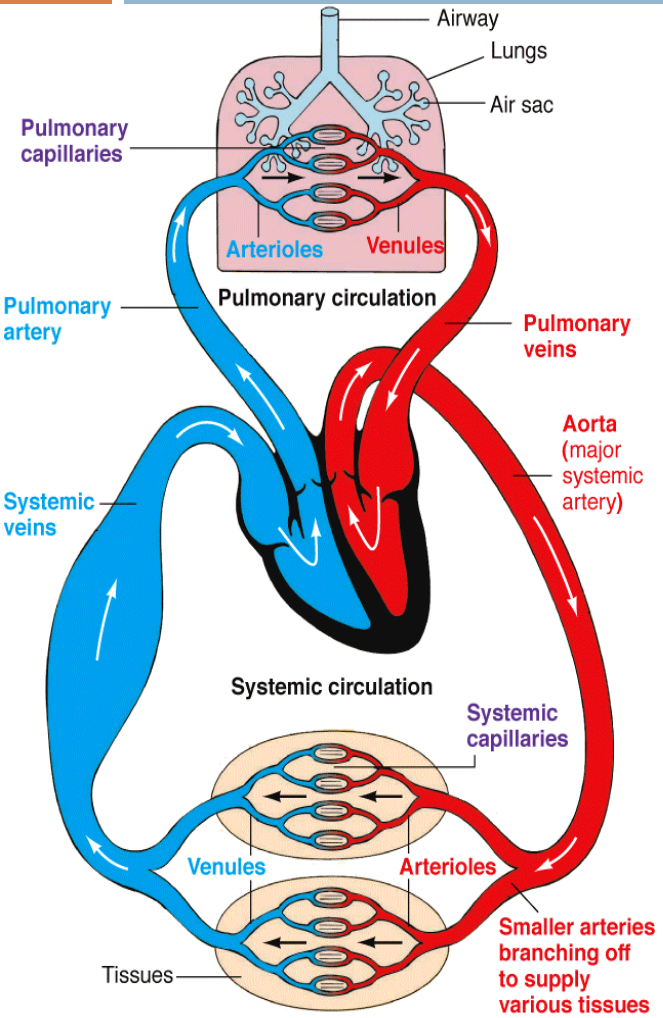
MEAN ARTERIAL BLOOD PRESSURE (MAP)



For simplicity, only two capillary beds within two organs are illustrated.

- *BP expressed as systolic BP (SBP), diastolic BP (DBP), pulse pressure (PP) & mean arterial blood pressure (MAP)*
- *MAP defined as **average pressure** in systemic arteries*
  - *Simplest form:*
    - *MAP = [SBP + DBP]/2*
  - *Determinants of MAP*
    - *Next slides*
  - *Calculation of MAP*
    - *See later*

DETERMINANTS OF MEAN ARTERIAL BLOOD PRESSURE (MAP)



For simplicity, only two capillary beds within two organs are illustrated.

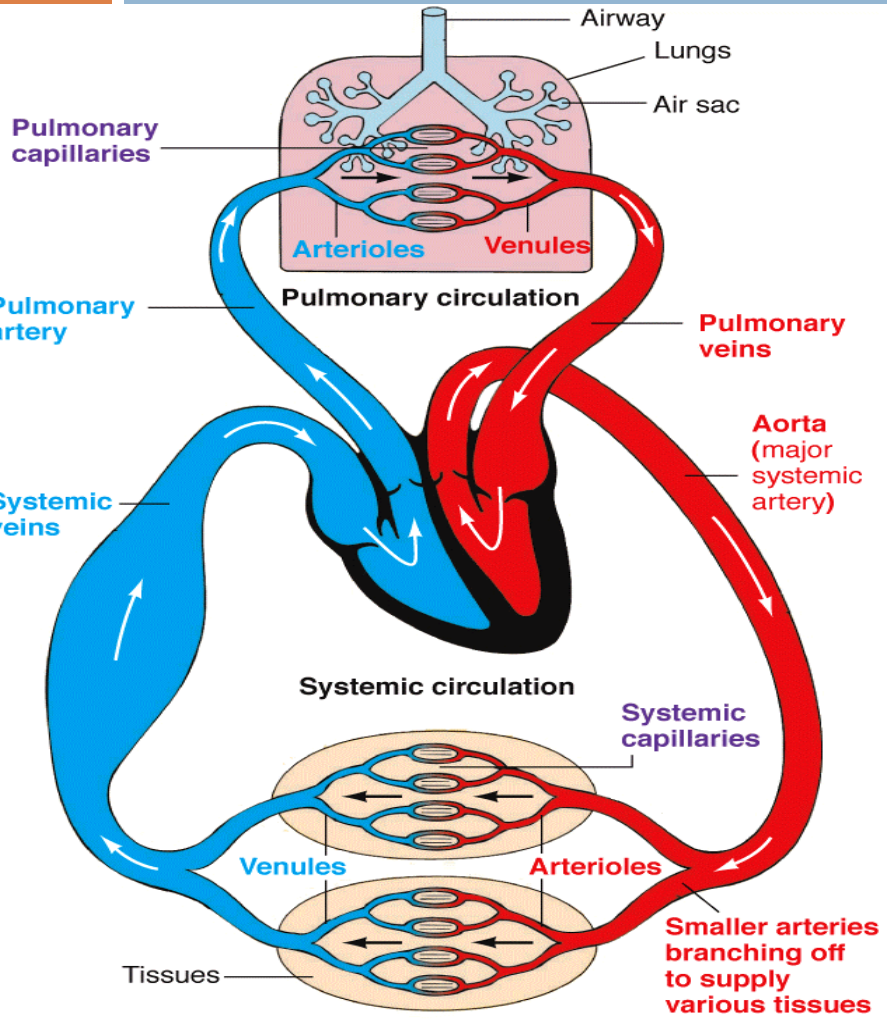
- *MAP determined by **2 factors:***
  - *Cardiac output (CO)*
  - *Total peripheral resistance (TPR)*

MAP = CO X TPR

1. CARDIAC OUTPUT (CO)

MAP = **CO** X TPR

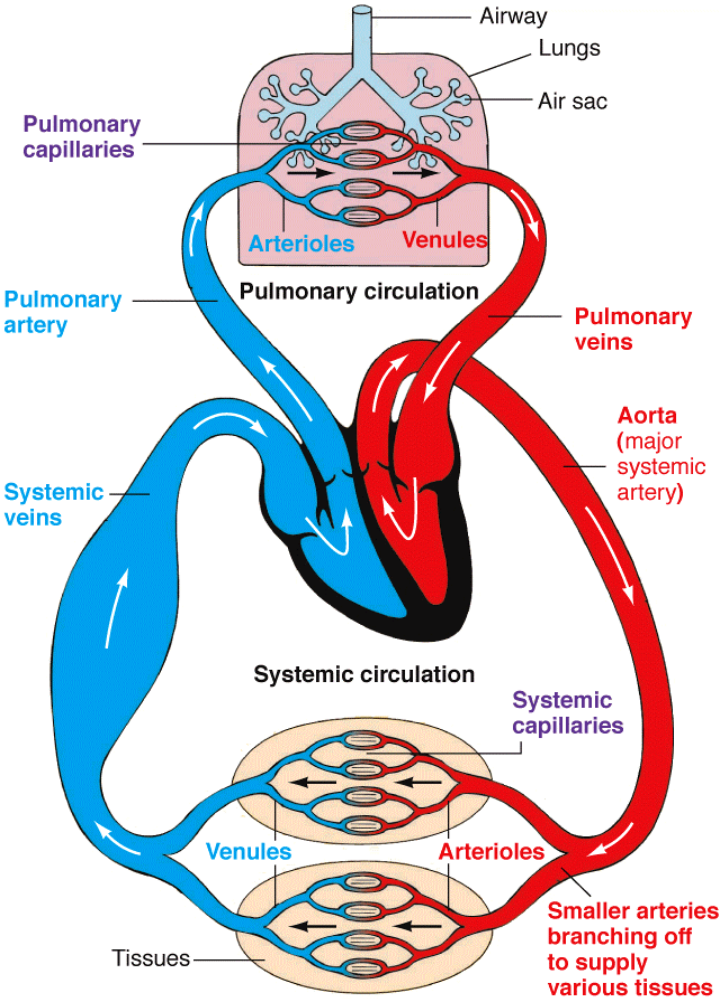
Definition of CO



or simplicity, only two capillary beds within two organs are illustrated.

- ***Volume*** *of blood pumped by left ventricle in* ***one minute***
  - *5 Litres/min (at rest)*
  - *25 Litres/min (exercise)*

