CIRCULATION AND PRESSURE FLOW DYNAMICS

F Bukachi

MBChB, MMed, MSc, DIC, PhD

Physician/Cardiologist

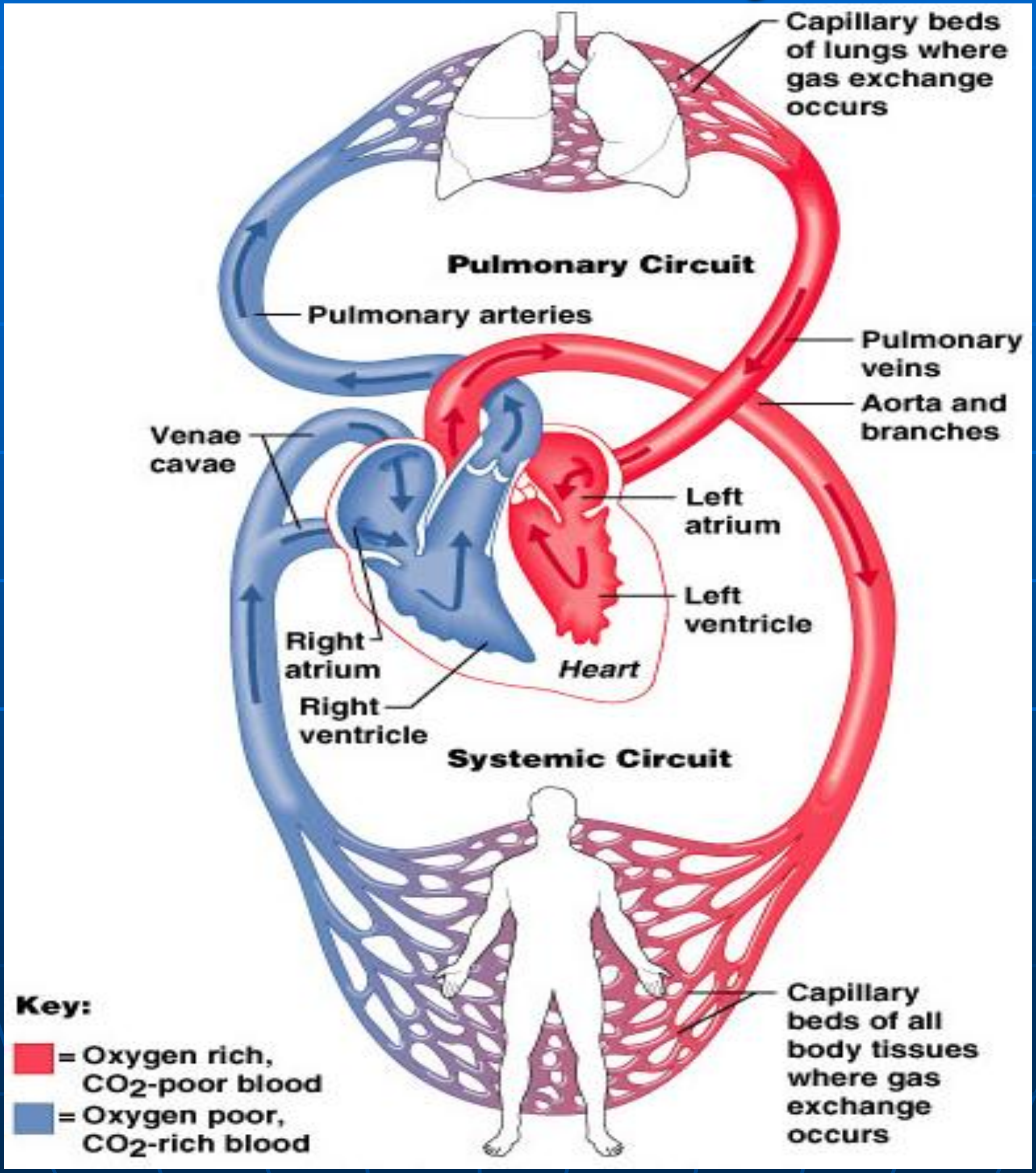
Department of Medical Physiology, University of Nairobi, Kenya

Objectives

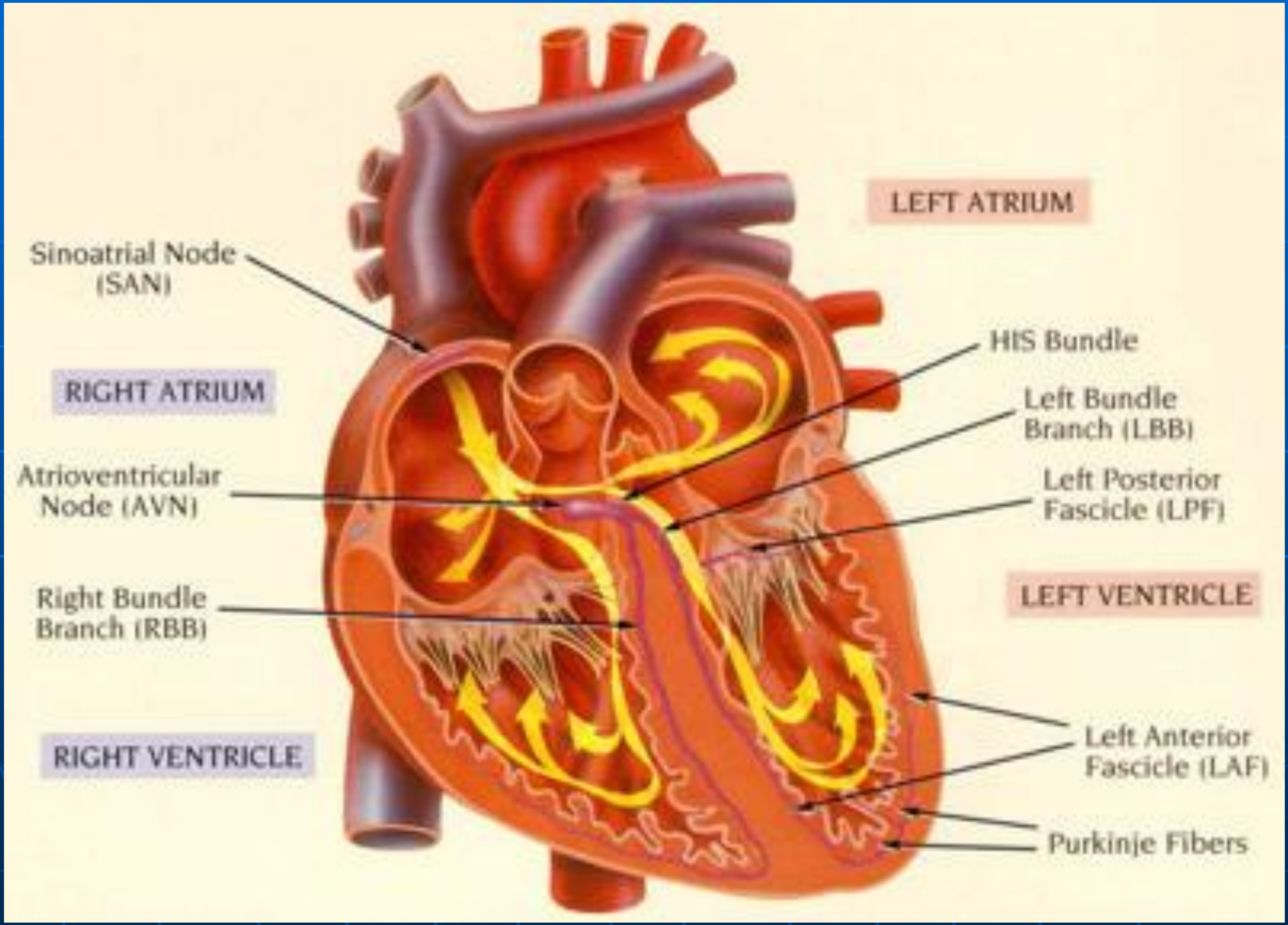
To understand:

