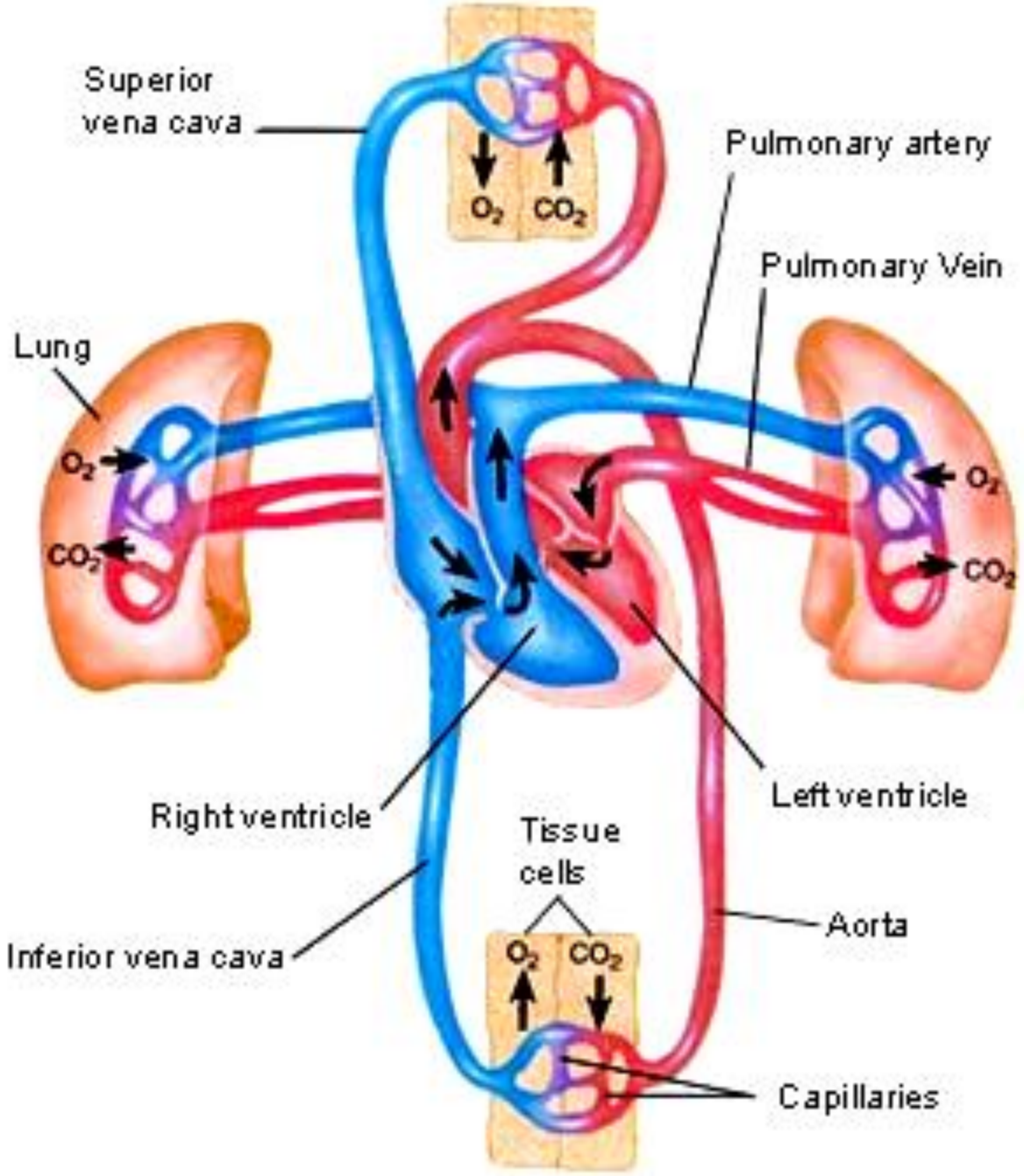
CHAPTER THREE-TRANSPORT

-- The Human Heart

OVERVIEW OF THE CARDIOVASCULAR SYSTEM

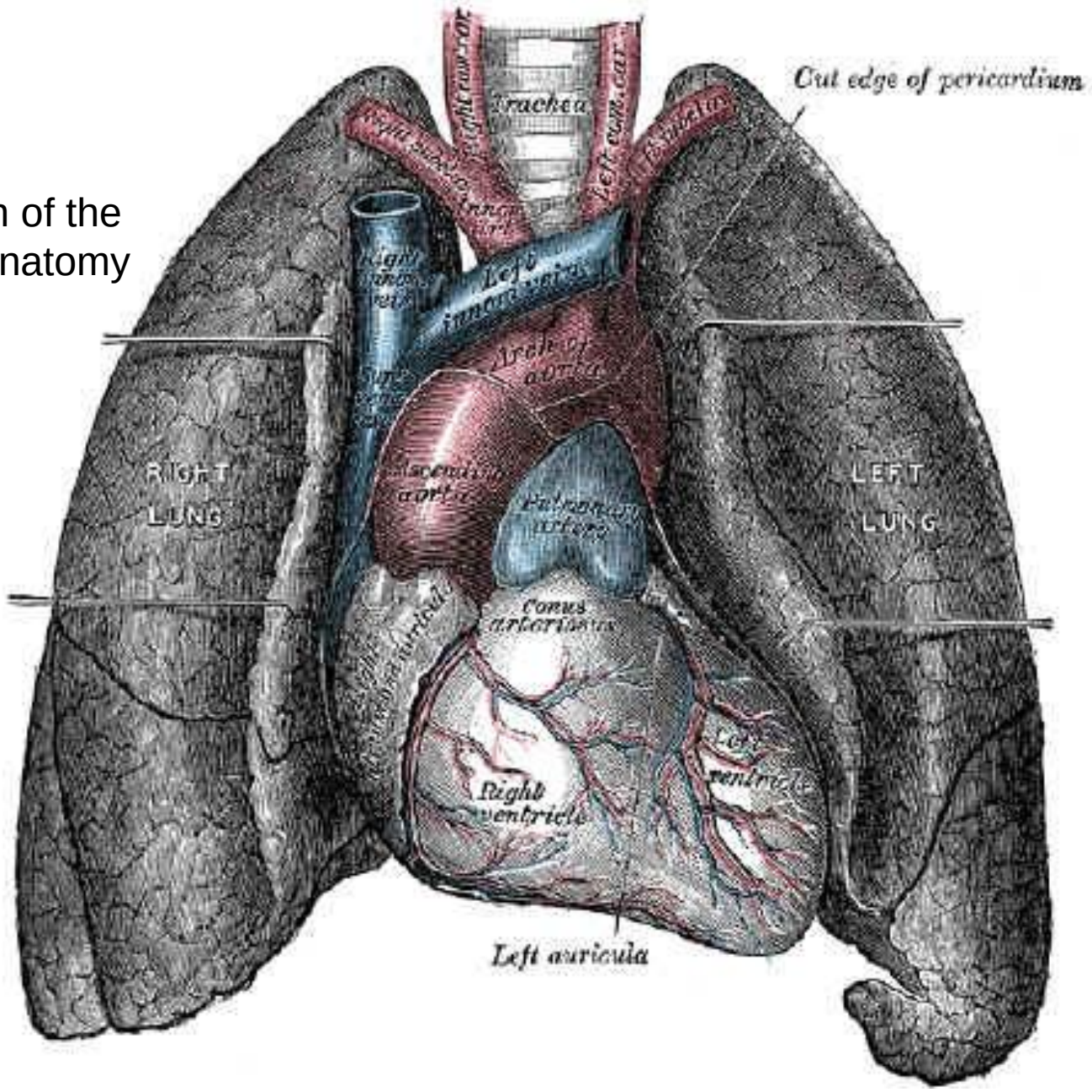
- Pulmonary circuit
- Systemic circuit
- Arteries (Including the coronary arteries)
- Veins (Including the coronary veins)
- Capillaries (Arterioles & Venules)
- Four chambers of the heart


Superior vena cava
O_2
CO_2
Pulmonary artery
Pulmonary Vein
Lung
O_2
CO_2
O_2
CO_2
Right ventricle
Left ventricle
Tissue cells
Inferior vena cava
Aorta
O_2
CO_2
Capillaries

HEART POSITIONING

- Located near the anterior chest wall
- Posterior to the sternum
- Lies slightly to the left of the midline
- Sits at an angle
- Rotated toward the left side

Anatomical position of the heart from Grays Anatomy



Pericardial Cavity

- Anterior cavity of the mediastinum
- Separates the two pleural cavities
- Contains the thymus, esophagus & the trachea

Pericardium

- Pericardial cavity is lined by the *pericardium*.
- Visceral pericardium (epicardium) covers the hearts outer surface.
- Parietal pericardium lines the inner surface of the pericardial sac that surrounds the heart.
- Pericardial fluid acts as a lubricant reducing friction.