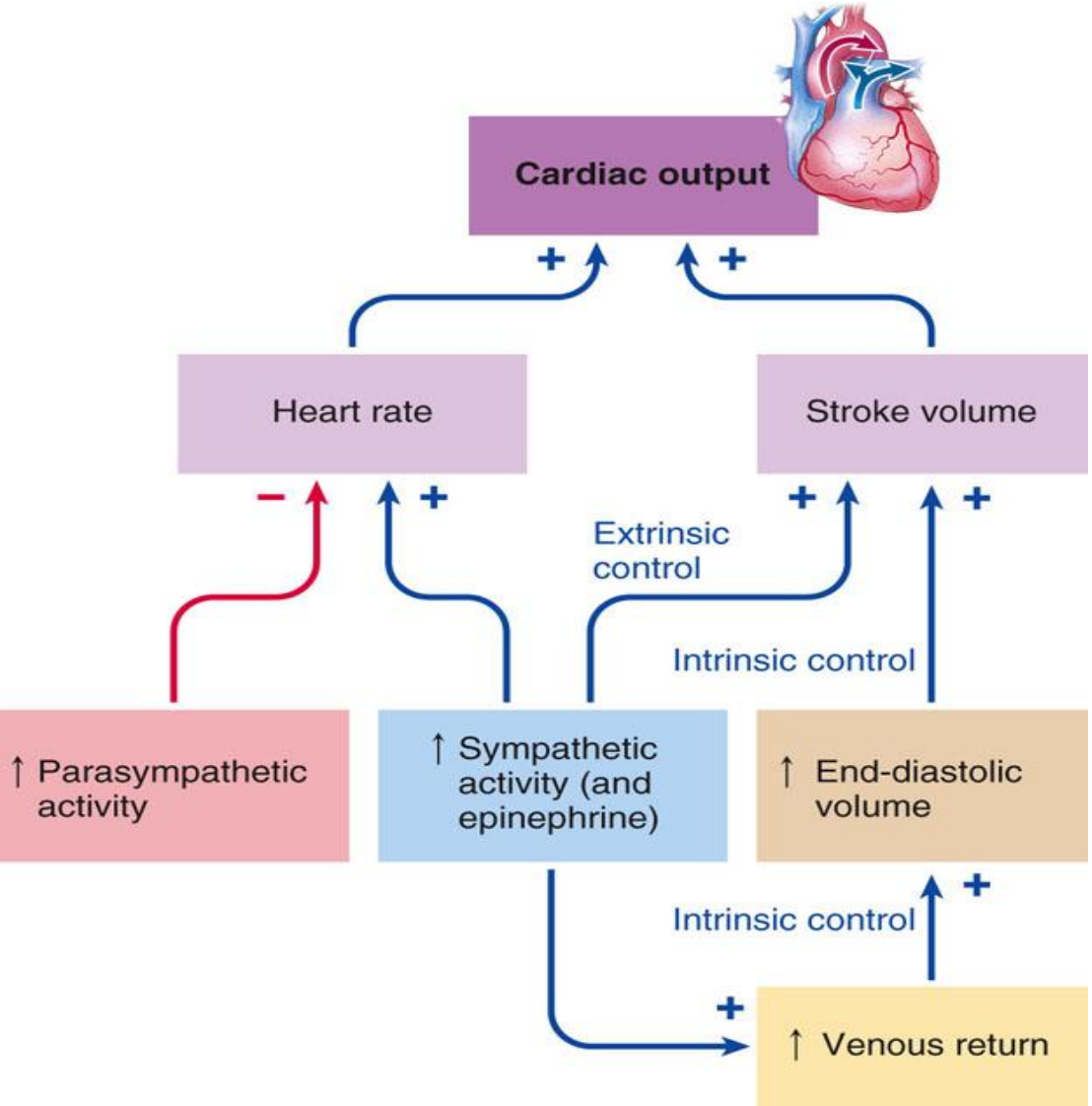
Determinants of CO



For simplicity, only two capillary beds within two organs are illustrated.

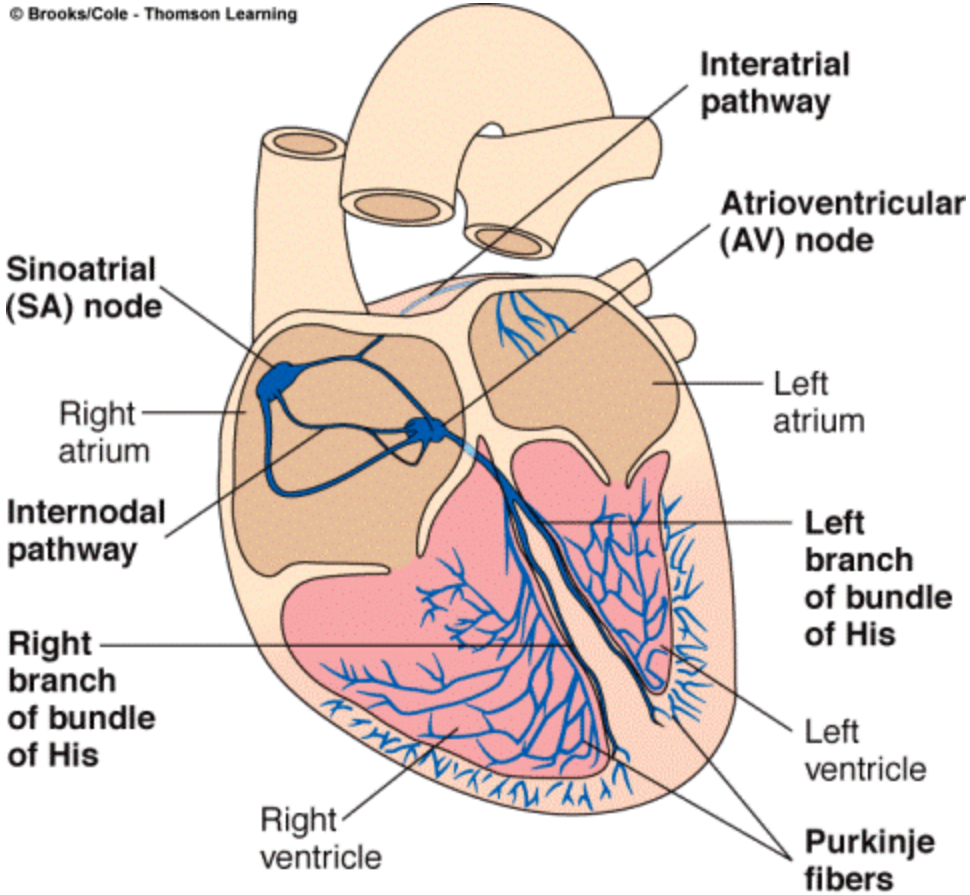
- *CO determined by **2 factors:***
  - ***Stroke volume (SV)***
    - ***Definition:*** *Volume of blood pumped out (ejected) by left ventricle into aorta during a **single contraction***
      - ***Regulated***
        - *70 ml – 140 ml*
  - ***Heart rate (HR)***
    - ***Definition:*** *Number of cardiac contractions in one minute*
      - ***Regulated***
        - *72 b/min – 200 b/min*
- *CO = SV (70 ml) X HR (72 b/min)*
- *Resting CO = 5 l/min*

Size of CO depends on regulation of HR and SV



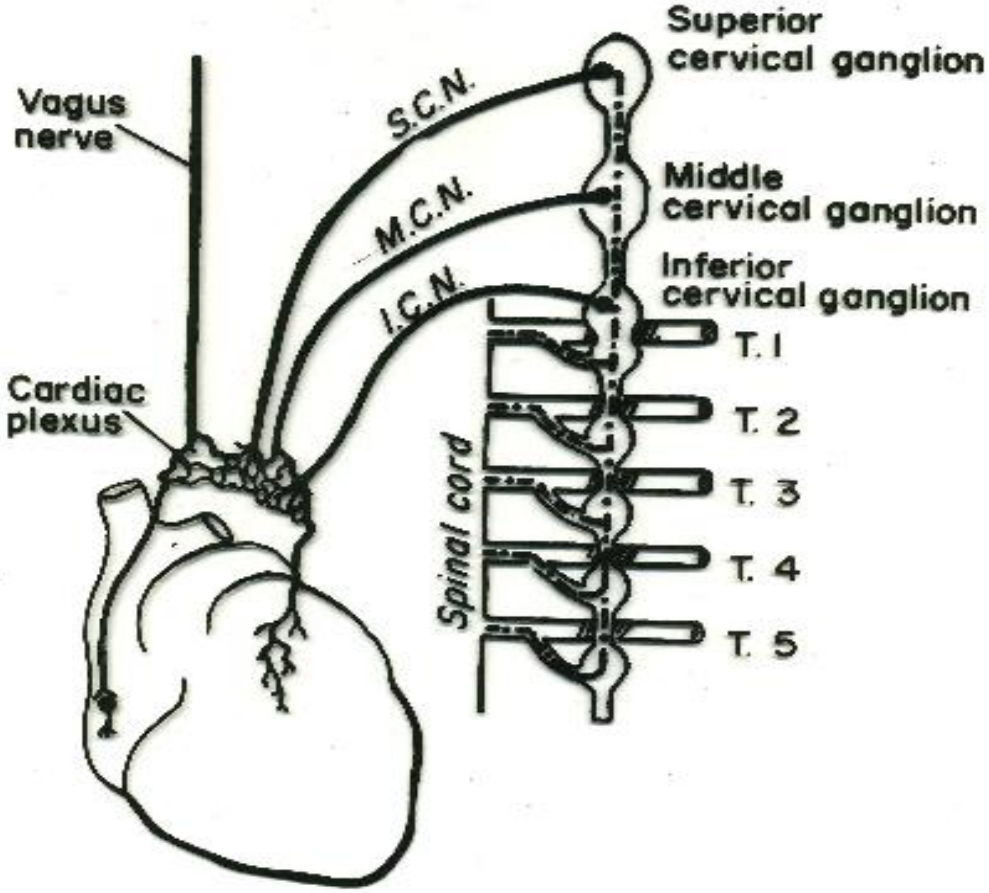
- *Regulated by*
  - *Extrinsic control*
  - *Intrinsic control*
- *CO varies between 5 and 25 l/min*

At rest, the heart contracts rhythmically at about 72 times/min (Resting HR = ±72 beats/min)



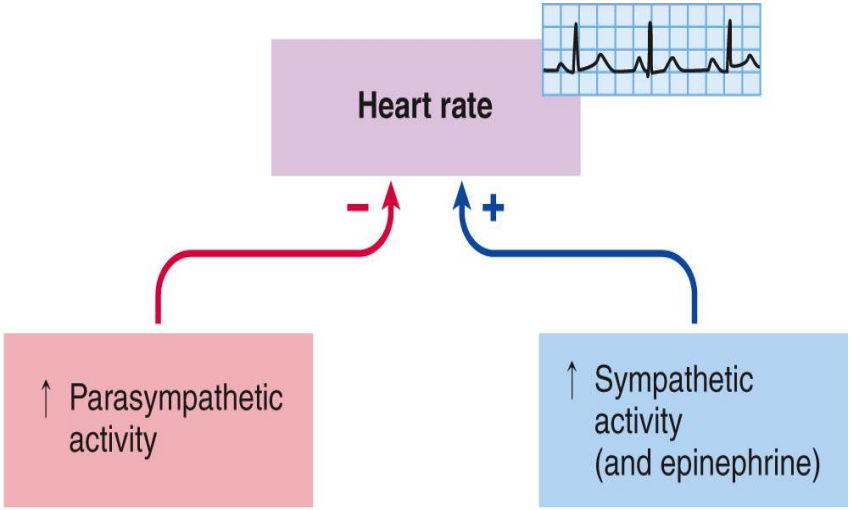
- *Due to **sinoatrial node (SAN)** generating action potentials spontaneously @ rate = ±72 times/min*
  - *Spread to atria & ventricles*
  - *Causing atrial & ventricular contractions*
    - *At a rate of ±72 times/min*

Number of action potentials generated by SAN (heart rate) **adjusted** by the autonomic nervous system via parasympathetic & sympathetic nerve stimulation



S.C.N. = Superior cardiac nerve
M.C.N. = Middle cardiac nerve
I.C.N. = Inferior cardiac nerve

HR at any given moment the result of balance between parasympathetic and sympathetic nerve stimulation