- General organization of the circulatory system
- Cardiac structure and Function
- Concepts: Pressure, Flow and Resistance
- BP: Measurement, Factors influencing
- Conclusions

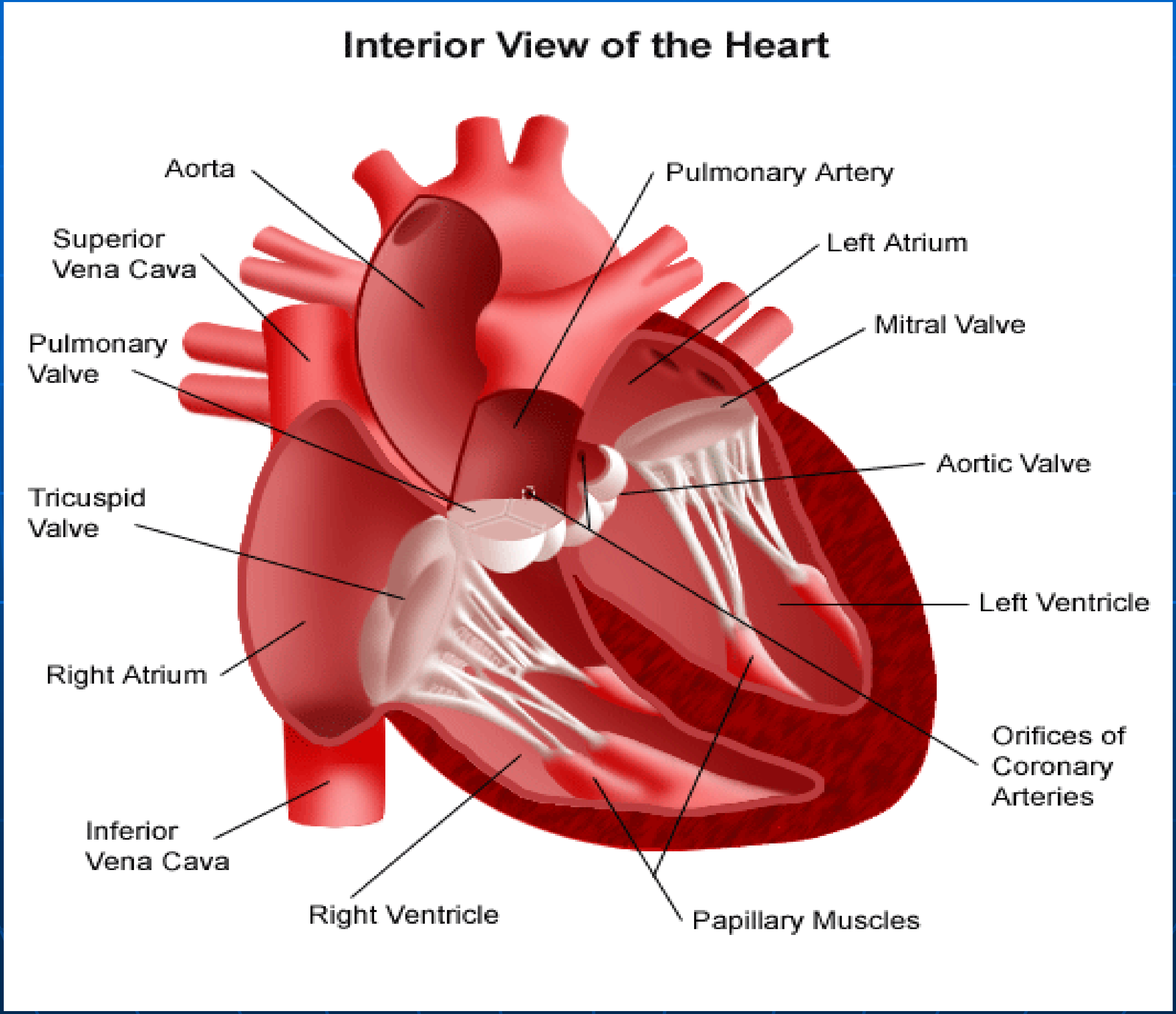
Review of CV System

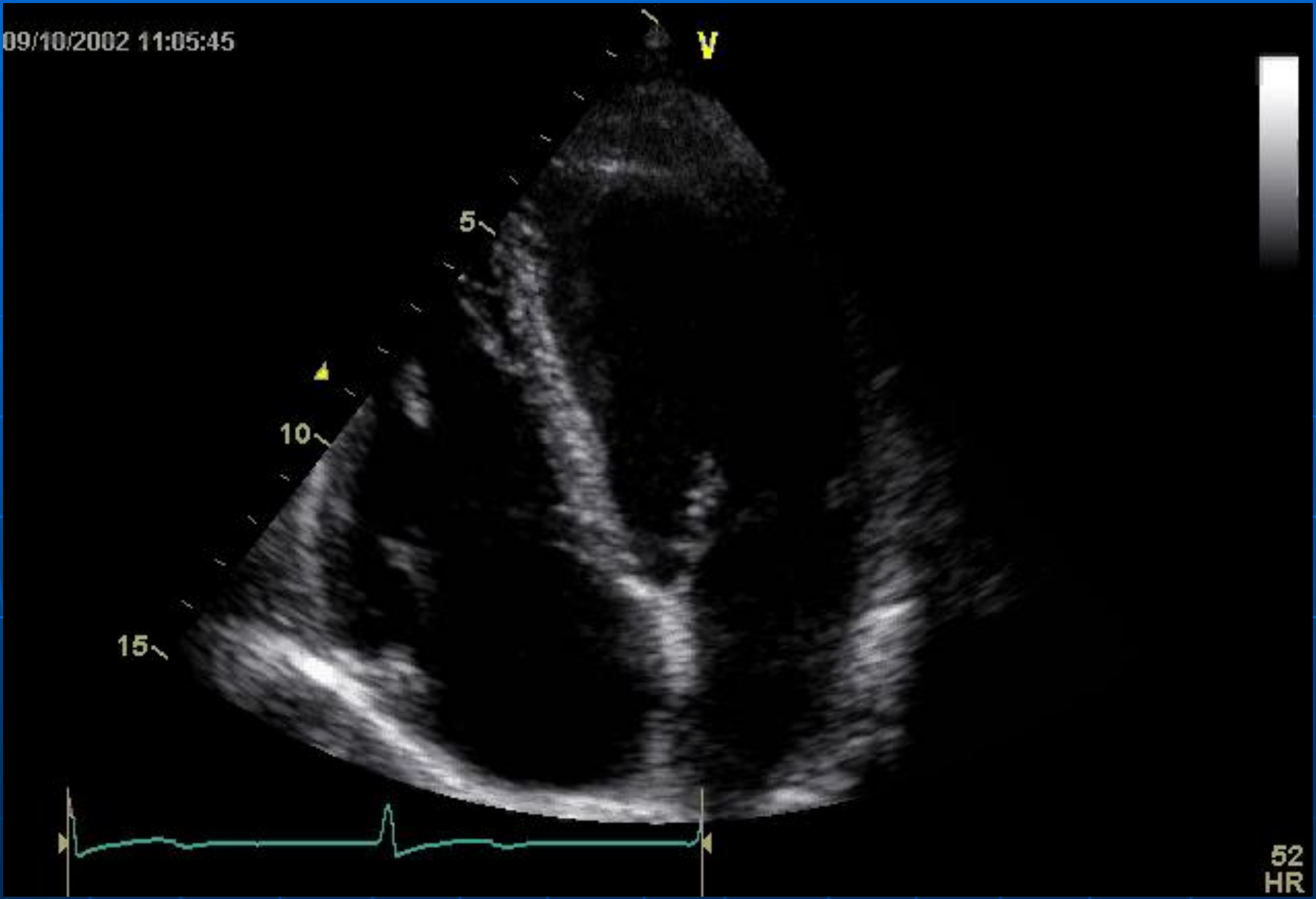


The Heart: Internal Structure I

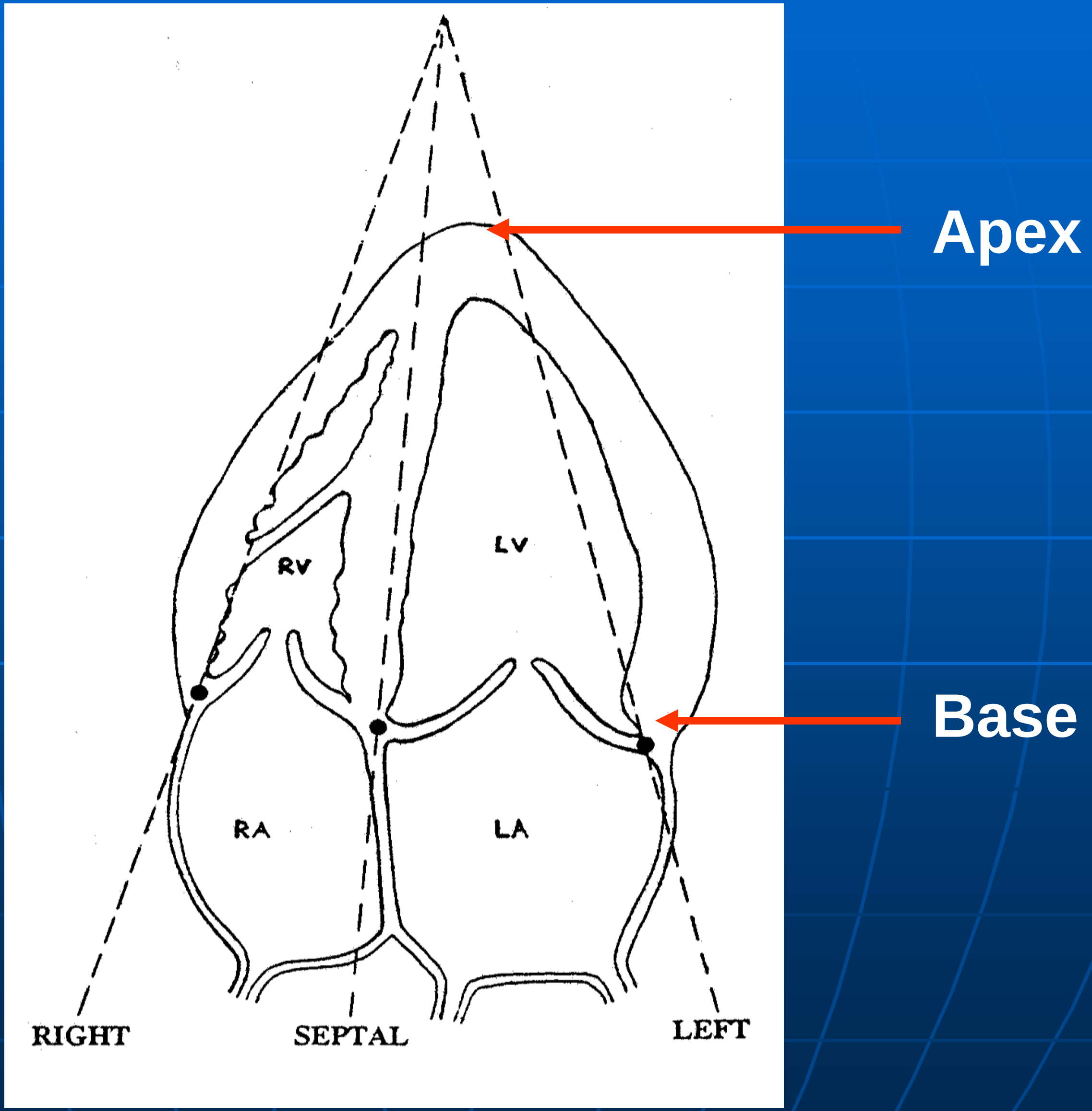