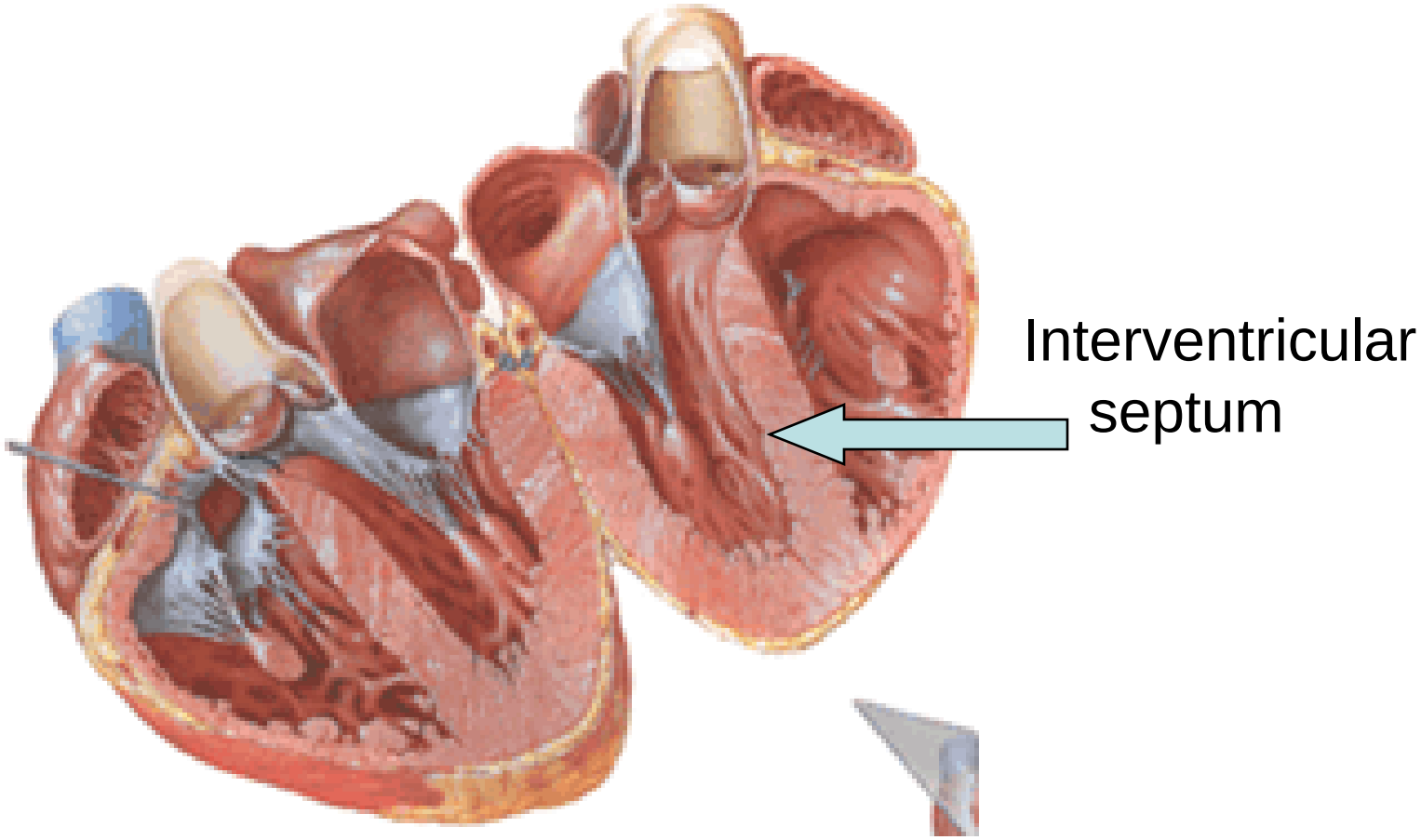
The clear tissue being
Lifted up by the scalpel
Is the pericardium

Pericarditis

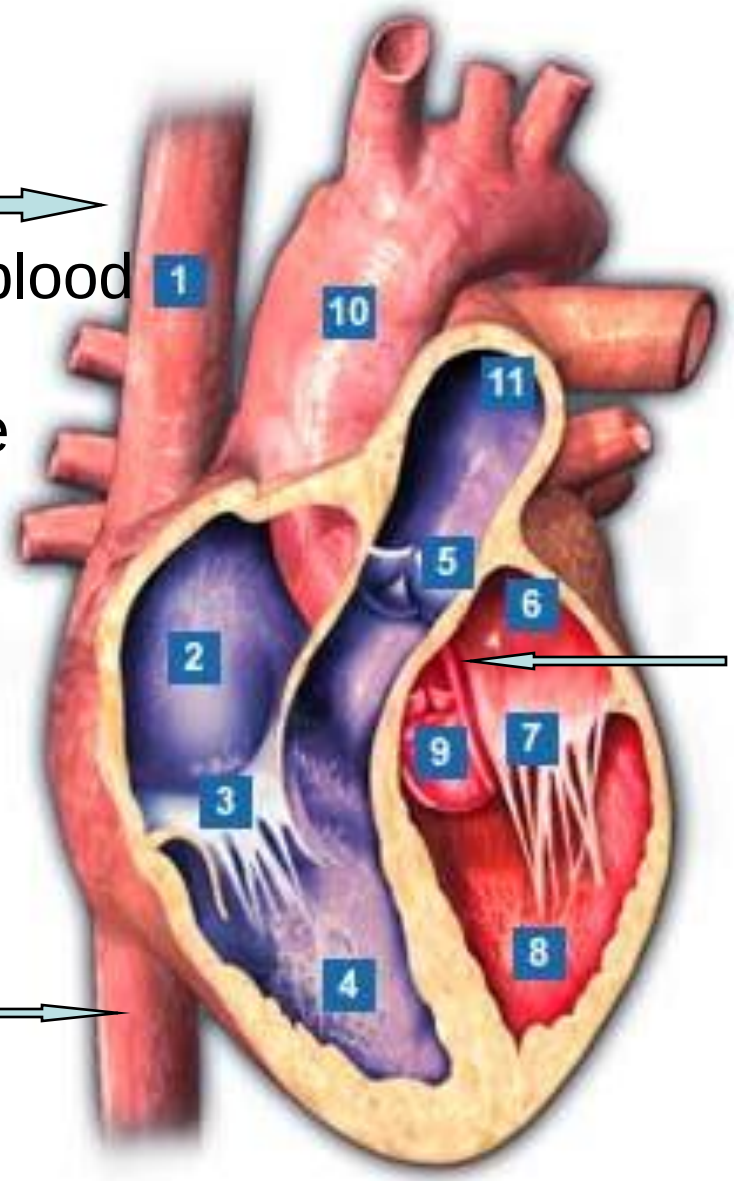
- Various pathogens may infect the pericardium.
- The inflamed pericardial surfaces rub against one another.
- Makes a distinct scratching sound.
- Cardiac tamponade could occur due to the increased pericardial fluid in the pericardial cavity. This condition restricts the movement of the heart.