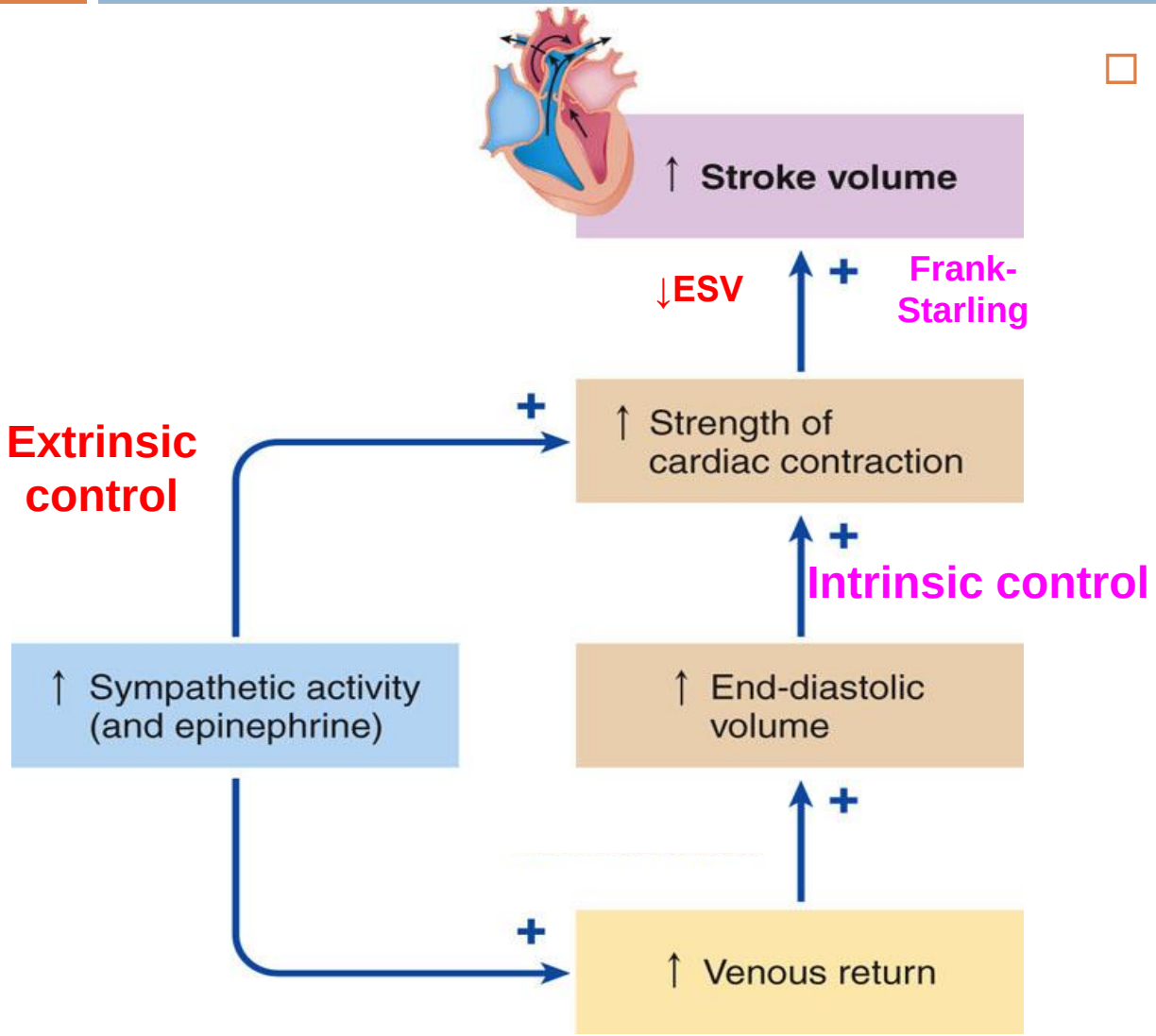


- ***Parasympathetic stimulation slows down HR***
  - *Responsible for normal resting HR of ±72 b/min*
  - *↓HR ±40-45 b/min in resting athletes*
- ***Sympathetic stimulation speeds up HR***
  - *↑HR up to ±200 b/min in heavy exercise*

Stroke volume (SV) at any given moment the result of EDV minus ESV *[SV = EDV - ESV]*

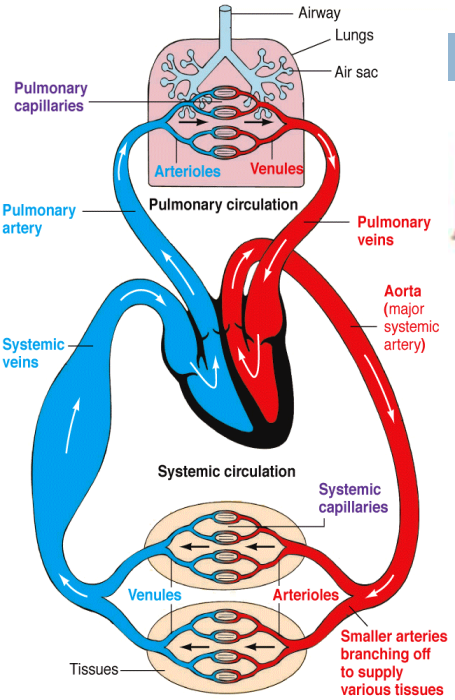
- *Definition of **end-diastolic volume (EDV)** = volume of blood present in ventricle **before contraction starts***
  - ***Regulated***
    - *135 ml – 175 ml*
- *Definition of **end systolic volume (ESV)** = volume of blood remaining in ventricle **after most of the blood has been pumped out of the ventricle into aorta (ejection)***
  - ***Regulated***
    - *65 ml – 35 ml*

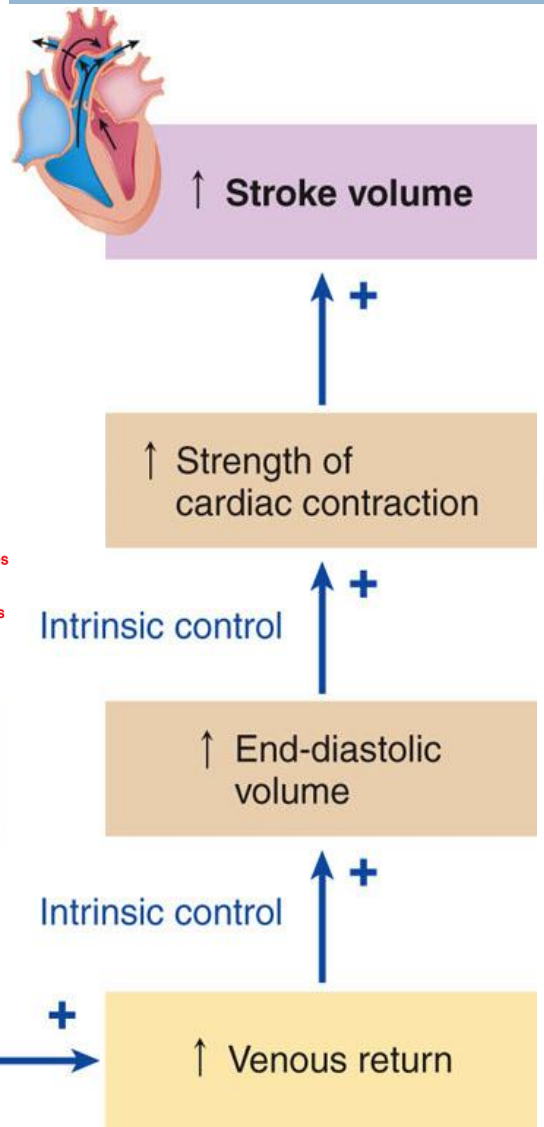
Size of SV regulated by changing the sizes of EDV & ESV



- *2 mechanisms involved:*
  - ***Frank-Starling mechanism***
    - *Depends on **EDV***
  - ***Sympathetic nerve stimulation of ventricles***
    - ***↓ESV***

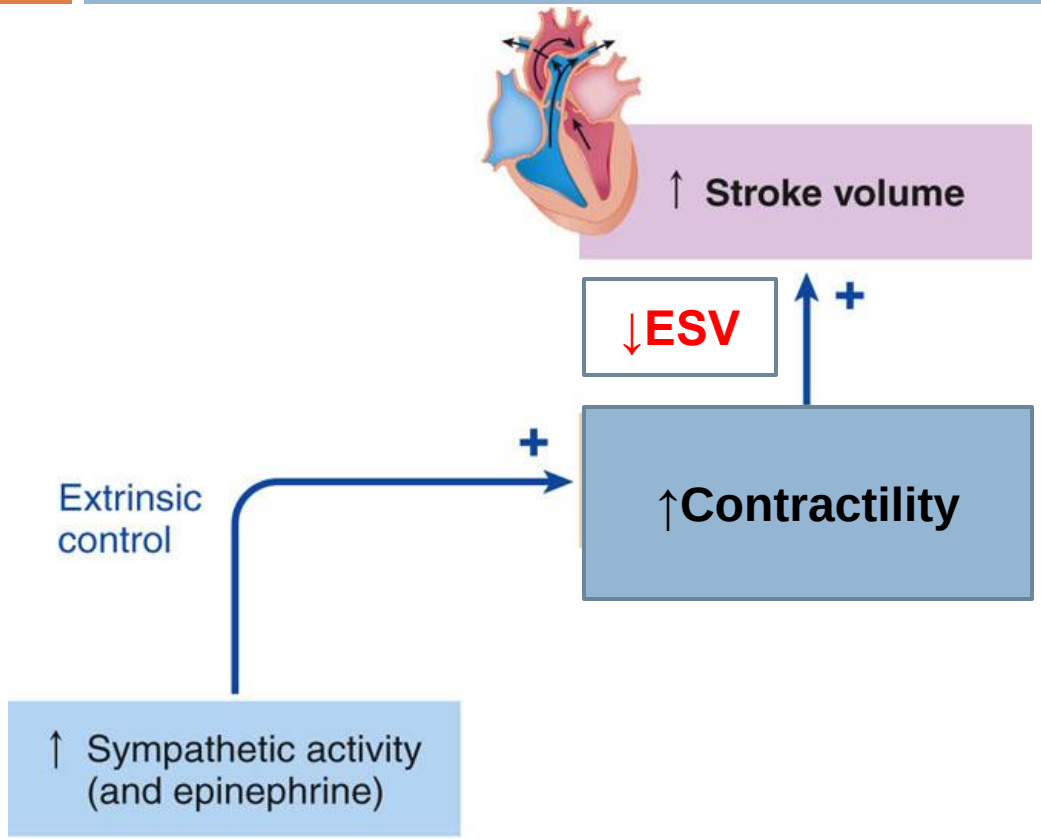
Frank-Starling mechanism depends on size of venous return (VR)