The Heart: Internal Structure II




09/10/2002 11:05:45
V
5
10
15
52
HR

Four-chamber view: cursor at AV ring



Blood Pressure, Flow and Resistance

Pressure, Resistance and Flow

- <u>BLOOD FLOW</u>

$$F = \Delta P / R = (P_1 - P_2) / R$$

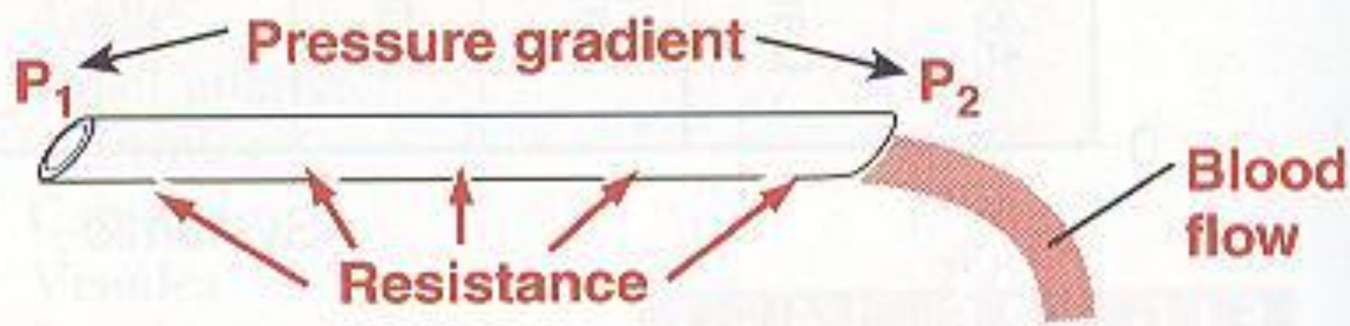


FIGURE 14-3

Relations among pressure, resistance, and blood flow.