Black looking structure is the heart bulging from the pericardial sac. Not only pathogens can cause a cardiac tamponade, but blunt force trauma can also cause it.

Cardiac tamponade


Interventricular
septum

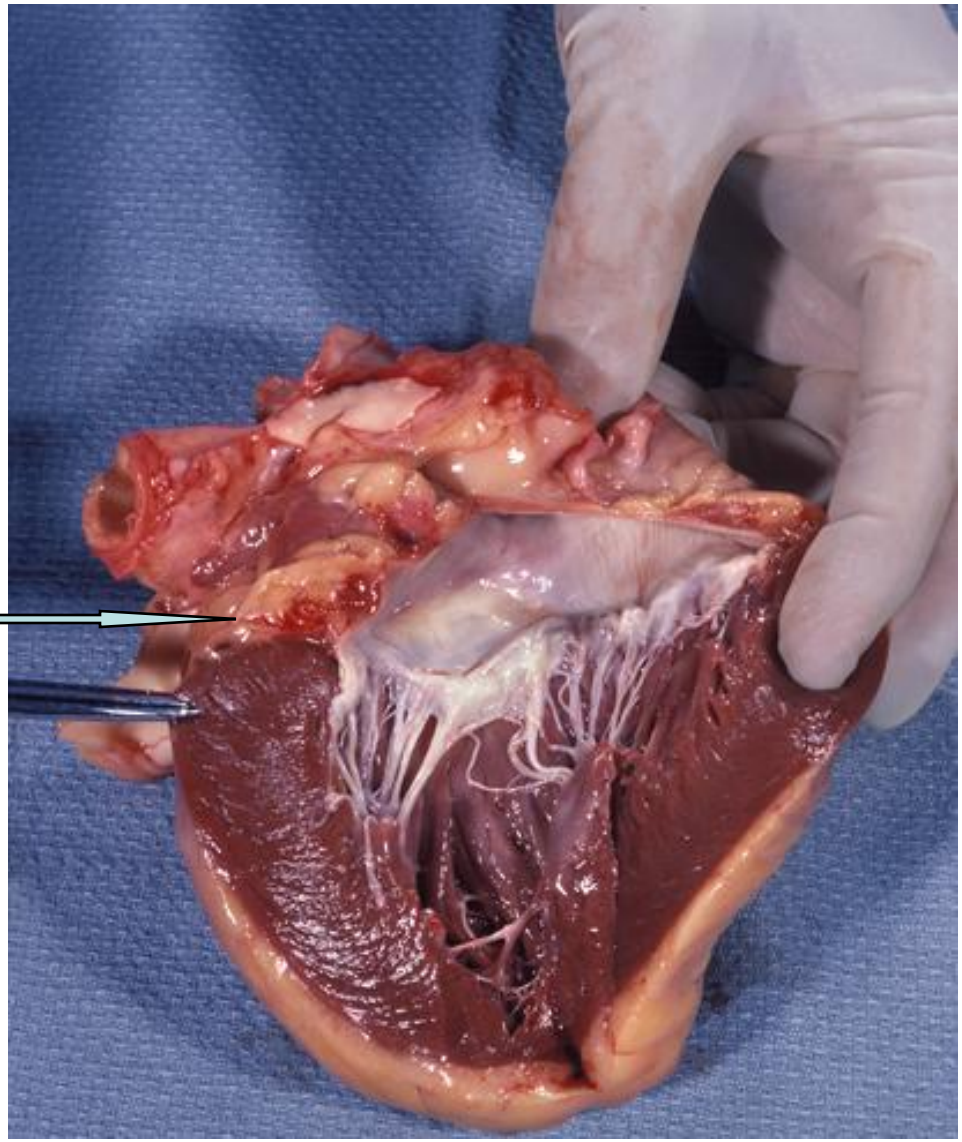
Superior Vena Cava. Brings blood from the head, neck and shoulders to the right atrium