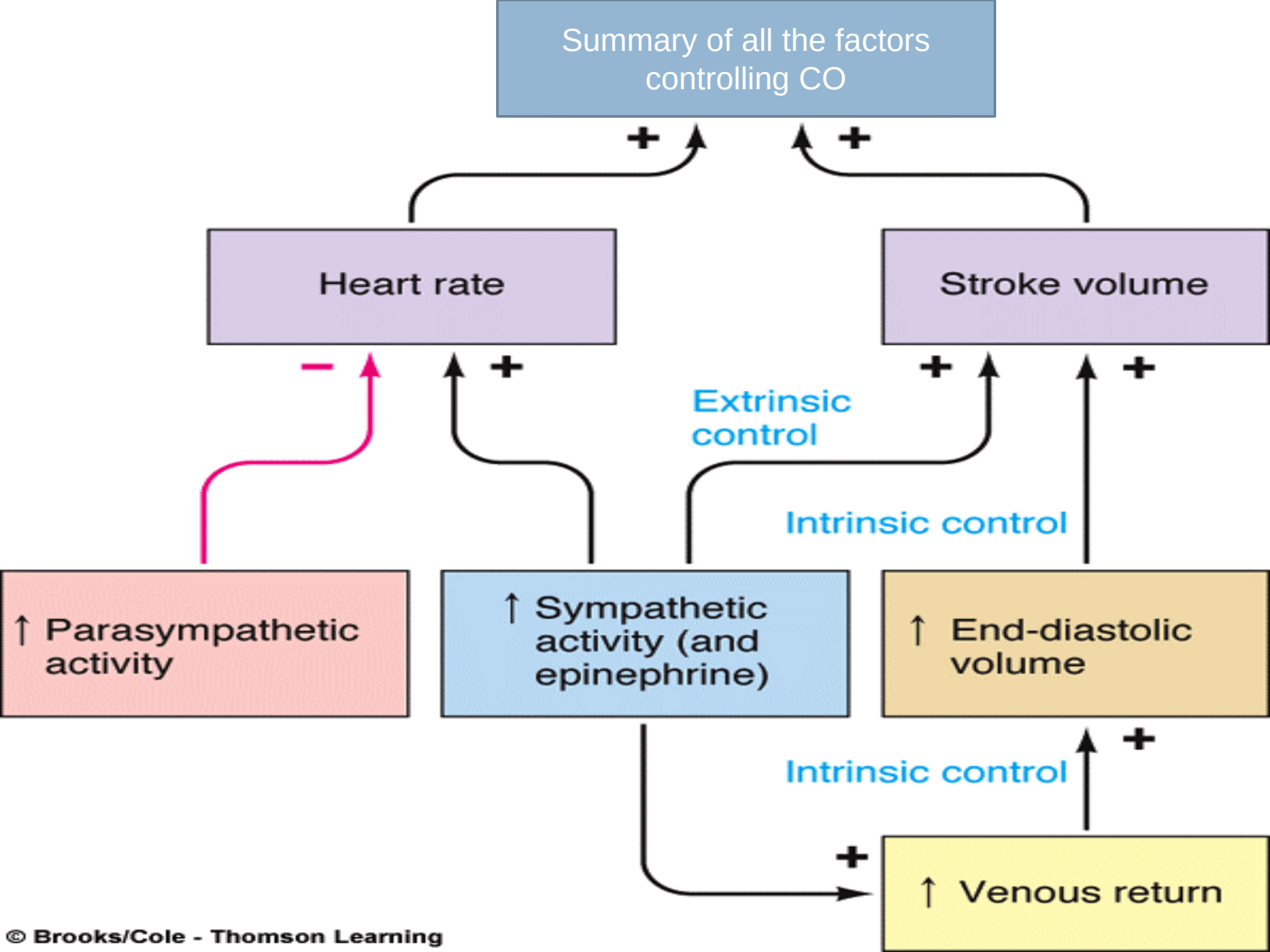


- ***Definition of VR:***
  - *Volume of blood returning from the organs entering the right/left ventricle per min*
- ***Frank-Starling mechanism:***
  - *↑Venous return*
    - *↑EDV*
      - *Stretches muscle fibres*
        - *↑Strength of ventricular contraction*
          - *↑SV*

Sympathetic control of SV



- *Sympathetic nerve stimulation (and adrenaline)*
  - ***↑Ventricular contractility***
    - *More complete emptying of ventricle at end of ventricular contraction period*
      - *Less blood remains in ventricle*
        - ***↓ESV***
          - *↑SV*


Summary of all the factors controlling CO
+
+
Heart rate
Stroke volume
−
+
+
+
Extrinsic control
Intrinsic control
↑ Parasympathetic activity
↑ Sympathetic activity (and epinephrine)
↑ End-diastolic volume
+
Intrinsic control
+
↑ Venous return
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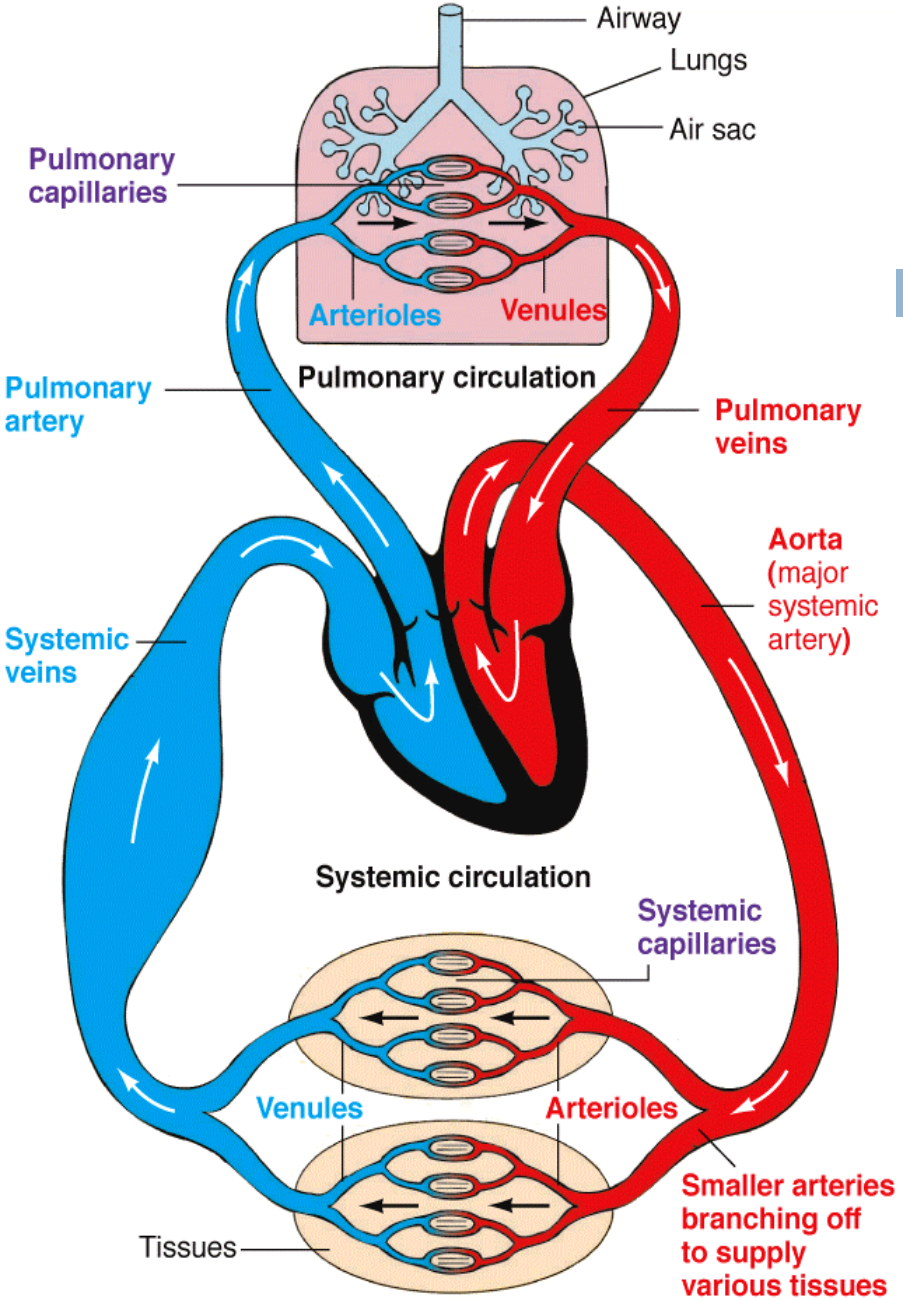
SHORT BREAK

2. TOTAL PERIPHERAL RESISTANCE (TPR)

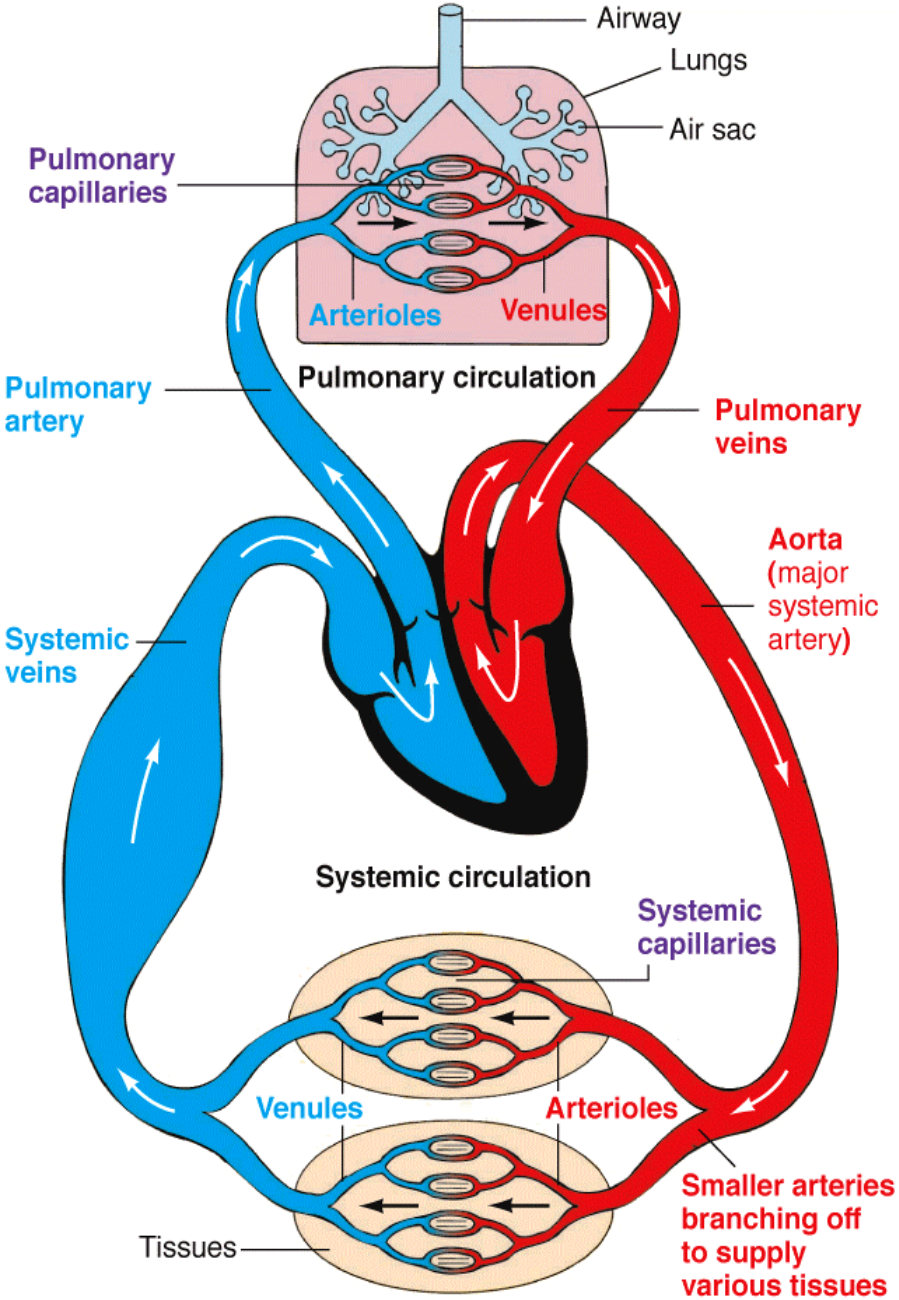
MAP = CO X **TPR**

THE VASCULAR SYSTEM



For simplicity, only two capillary beds within two organs are illustrated.