Flow Dynamics I

DEFINITIONS:

Cardiac Output (CO) = Amount of blood ejected by each ventricle per minute

Stroke volume (SV) = Amount of blood ejected by each ventricle per beat

Preload = Venous return

Afterload = Resistance OR Total Peripheral Resistance (TPR)

Flow Dynamics I

Applied to systemic circulation:

Flow = Cardiac Output (CO),
Driving Pressure = [mean arterial pressure (Pa) – central venous pressure (CVP)],
Resistance = Total Peripheral Resistance (TPR)

Thus, CO = $\frac{(Pa-CVP)}{TPR}$

Since CVP ≈ 0, CO = Pa/TPR or $P_a = CO \times TPR$

Homework: Read about Bernoulli theory and law

Flow of Blood in Vessels

- Three flow patterns recognised:
  - Laminar
  - Turbulent
  - Single-file
- Laminar flow – silent and occurs in:
  - ✓ Normal arteries
  - ✓ arterioles
  - ✓ Venules and veins
  - ➢ Silent up to a ‘critical pressure’ above which, it becomes turbulent.
- Turbulent flow –noisy, occurs in the ventricles
- Normal Single-file - occurs in capillaries

Blood flow patterns in a large vessel and capillary

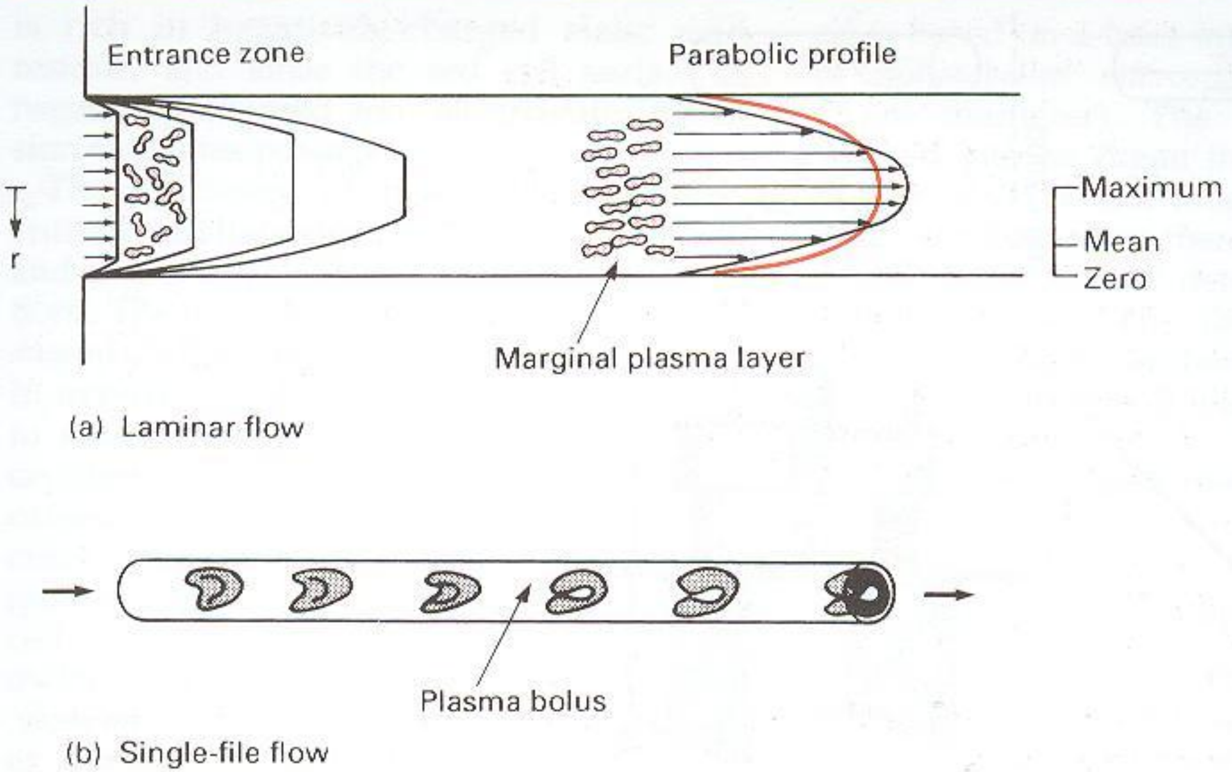


Figure 8.2 Blood flow patterns in a large vessel (a) and capillary (b). In (a), arrow velocity (v) of each lamina. For a Newtonian fluid in fully-developed laminar flow, v function of radial position (r): $v = v_{max}(1 - r^2/R^2)$ where R is tube radius. Mean ve profile is blunter for a non-Newtonian fluid like blood (red line). The gradient of t called the 'shear rate'. (b) In capillaries the red cells deform into parachute/slipper and folded shapes (right). (After Chien, S., Usami, S. and Skalak, R. (1984) see Furtl

Measurement of Blood Flow

- Electromagnetic flow meter
- Doppler flow meters
- Indirect methods:
  - Fick’s principle
  - PAH (Para Amino Hippuric Acid)
- Venous occlusion plethysmography
- Kety’s tissue clearance method

- Homework!: read more about these methods

Heamodynamics in the arteries I

Definitions:

- Capacitance vessels – veins – hold a large amount of blood ≈ 50% of circulating volume
- Resistance vessels – small arteries and arterioles – principal site of peripheral resistance
- "High pressure system" – arterial system
- "Low pressure system" - systemic veins, pulmonary circulation, and heart chambers except Left Ventricle.

Heamodynamics in the arteries II

Waveform of the arterial pressure pulse

- Arterial pressure oscillates or fluctuates (see figure) due to:

- volume and speed of ventricular ejection
- rate of runoff through resistance vessels
- arterial wall distensibility

- Pulsatile flow – not well understood – but maintains optima function of tissues

Pressure waveform in large artery

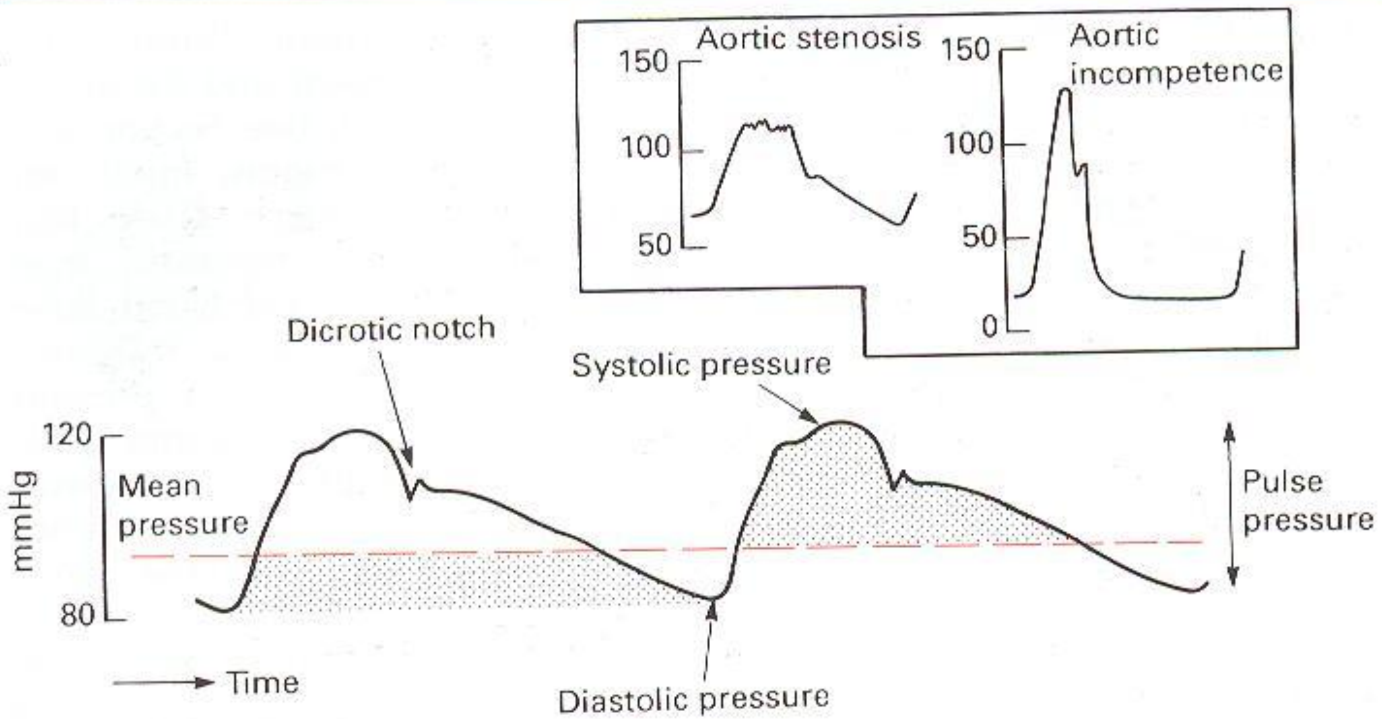


Figure 8.6 Pressure wave in human subclavian artery over two cycles recorded by an electronic pressure transducer. The mean pressure, averaged over time, is the pressure at which the area above the mean (grey area, $\int P \, dt$) equals the area below the mean. Inset shows abnormal waveform in aortic valve stenosis (slow rise, prolonged plateau) and aortic incompetence (excessive pulse pressure, low diastolic pressure) (After Mills, C. J., Gale, I. T., Gault, J. H. *et al.* (1970) *Cardiovascular Research*, **4**, 405, omitting variable minor waves on the descending limb caused by reflections)