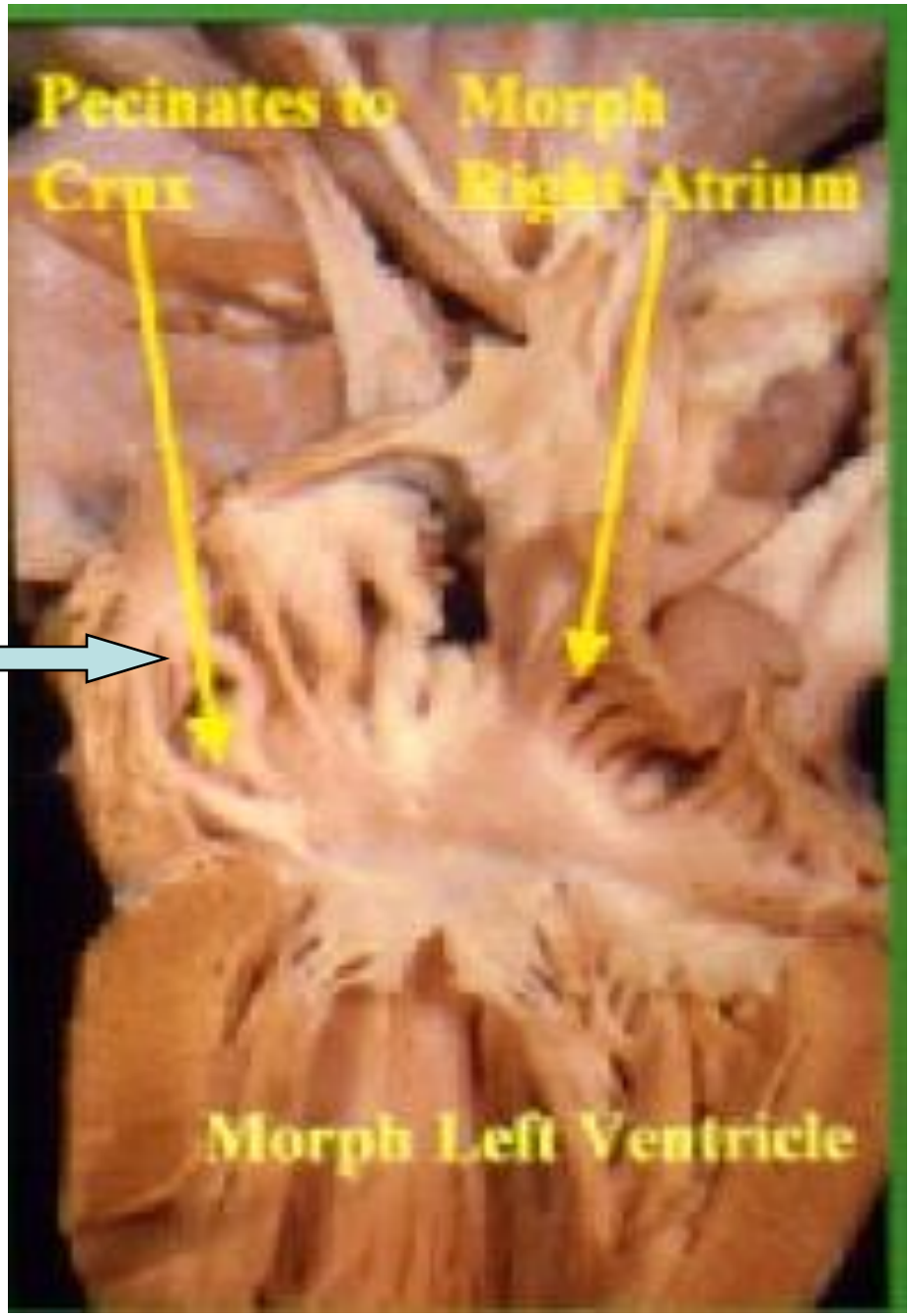
Interatrial septum

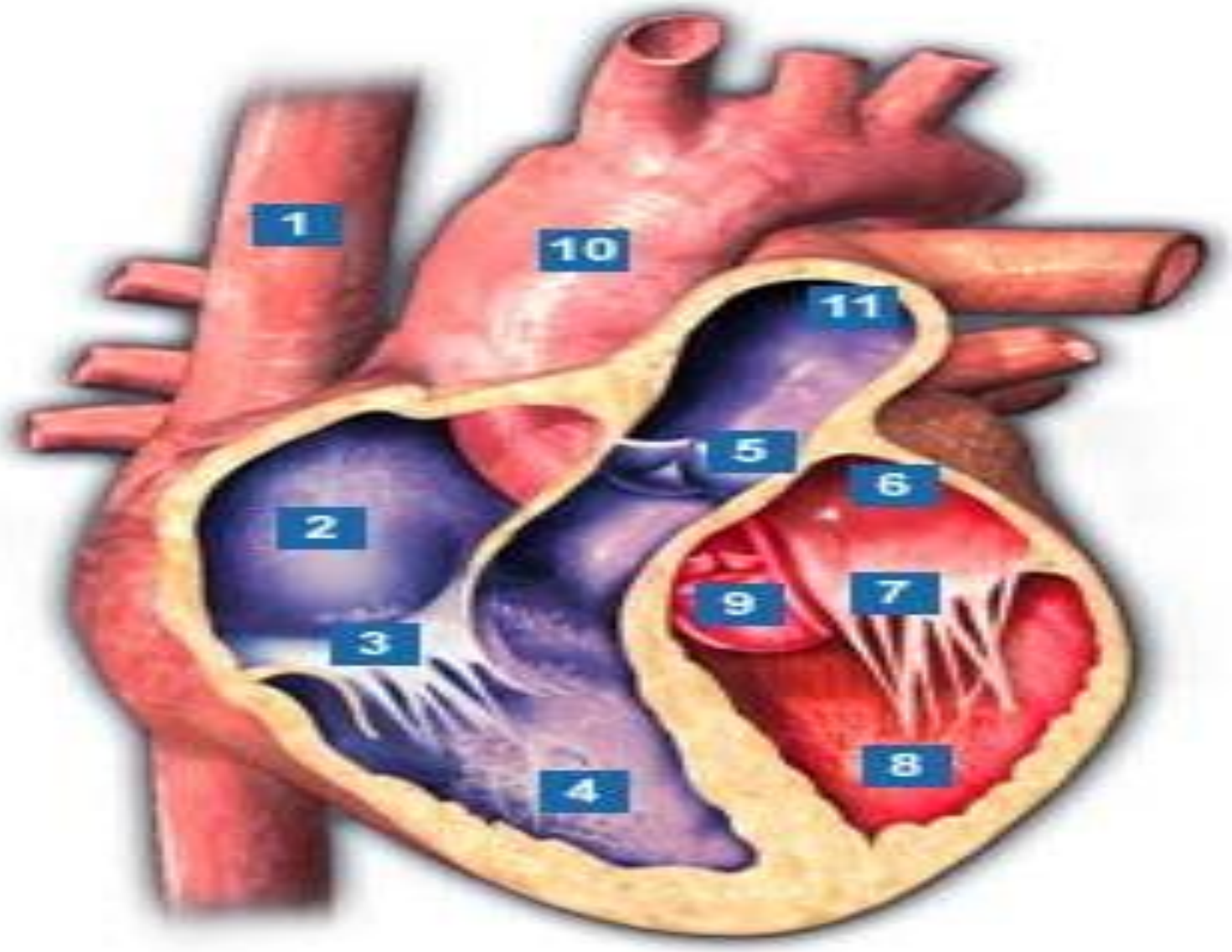
Inferior Vena Cava Brings blood back to the right atrium from the rest of the body