- *Pulmonary circulation*
- *Systemic circulation*

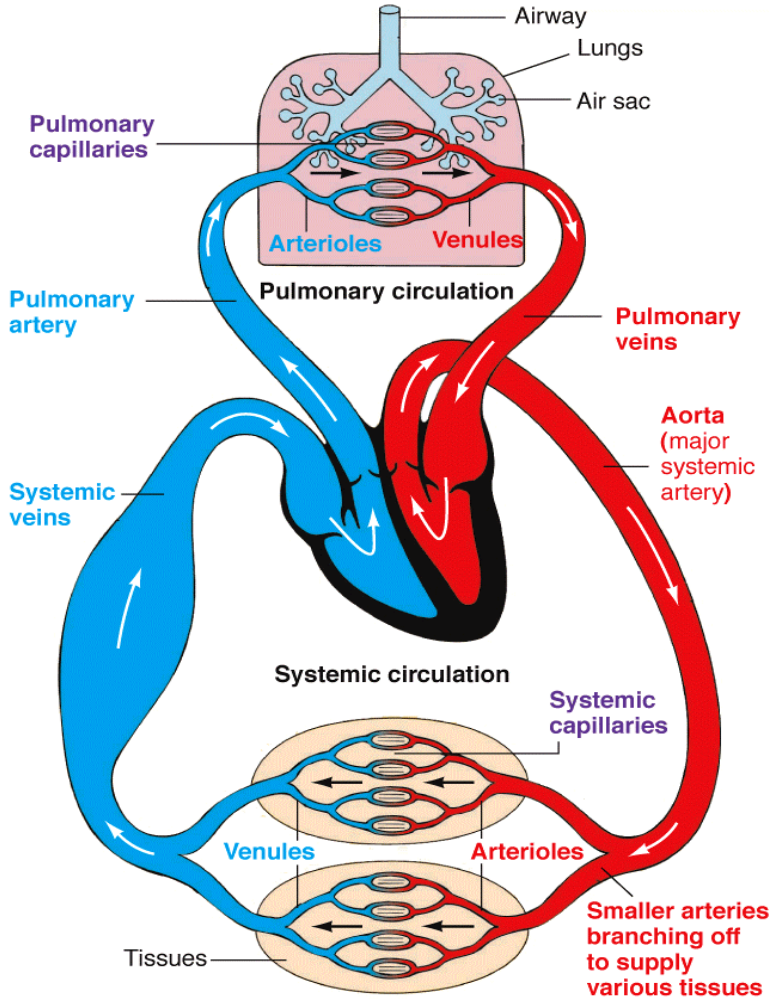


For simplicity, only two capillary beds within two organs are illustrated.

Systemic circulation

- *Aorta*
  - *Major systemic artery leaving the **left ventricle***
- *Smaller arteries*
- *Arterioles*
  - *Radii adjustable*
  - *Resistance vessels (TPR)*
- *Capillaries*
  - *Exchange of materials between blood and cells*
- *Venules*
- *Small veins*
- *Large systemic veins*
  - *Entering **right atrium***

MICRO CIRCULATION



For simplicity, only two capillary beds within two organs are illustrated.

- ***Arterioles***
- *Capillaries*
- *Venules*

RELATIONSHIP BETWEEN BLOOD FLOW BLOOD PRESSURE AND RESISTANCE

*Blood flow (**BF**) through blood vessel directly proportional to **pressure gradient (ΔP)** and inversely proportional to **vascular resistance (R)***

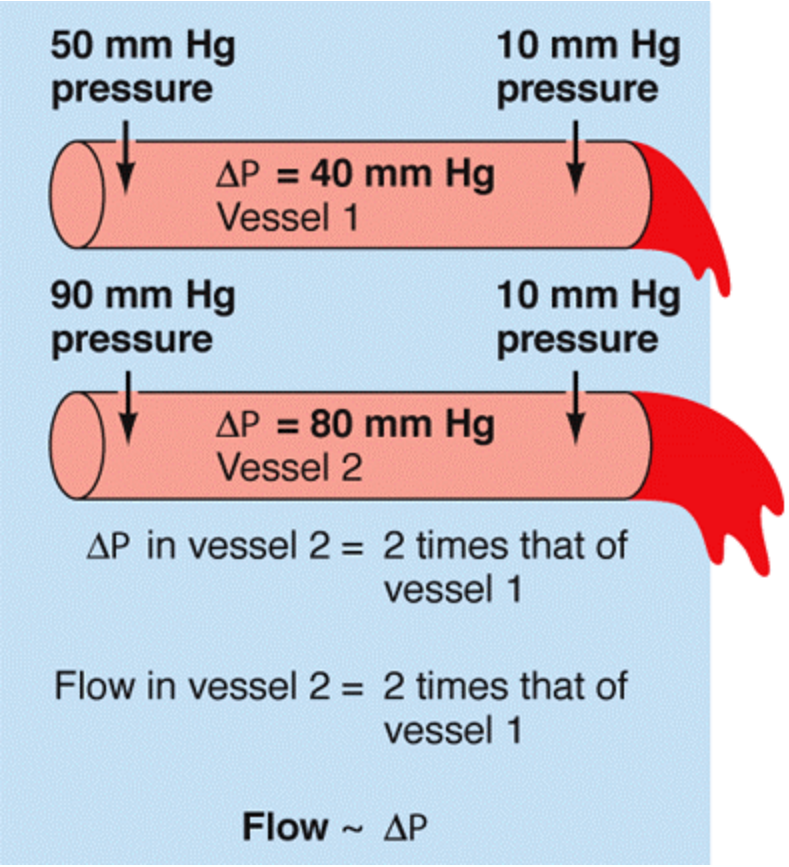
BF = ΔP/R

BF = blood flow rate (ml/min)

ΔP = pressure gradient

R = resistance

Pressure Gradient (ΔP)



- *Main driving force for **BF***
  - *Blood flows from high to low pressure area*
  - *The greater the pressure gradient the greater the **BF***
  - *Doubling pressure gradient would double **BF***
  - *Important to be regulated at correct level*

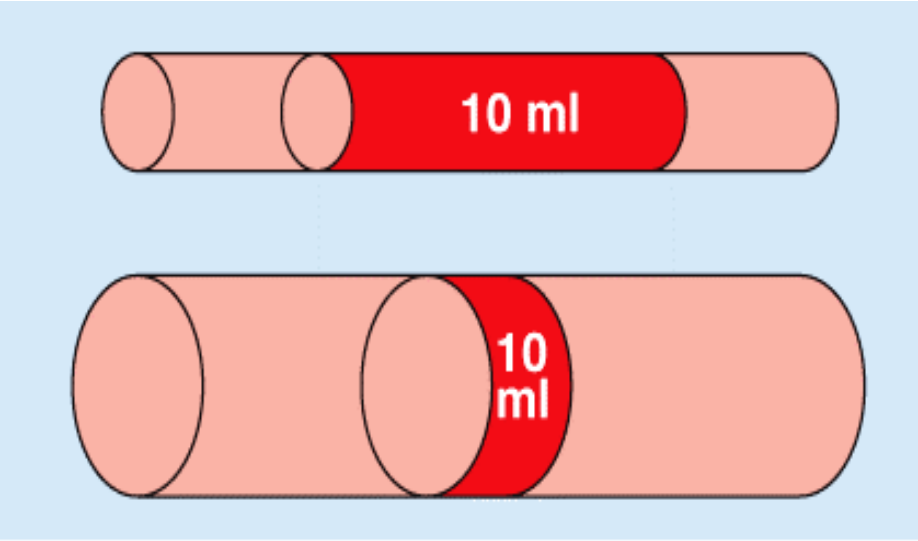
Resistance (R)

- *Friction between moving blood and blood vessel wall*
  - *The higher the resistance the smaller the* ***BF***

Resistance depends on 3 factors

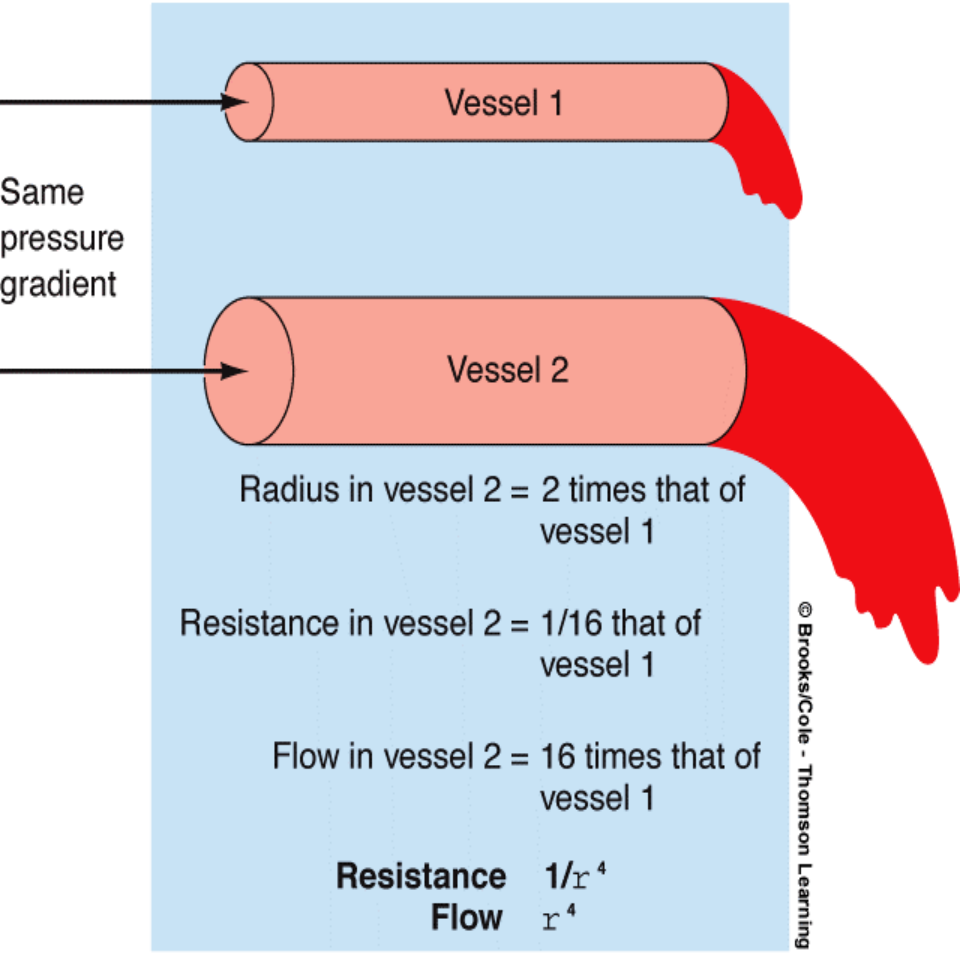
- ***Viscosity of blood***
  - *Concentration of plasma proteins*
  - *Number of red blood cells*
- ***Blood vessel length***
  - *Longer vessels ↑resistance*
- ***Blood vessel radius***
  - *Major determinant of resistance*