Pressure waveform in large artery II

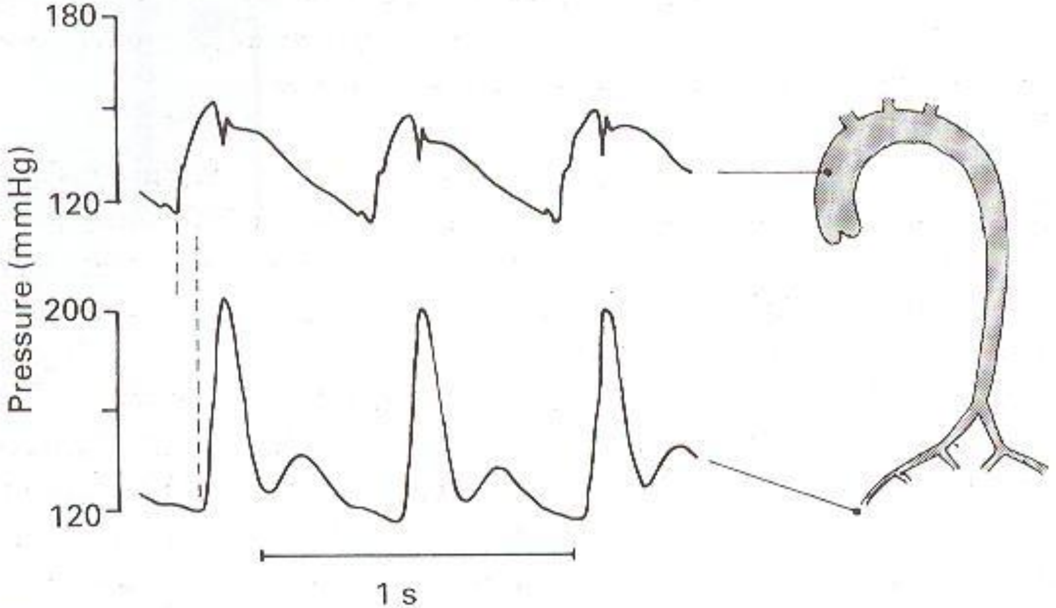


Figure 8.11 Simultaneous records of the pressure-wave in the canine ascending aorta and femoral artery. The dashed lines show the time required to propagate the pulse, namely 86 ms foot-to-foot. (From Noble M. I. M. (1979) *The Cardiac Cycle*, Blackwell, Oxford, by permission)

Heamodynamics in the arteries III

- Mean arterial pressure = P_a

 - not arithmetic average of Systolic and diastolic pressures

 - blood pressure spends relatively more time near Diastolic BP

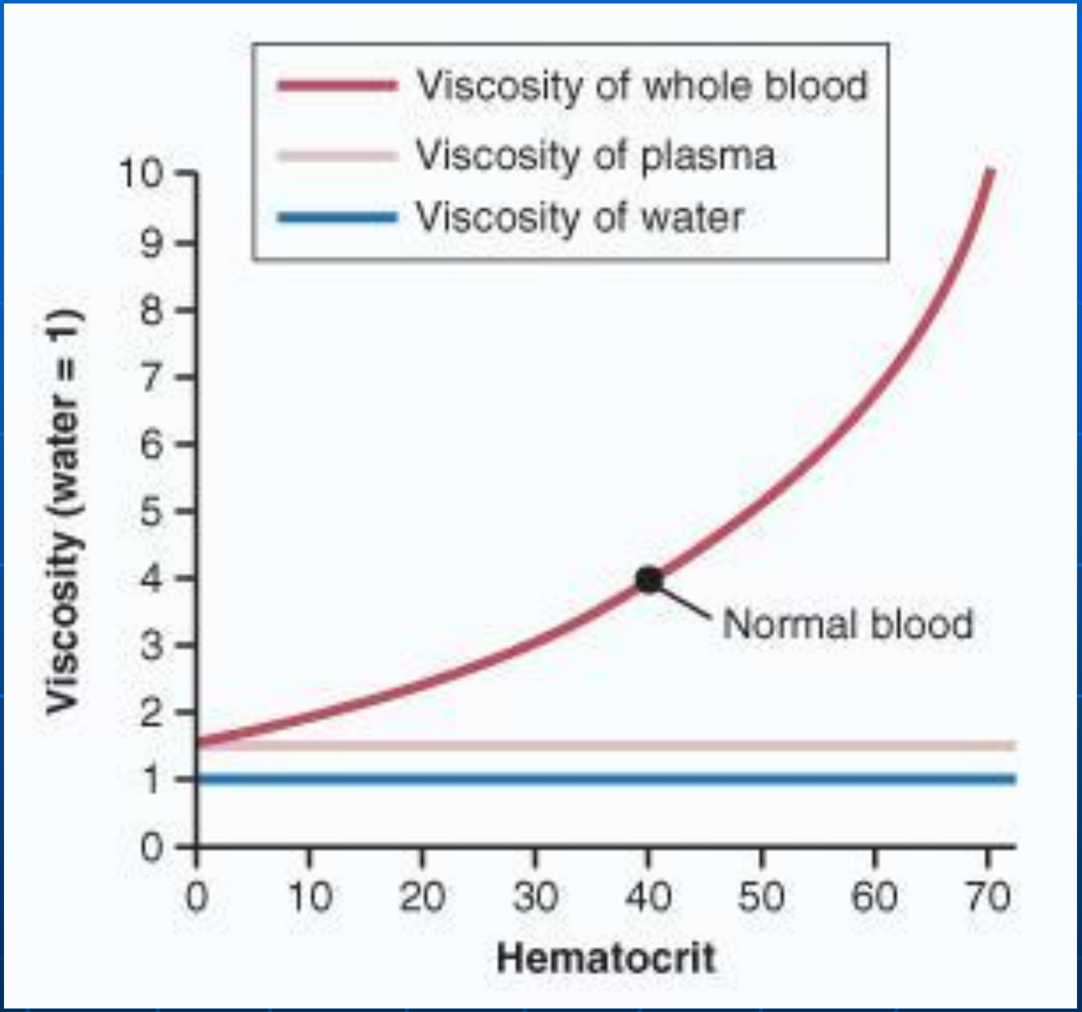
Thus, $P_a = P_{diast} + (P_{sys} - P_{diast})/3$

- Pulse pressure = $(P_{sys} - P_{diast})$ depends on Arterial compliance, stroke volume, ejection rate, and runoff