Interatrial Septum. Lateral view



The pectinate muscles are prominent muscular ridges found in the atrial walls

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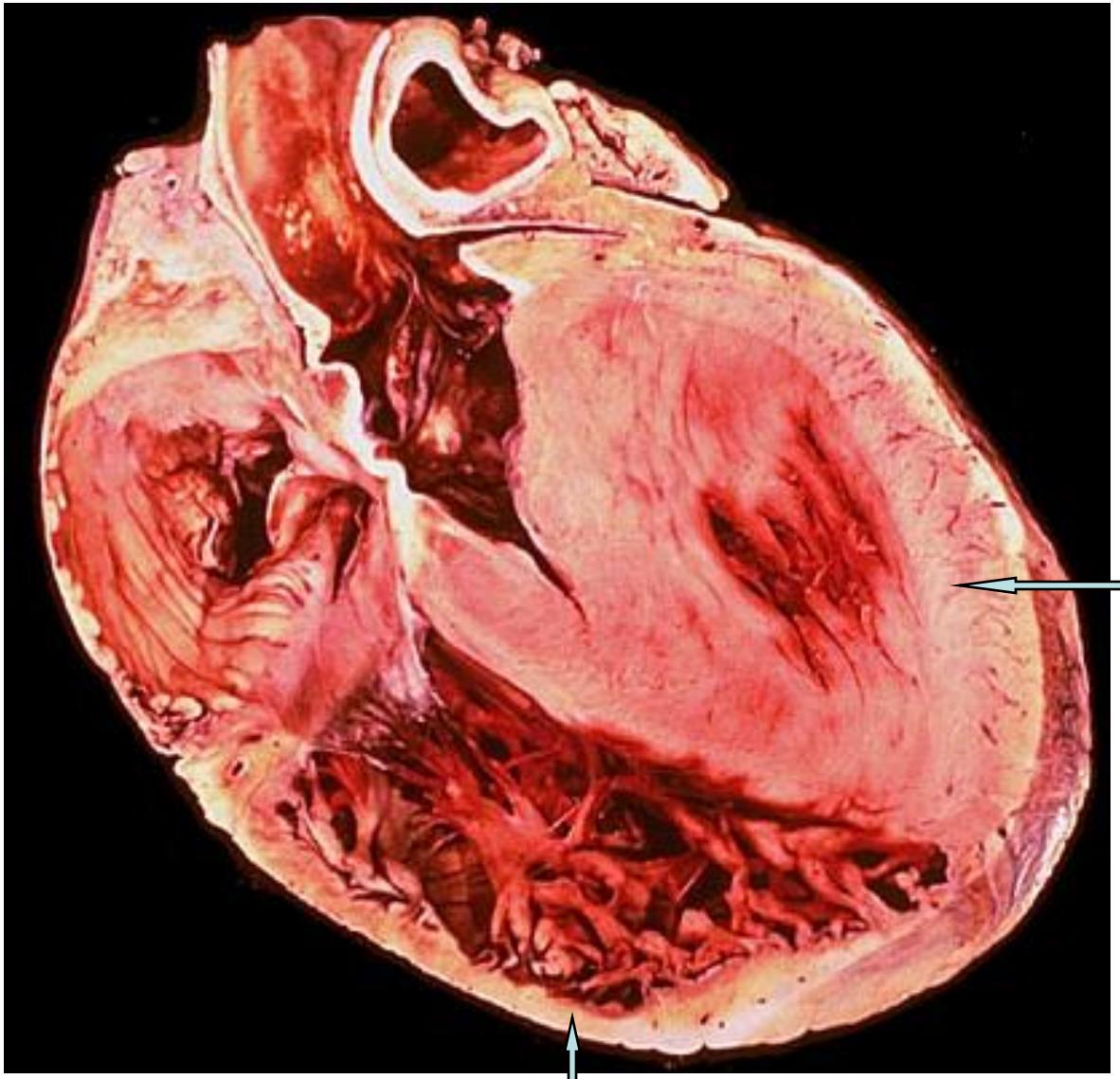
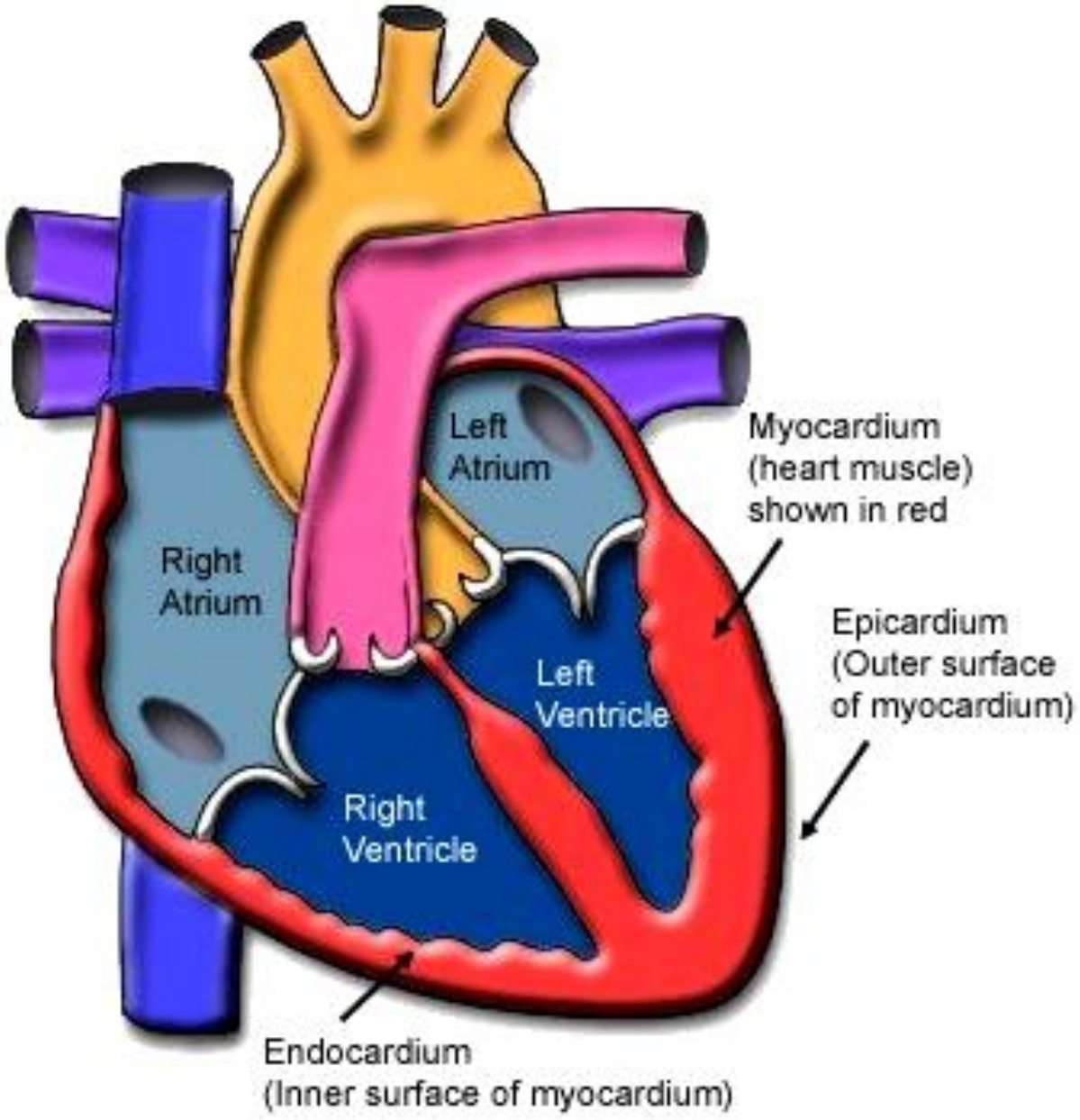


Left Ventricle Heart Wall

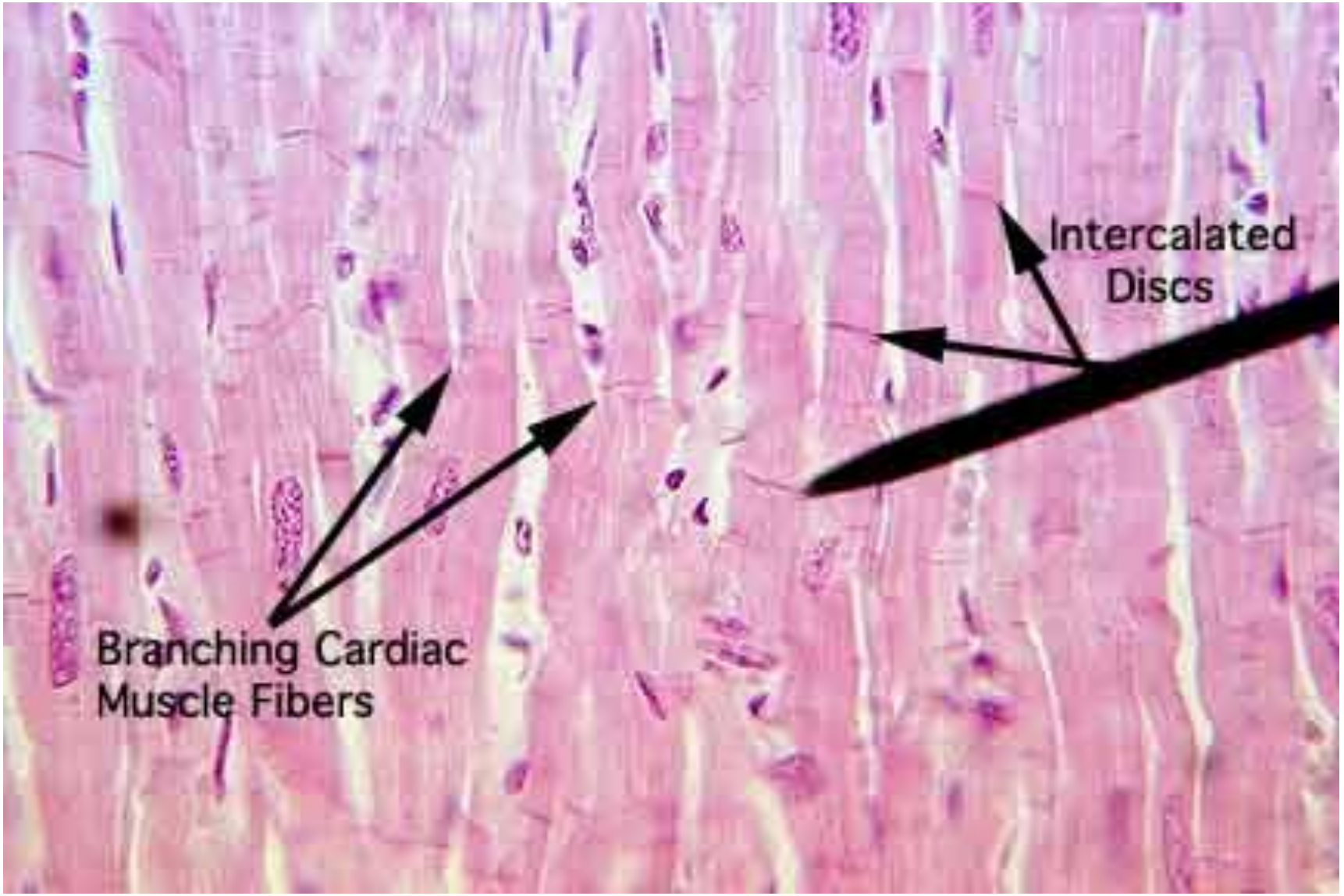
Right Ventricle Heart Wall

The Heart Wall

- Bulk of the heart consists of the muscular myocardium and endocardium, that covers the inner surface of the heart.
- The epicardium is the visceral pericardium that covers the outer surface of the heart.