Blood vessel radius (r)



- *Fluid passes rapidly through large vessels*
  - *Given volume of blood comes into contact with less surface area*
    - *↓Resistance*
    - ***↑BF***

Resistance inversely proportional to 4th power of the vessel radius

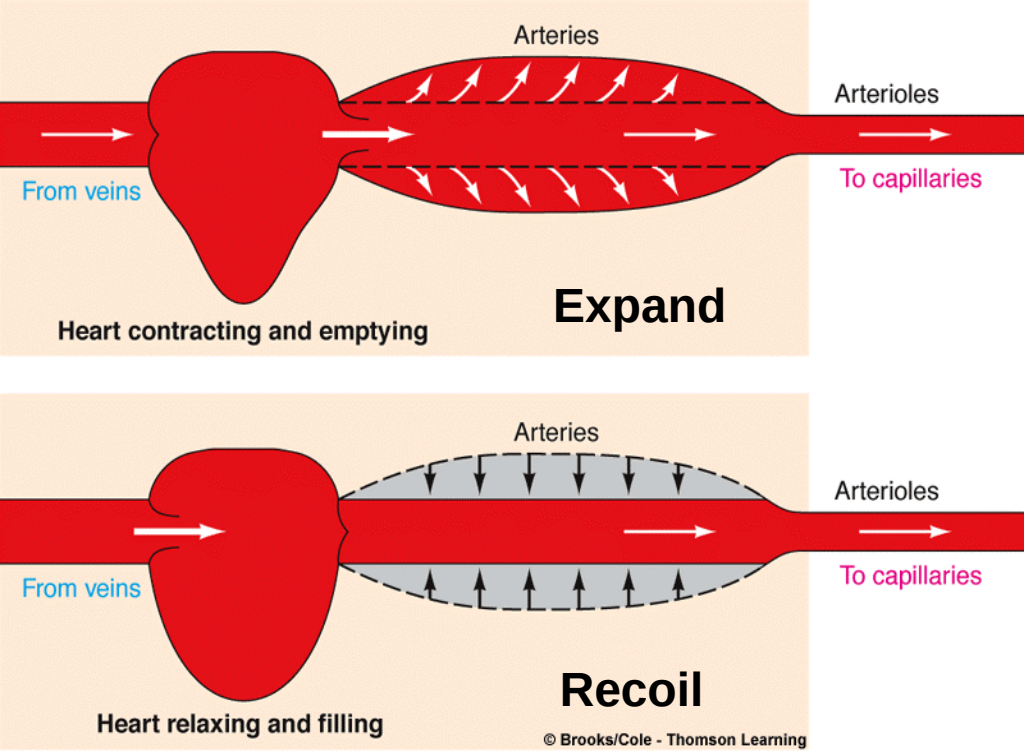


- *$R \propto 1/r^4$*
- *Small changes in blood vessel radius bring about large changes in resistance*
  - *Doubling vessel radius*
    - *↓Resistance* ***16 times***
    - ***↑BF 16 times***

Arteriolar radius most important factor to control resistance

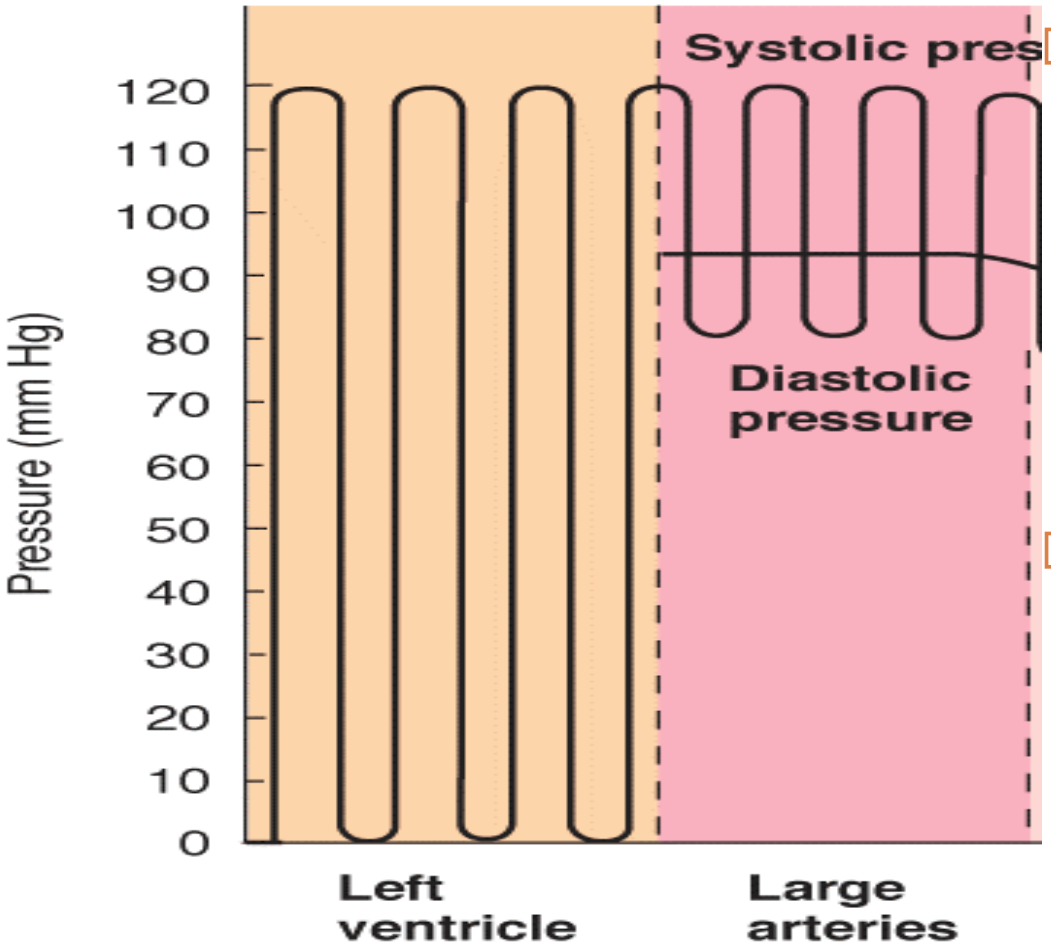
- ***Radii of arterioles regulated (see later)***
  - ↓*Radii*
  - ↑*Resistance*
    - ***↓BF***
    - ***↑Arterial blood pressure (BP)***

ROLE OF ARTERIES IN ARTERIAL BLOOD PRESSURE



- *Large radii offer little resistance*
  - *Elastic walls **expand** during ventricular contraction (systole)*
  - *Walls **recoil** during ventricular relaxation*
    - *Providing a driving force for **BF** during ventricular relaxation (diastole)*

Arterial BP fluctuates in relation to left ventricular contraction and relaxation

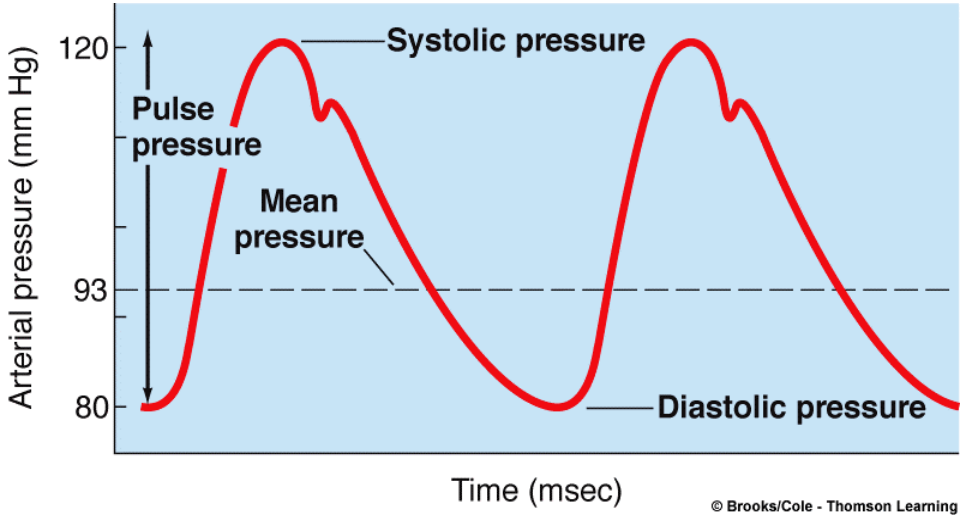


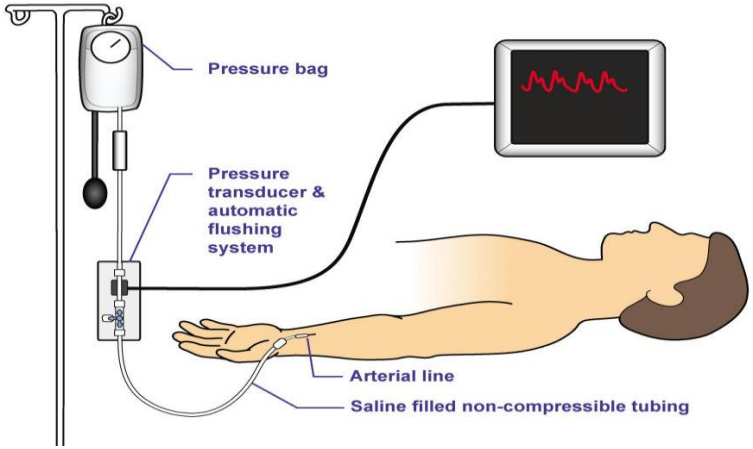
- *Systolic pressure*
  - ***Maximum*** *pressure in arteries during LV contraction*
    - *Averages* ***120 mmHg***
- *Diastolic pressure*
  - ***Minimum*** *pressure to which BP declines during LV relaxation while arteries recoil*
    - *Averages* ***80 mmHg***