Viscosity AND blood flow

↑viscosity→↓blood flow

- The large numbers of suspended red cells make the viscosity of normal blood three times as great as the viscosity of blood.
- Viscosity of blood increases drastically as the haematocrit increases as in polycythemia



Normal BP in the circulatory system

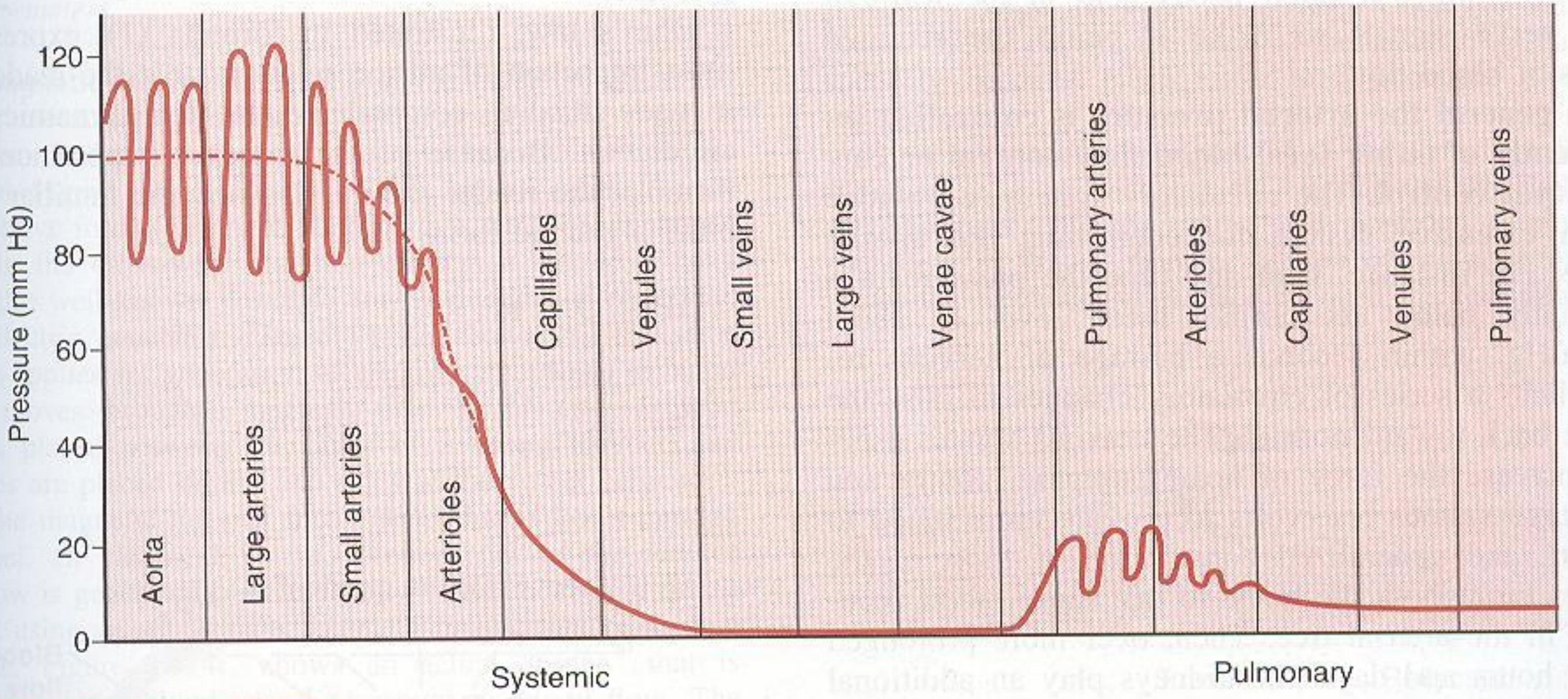


FIGURE 14–2

Normal blood pressures in the different portions of the circulatory system when a person is lying in the horizontal position.

Measurement of arterial pressure

Measurement of arterial pressure I

- Direct methods – first methods to be used in the measurement of BP
- Indirect methods (see fig)

- Syphygmomanometry – mercury manometer (read about the principle)
- Riva-Rocci cuff over brachial artery
- Cuff inflated to obliterate the radial pulse
- following sequence of sounds heard:

Measurement of blood pressure

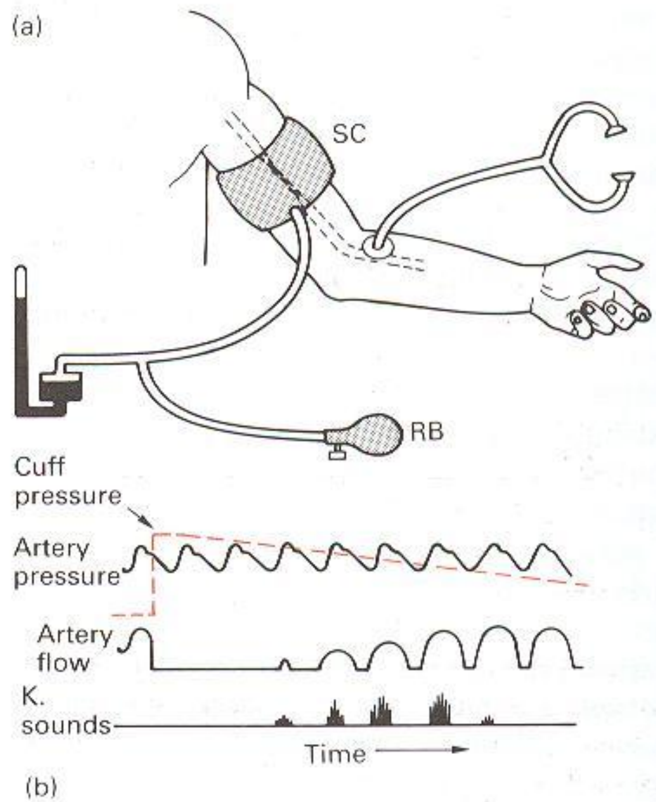


Figure 8.7 Measurement of human blood pressure. (a) Dashed line represents compressed brachial artery under the sphygmomanometer cuff (SC). Cuff pressure is controlled by the rubber bulb (RB) and measured by the mercury column. (b) Korotkoff sounds begin when cuff pressure is just below systolic pressure and diminish when cuff pressure is close to diastolic pressure

Measurement of arterial pressure II

- At cuff-pressure just below systolic pressure – artery opens briefly during each systole – transient spurt of blood vibrates the artery wall downstream---- tapping noise called a Koroktoff sound (approximates SBP – though it's 10mmHg less!)
- Koroktoff sounds become louder as the cuff pressure is lowered (Phases I- V)
- Cuff pressure close to DBP the sounds disappear – vessel is patent - (approximates SBP – though it's 8 mmHg higher!)
- Digital automated cuffs are now available.