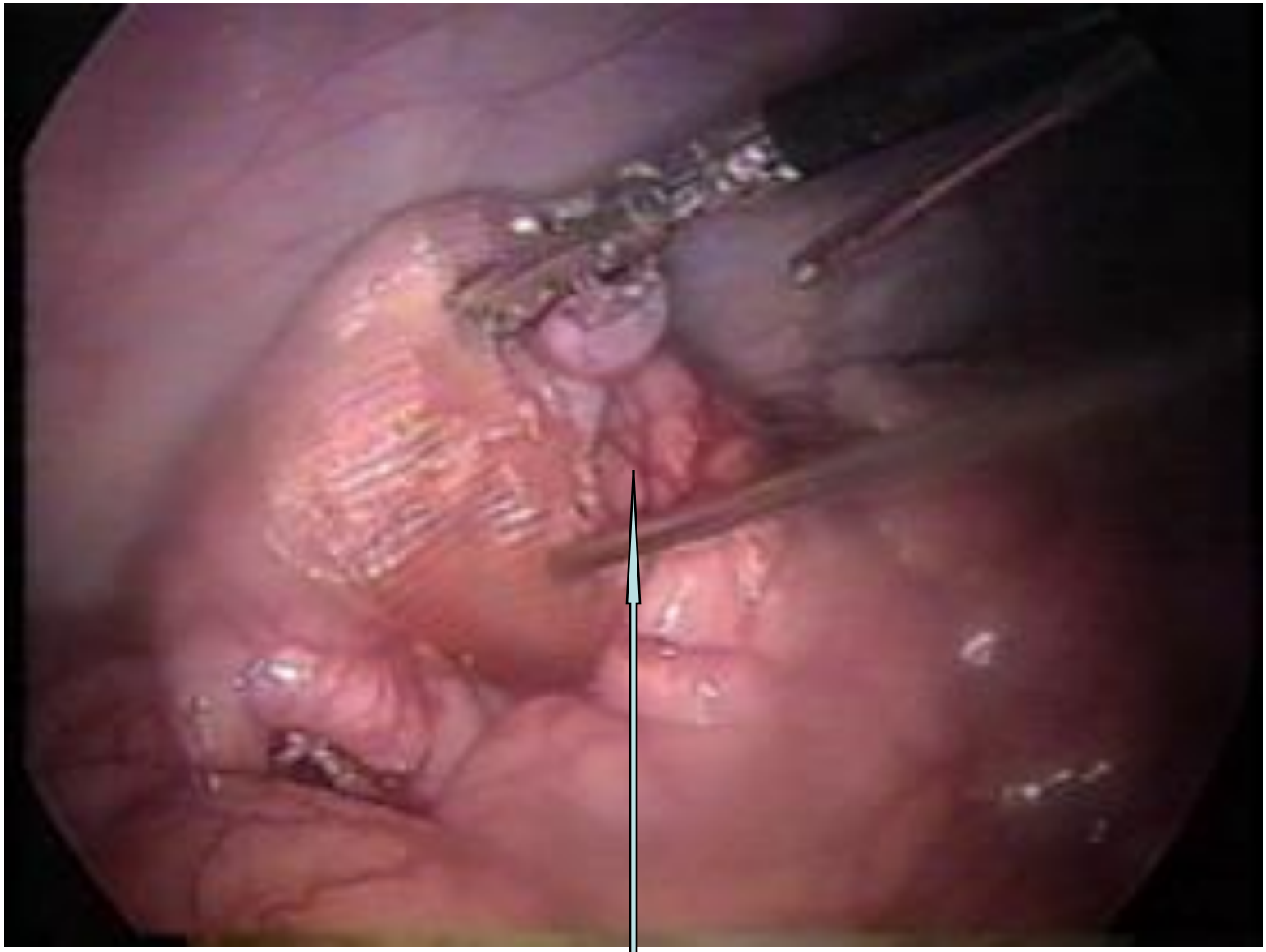

Left
Atrium
Myocardium
(heart muscle)
shown in red
Right
Atrium
Epicardium
(Outer surface
of myocardium)
Left
Ventricle
Right
Ventricle
Endocardium
(Inner surface of myocardium)

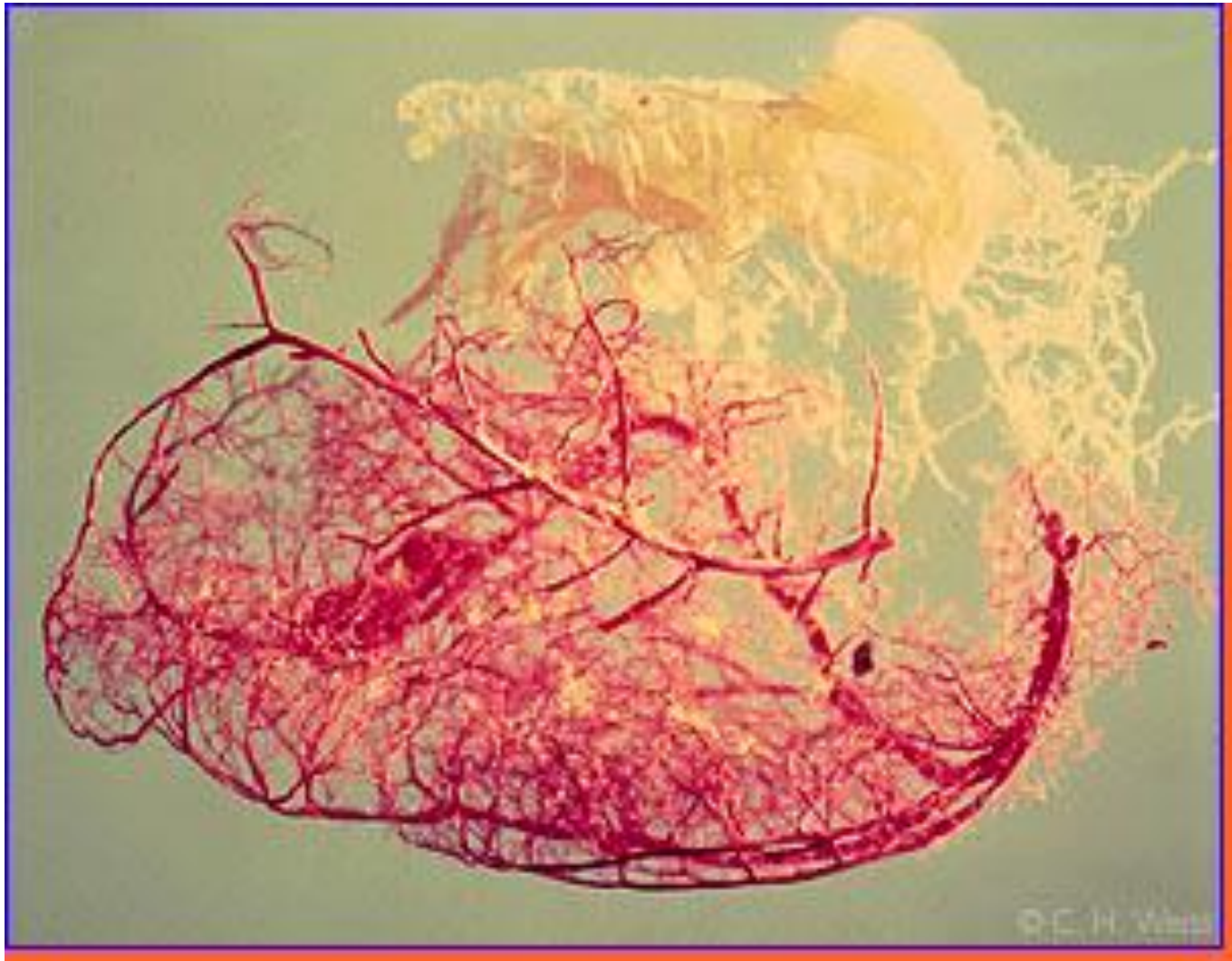
- Cardiac muscle cells are interconnected by intercalated discs which convey the force of contraction from cell to cell and conduct action potentials.