MEASUREMENT OF ARTERIAL BP

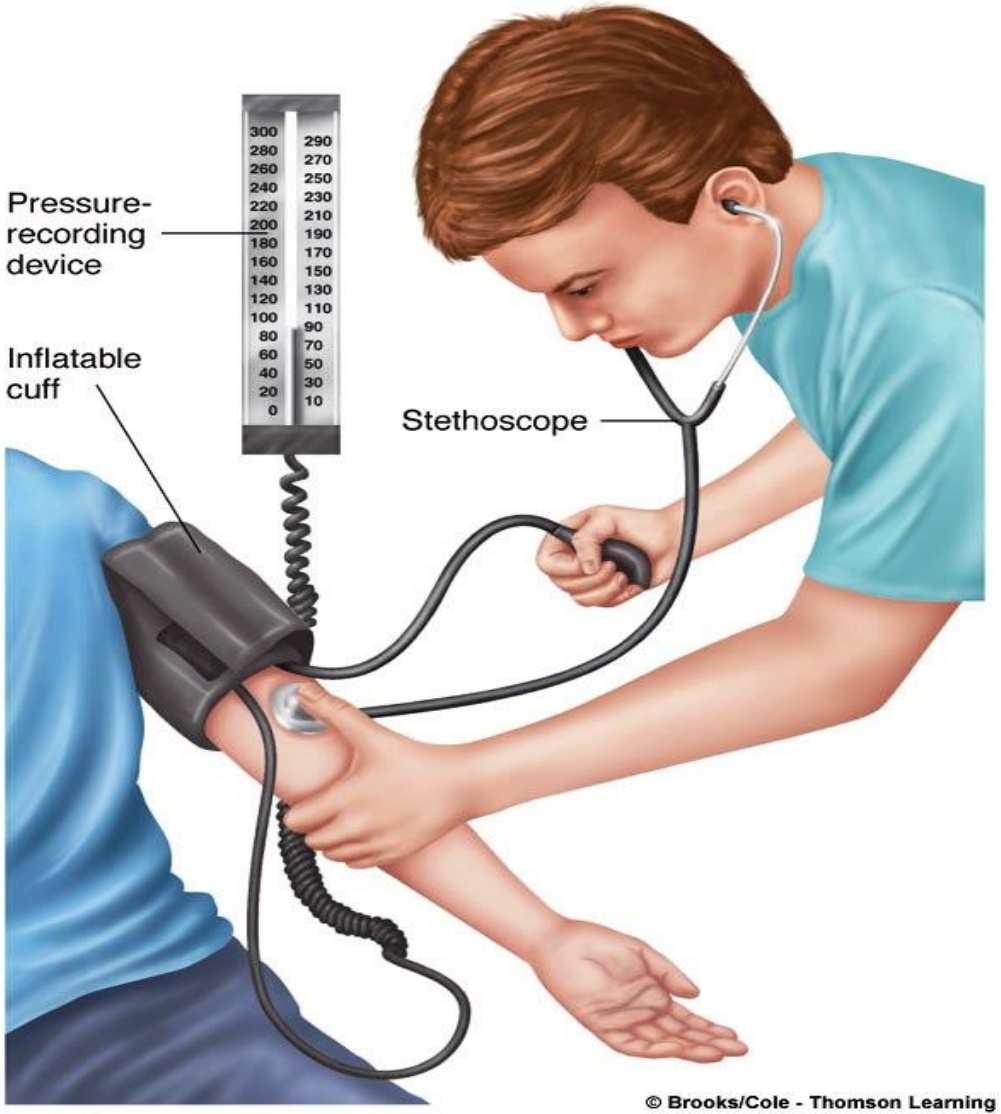
Direct measurement of arterial blood pressure

- *Insert a catheter via a needle into a major artery*
  - *Withdraw needle*
  - *Connect catheter to pressure transducer*
    - *Record arterial pressure waves*





Indirect measurement of arterial blood pressure



- *Systolic and diastolic BP estimated*
  - *Sphygmomanometer*
  - *Inflatable cuff*
  - *Stethoscope*
- *Explained later in the course*

Reading expressed as systolic blood pressure over diastolic diastolic pressure (SBP/DBP) (120/80)

- *Difference between systolic and diastolic pressure*
  - *Known as **pulse pressure***
    - *40 mmHg when blood pressure is 120/80*
      - *Pulsation felt in an artery lying close to skin surface*
        - ***Radial pulse** typically felt over radial artery,*
        - ***Brachial pulse** typically felt over brachial artery*
        - ***Carotid pulse** typically felt over carotid artery*

MEAN ARTERIAL BLOOD PRESSURE (MAP)

- *Average BP in systemic arteries*
  - *At resting HR (±72 beats/min) about 2/3 of cardiac cycle spent in diastole*
    - ***MAP closer to diastolic pressure***
  - *A cardiac cycle consists of a period of contraction (systole) and a period of relaxation (diastole)*

CALCULATION OF MAP

- **MAP = diastolic pressure + 1/3 pulse pressure**
- *BP = 120/80*
- *MAP = 80 + (1/3) 40*
- *MAP = <u>93 mmHg</u>*

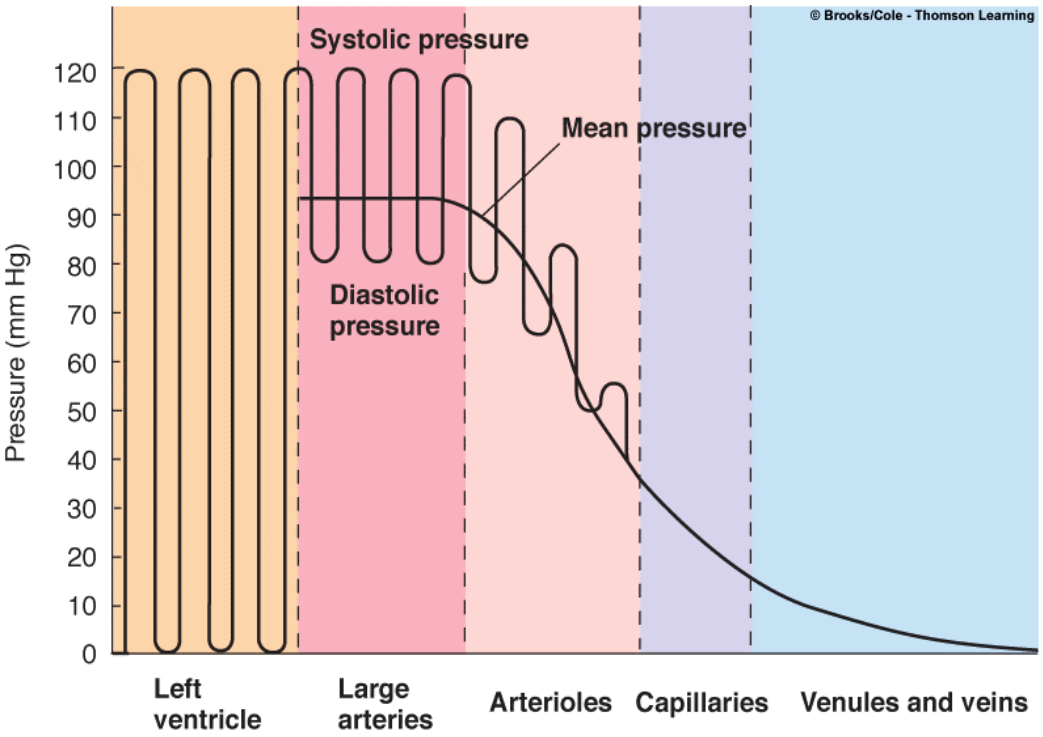
Determinants of MAP

MAP = CO X **TPR**

CO: cardiac output

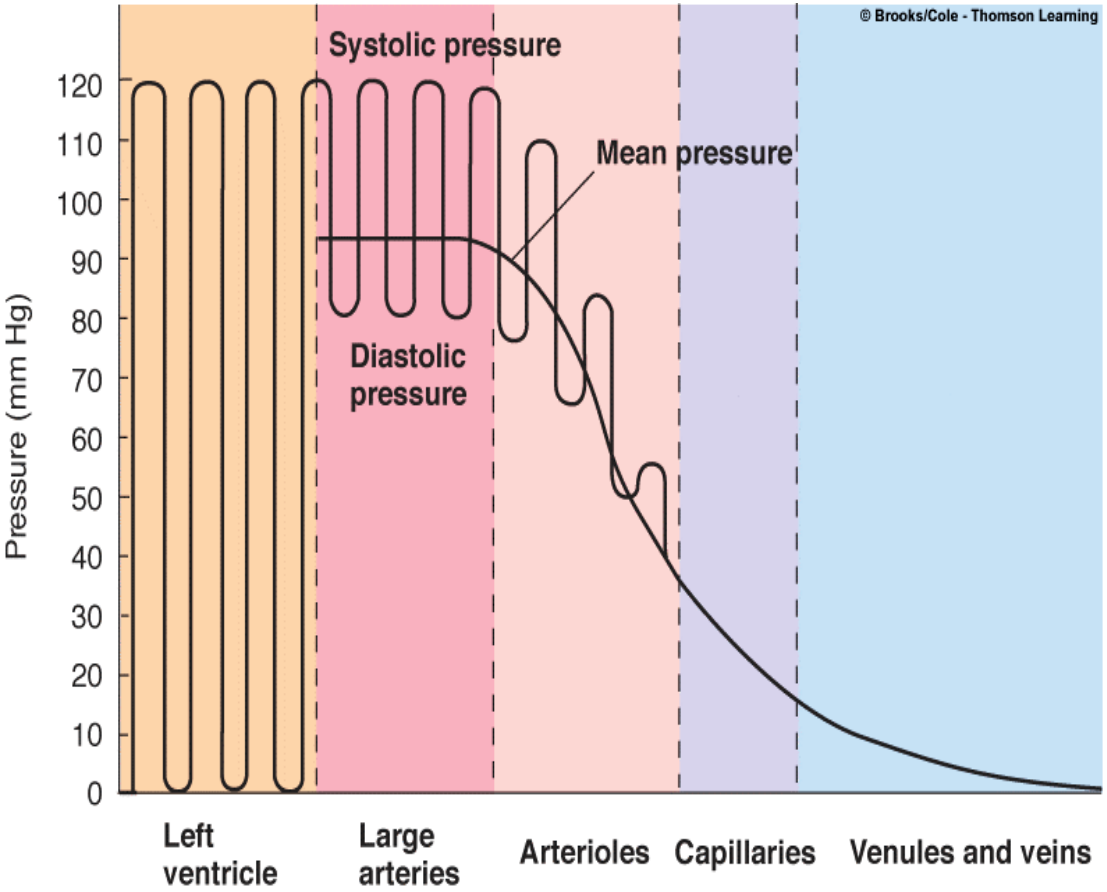
TPR: total peripheral resistance

ARTERIOLES RESPONSIBLE FOR TOTAL PERIPHERAL RESISTANCE (TPR)