Blood Pressure

- What is normal blood pressure?
- Pressure is labile over 24 hour period (see fig)
- Measured in mmHg - or kPa (SI units)
- 1 mmHg = 0.133 kPa

Blood Pressure: 24 hour period

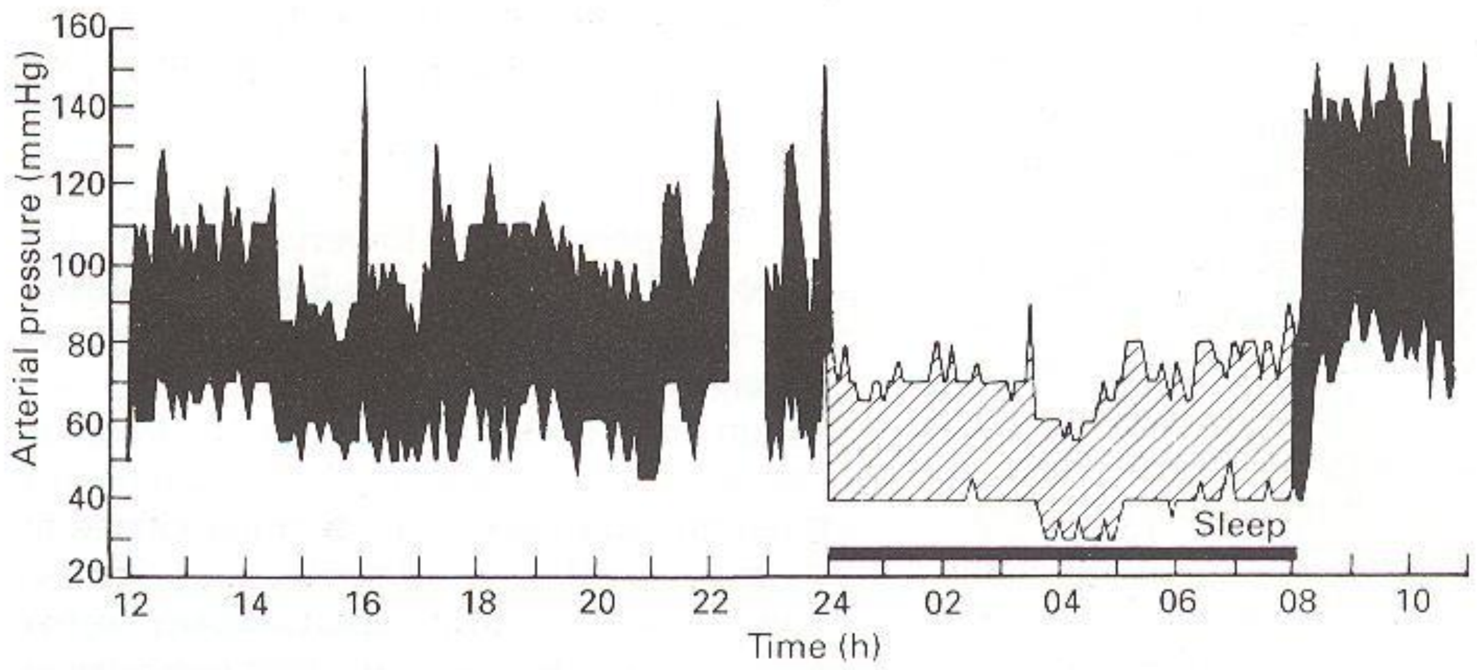


Figure 8.8 Arterial pressure in a normal subject recorded continuously for 24 h. Sleep (hatched period) lowered the pressure. A painful stimulus at 16.00 h and sexual intercourse at 24.00 h markedly raised pressure. (From Bevan, A. T., Honour A. J. and Stott, F. H. (1969) *Clinical Science*, **36**, 329, by permission)

Blood Pressure – factors affecting

1. Age – increases with age; pulse pressure also increases
2. Sleep – pressure falls - can fall below 80/50 mmHg
3. Gravity: direct and indirect effects
4. Emotion and stress
5. Other factors – respiration, Valsava manoeuvre, pregnancy, full bladder

BP in different parts of the circulatory system

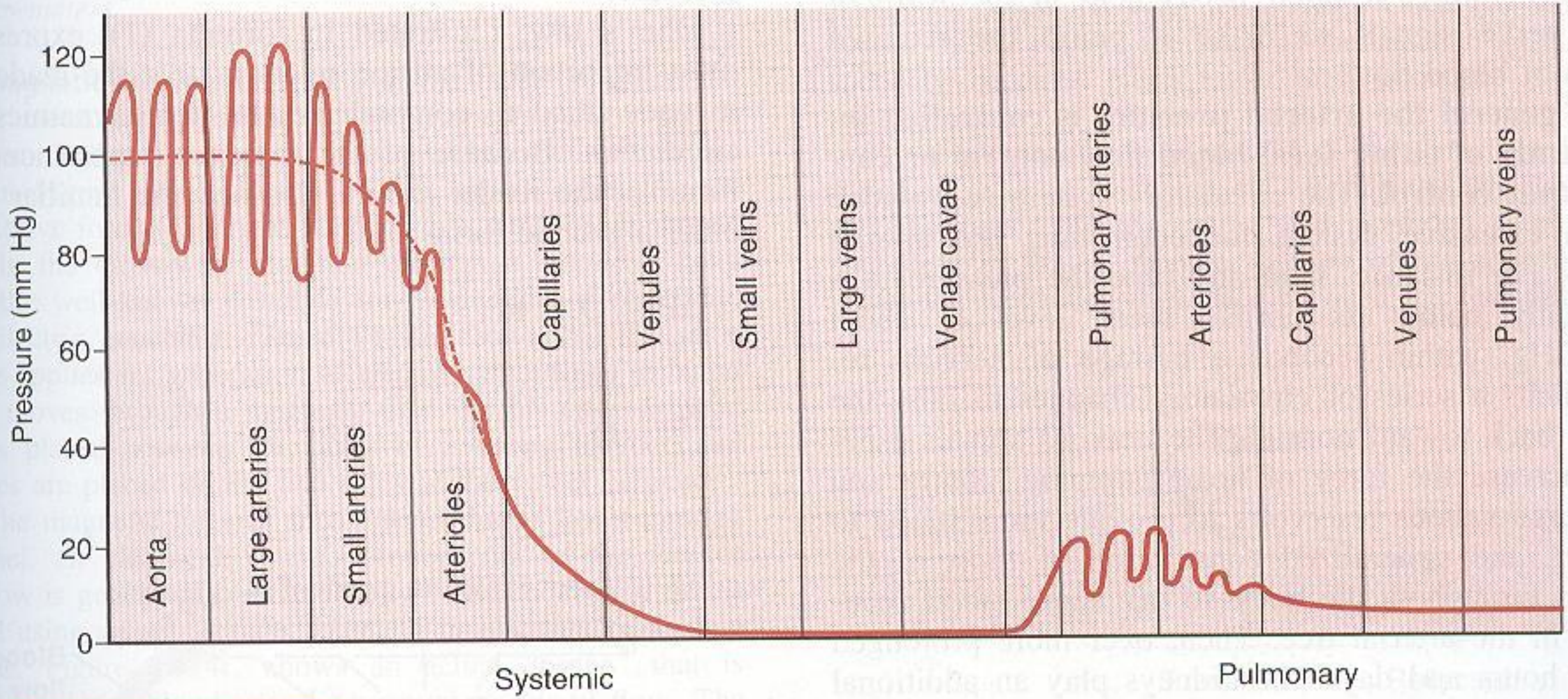
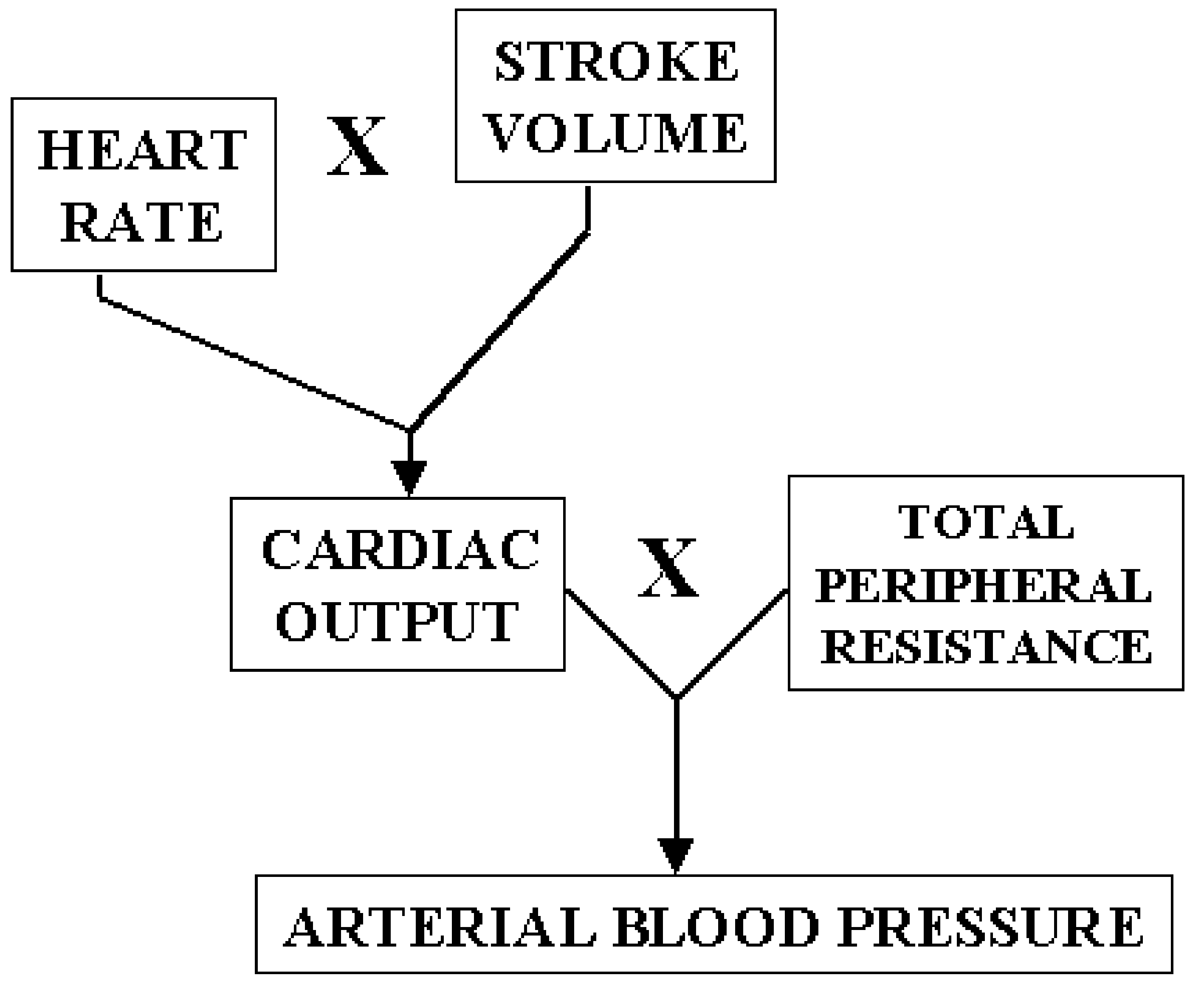