Intercalated
Discs
Branching Cardiac
Muscle Fibers

Heart Blood Supply

- Coronary circulation demands high oxygen and nutrients for the cardiac muscle cells.
- Coronary arteries originate at the base of the ascending aorta.
- Interconnections between arteries called *anastomoses* ensure a constant blood supply.

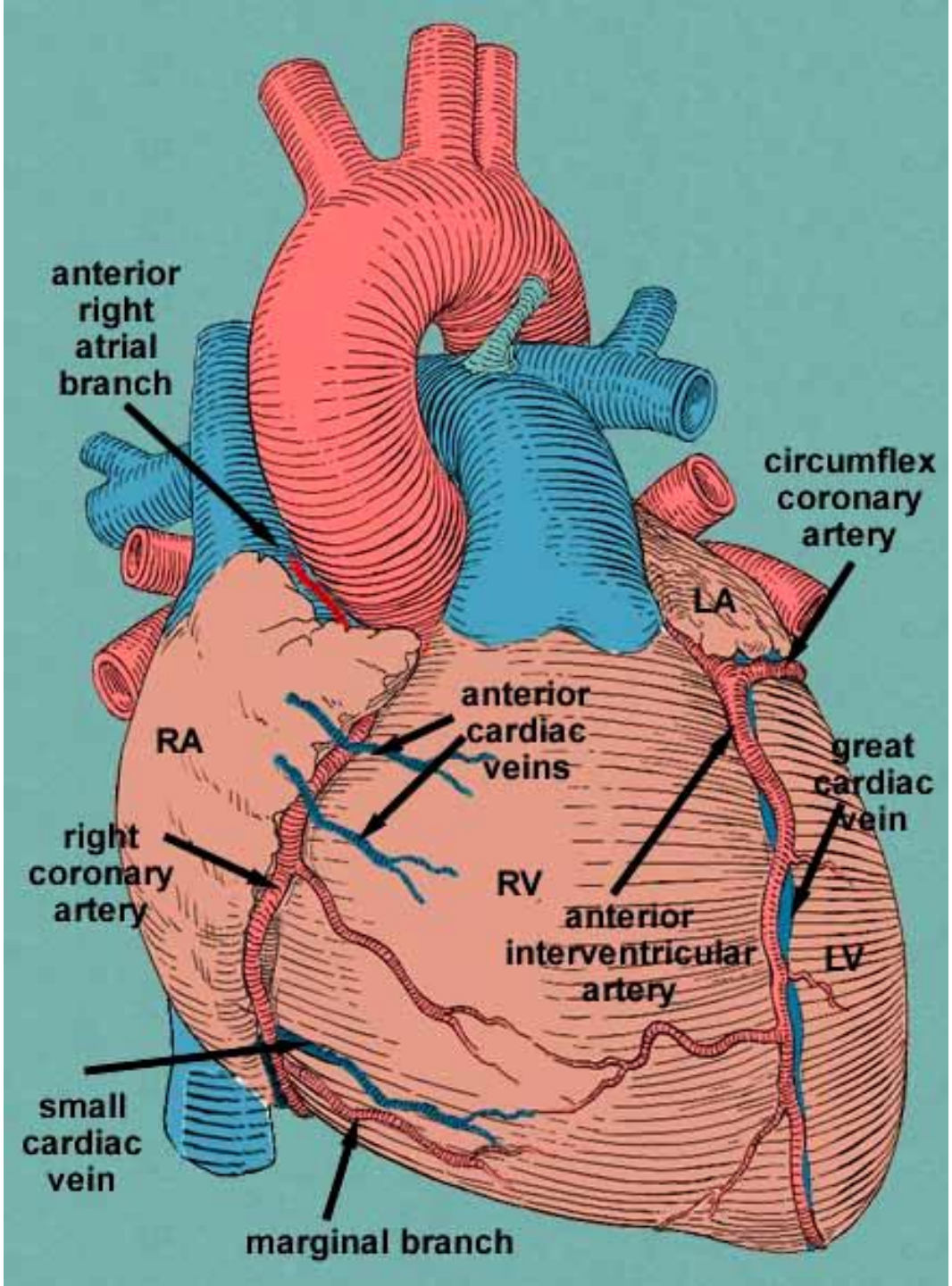

Anastomoses



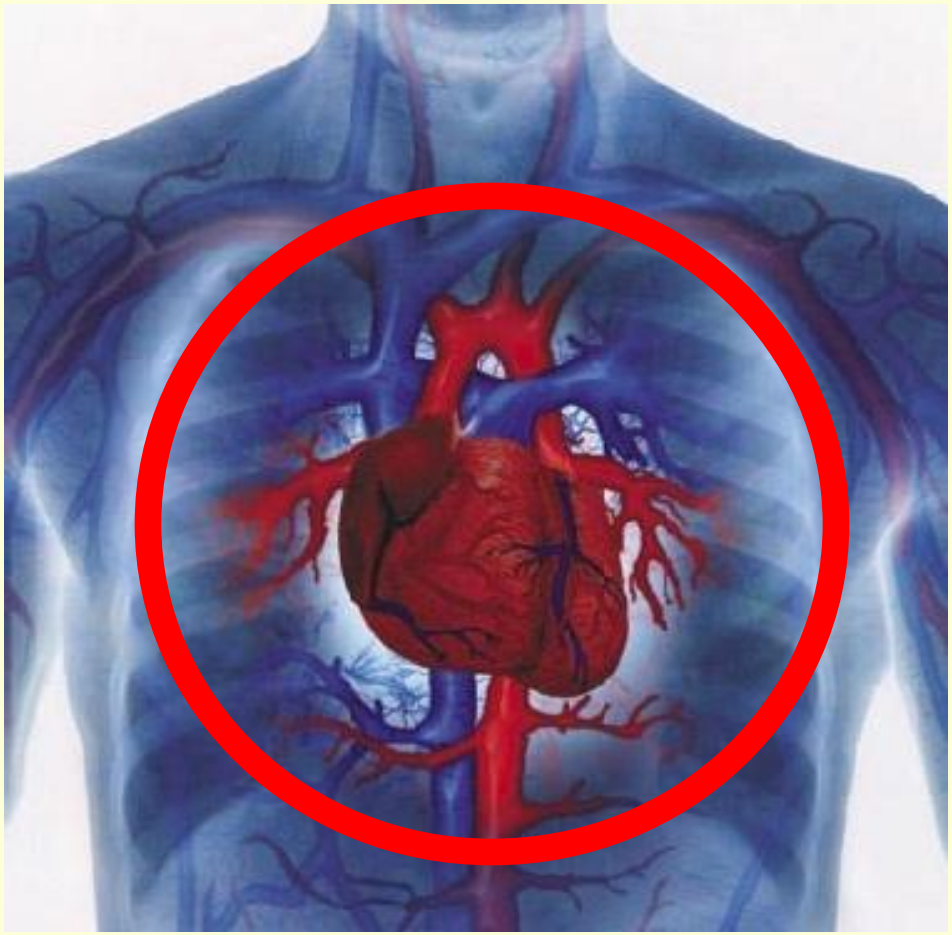
Coronary arteries are the network of blood vessels that supply the heart. In this photograph, the left coronary artery has been injected with a red dye, and the right coronary artery with white.