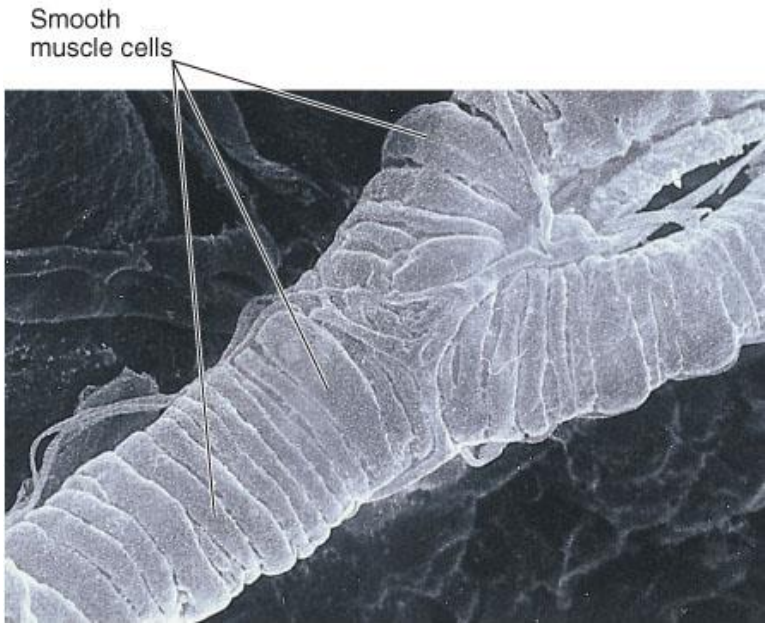
- *Small radii offer* ***resistance***
  - ***Contributes to pressure behind them***
  - ***Causes pressure to fall in front of them***

When blood enters arterioles MAP falls from 93 mmHg to 37 mmHg at end of arterioles



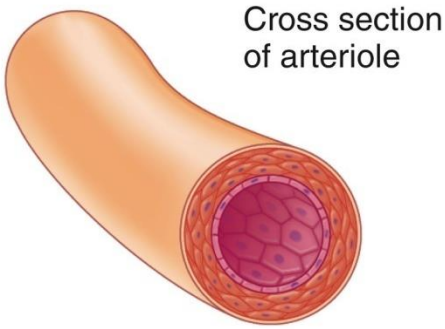
- ***Pressure gradient***
  - *Promotes **BF** through the circulation (from left ventricle back to right atrium)*

Radii of arterioles regulated because smooth muscle contraction and relaxation allows constriction or dilatation of arterioles



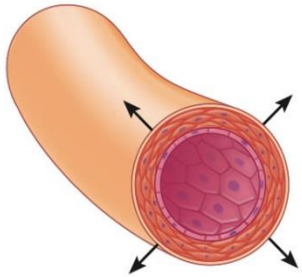
- *Smooth muscle react to:*
  - ***Blood chemicals***
  - ***Sympathetic nerve stimulation***
  - ***Certain hormones***

Arteriolar smooth muscle always partially contracted to maintain normal arteriolar tone

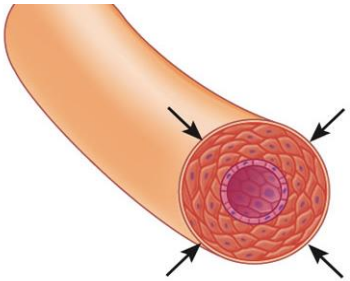


(b) Normal arteriolar tone

- *Relaxation of smooth muscle*
  - *Vasodilation*



- *↑Contraction of smooth muscle:*
  - *Vasoconstriction*



A wide variety of intrinsic and extrinsic factors constrict or dilate arterioles

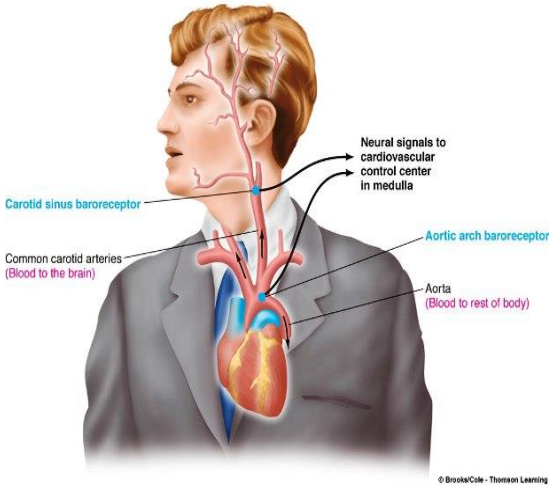
- ***Influencing resistance***
  - *Influences BF*
  - *Influences BP*

Local blood chemicals (intrinsic factors) influencing blood flow and TPR

- *Major influence on **blood flow control** to individual tissues*
  - *Production rate of local chemicals depend on metabolic rate of the tissues*
- *Also influence TPR*
  - *Some can also be clinically manipulated to influence **TPR and MAP***
    - *Nitric oxide (dilator)*
    - *Endothelin-1 (constrictor)*
    - *PGI_2 (dilator)*
    - *TXA_2 (constrictor)*
    - *CO_2 (dilator)*
    - *O_2 (constrictor)*
    - *Metabolites (mainly dilators)*
    - *Histamine (dilator released during tissue damage)*

Extrinsic factors influencing total peripheral resistance

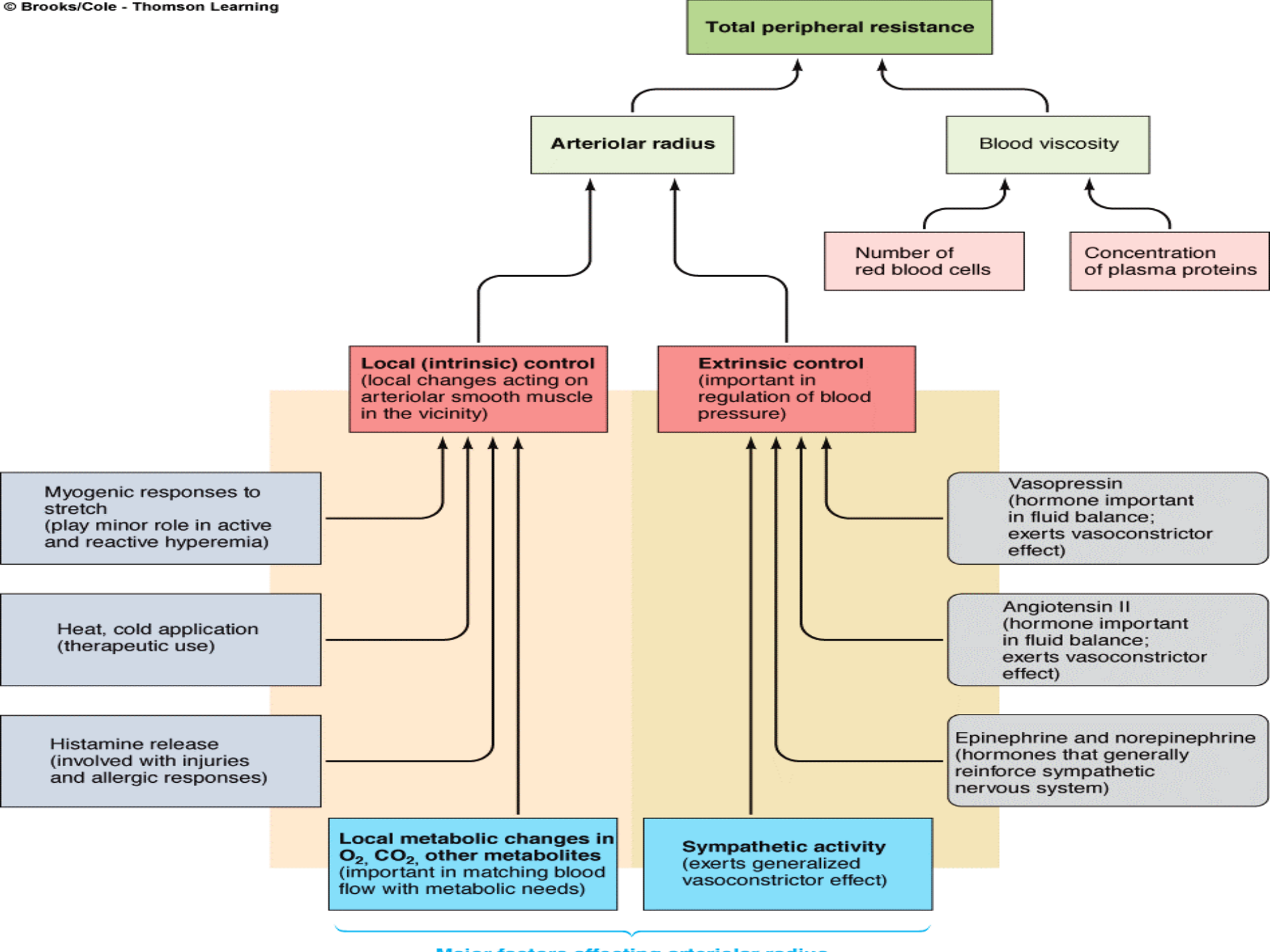
- *Major influence on **MAP***
  - *Radii of **all** arterioles affected to influence total peripheral resistance (TPR) and MAP*
    - ***Sympathetic nervous system***
      - ***Baroreceptor BP control system***



    - ***Hormones***

Hormonal control of arteriolar resistance include

- *Circulating adrenaline and noradrenaline*
  - *Constrict arterioles*
- *Vasopressin (ADH)*
  - *Constricts arterioles*
- *Angiotensin II*
  - *Constricts arterioles*
- *Kinins*
  - *Dilate arterioles*
- *Vasoactive intestinal peptide (VIP)*
  - *Dilates arterioles*
- *Atrial natriuretic peptide (ANP)*
  - *Dilates arterioles*



MANY DRUGS AVAILABLE TO MANIPULATE MAP

- *Aimed at influencing HR, SV, TPR and blood volume in order to decrease BP of hypertensive patients*
- *Details will be dealt with later in the course*

END