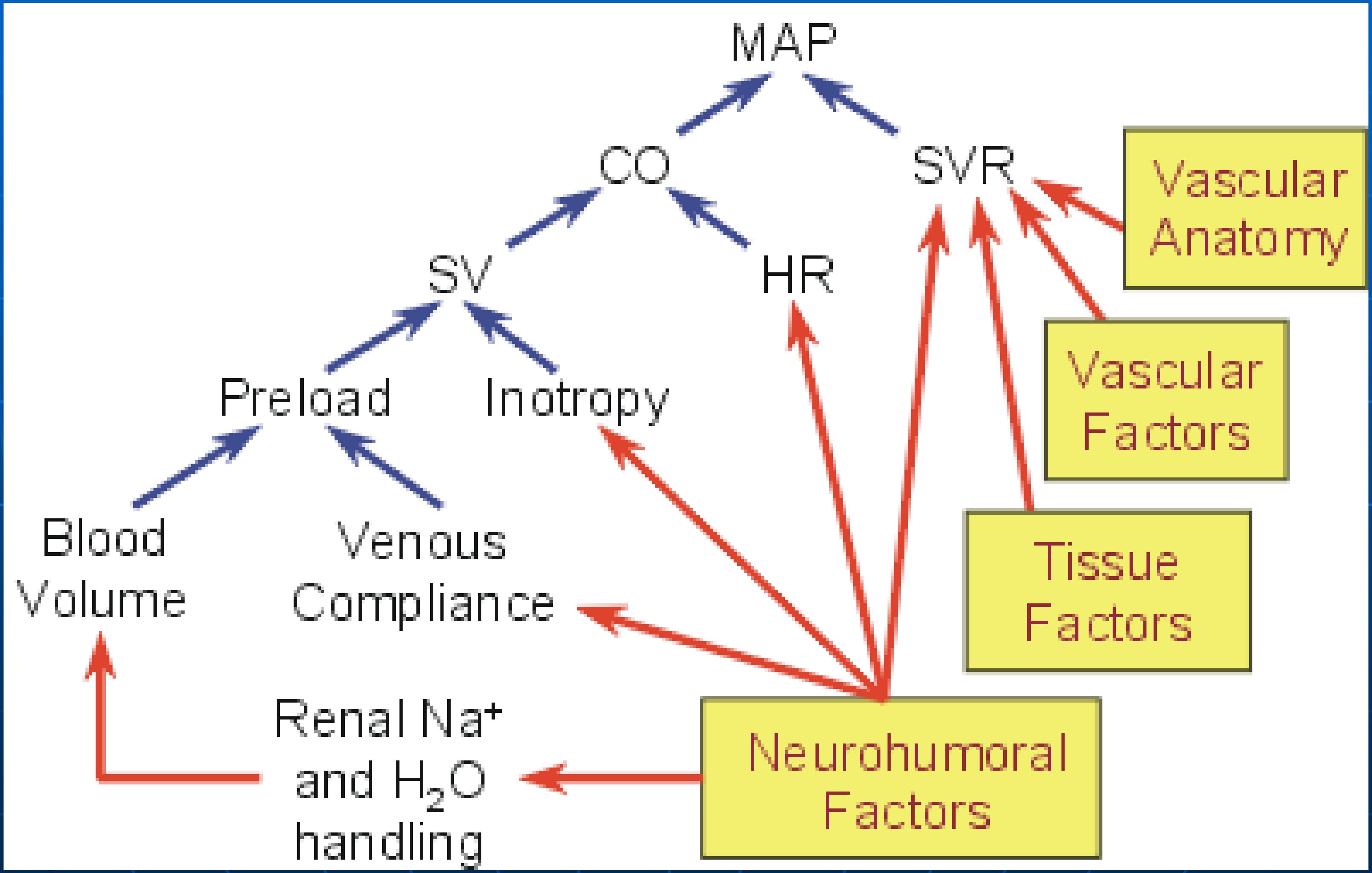
FIGURE 14-2

Normal blood pressures in the different portions of the circulatory system when a person is lying in the horizontal position.

Factors influencing arterial blood pressure I



Factors influencing arterial blood pressure II



Vascular Resistance

Homework! – Read about Poiseuille's and Laplace's laws

Laplace's laws: outline

- Blood vessels are distensible, thus
- Width of a given vessel depends on
- (i) blood pressure (which tends to distend it)
- (ii) surrounding pressure (which tends to compress it)
- (iii) tension in the wall (which counterbalances the pressure drop across the wall)