Great, Posterior, small,
Anterior, Middle Cardiac
Veins carry blood from
The coronary capillaries
To the coronary sinus.

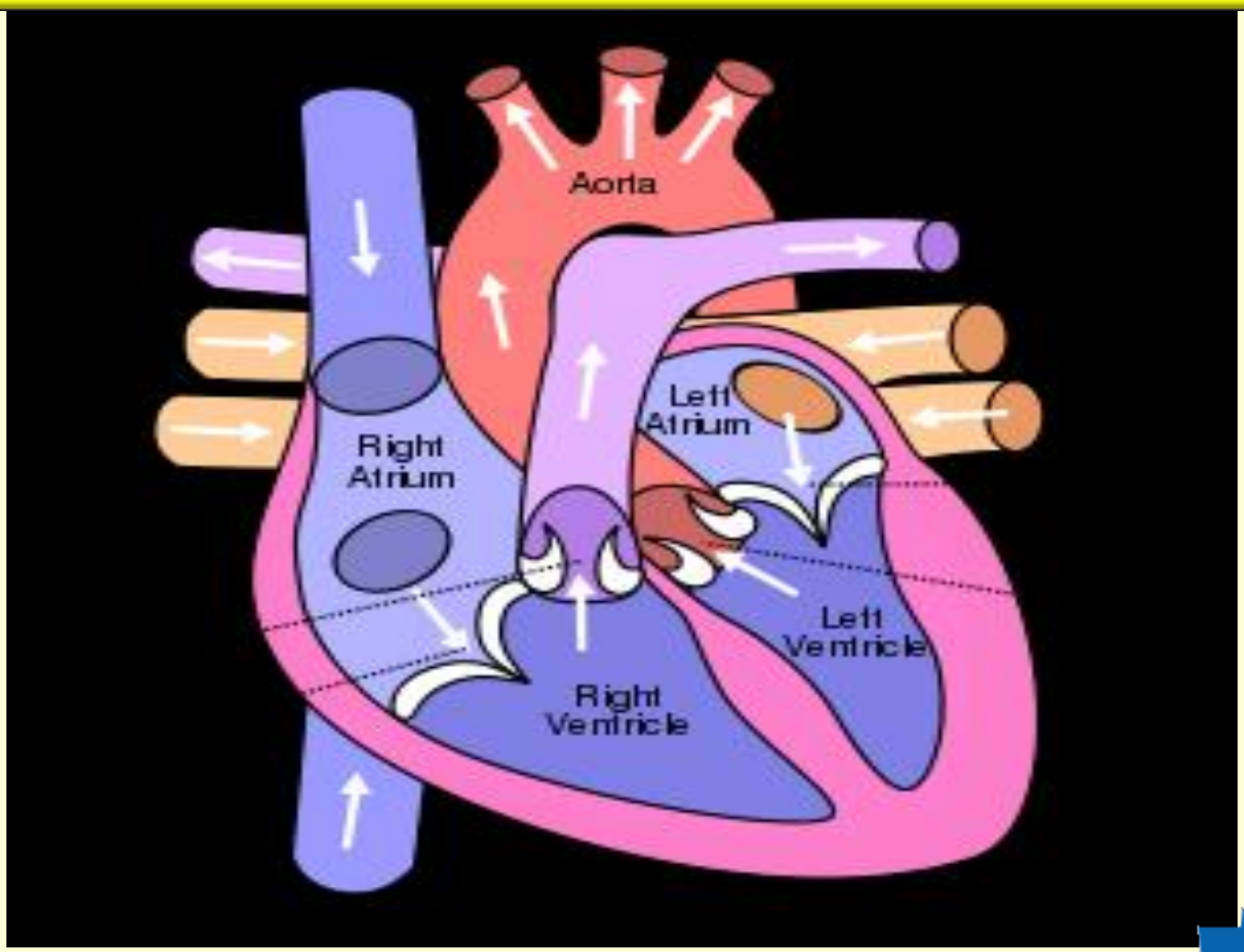
Left coronary artery supplies
The left ventricle. Circulflex
Curves left meeting with
The right coronary artery.
Left anterior decending
Supplies the posterior
Decending artery
(interventricular).



STRUCTURE OF A HUMAN HEART



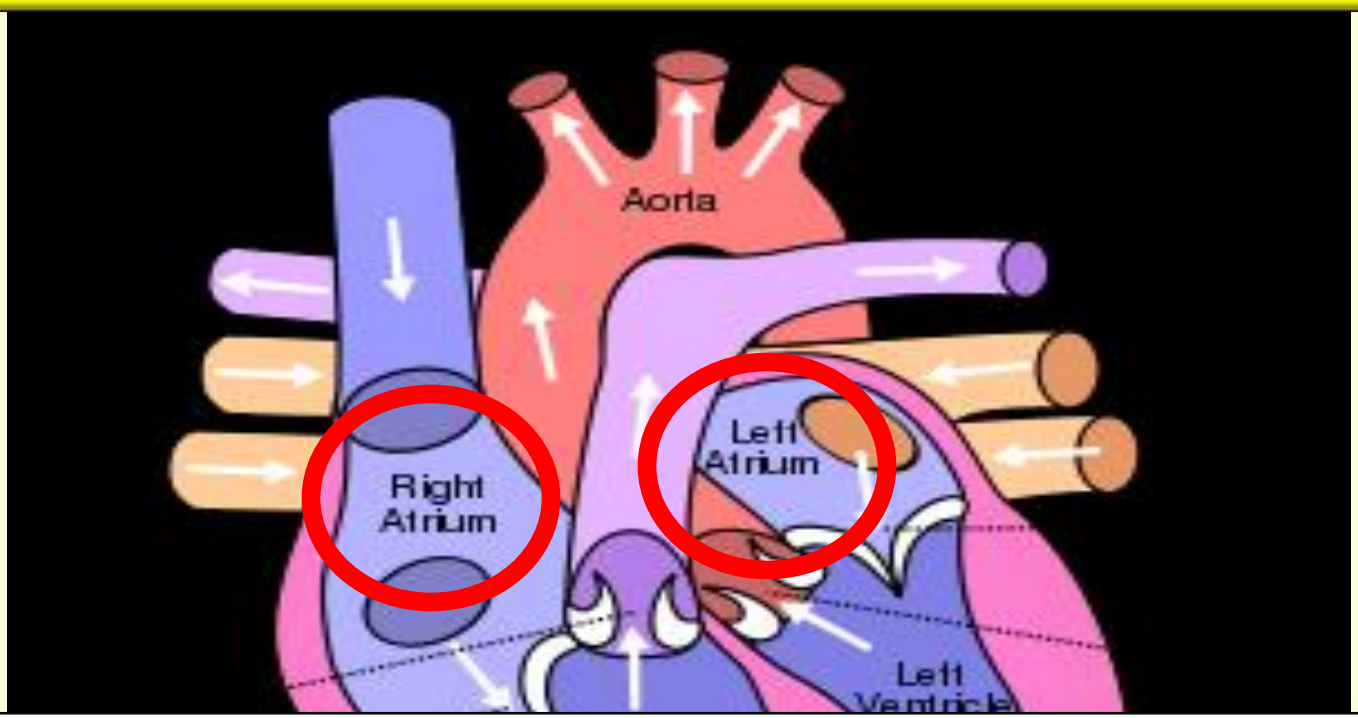
STRUCTURE OF A HUMAN HEART



STRUCTURE OF A HUMAN HEART

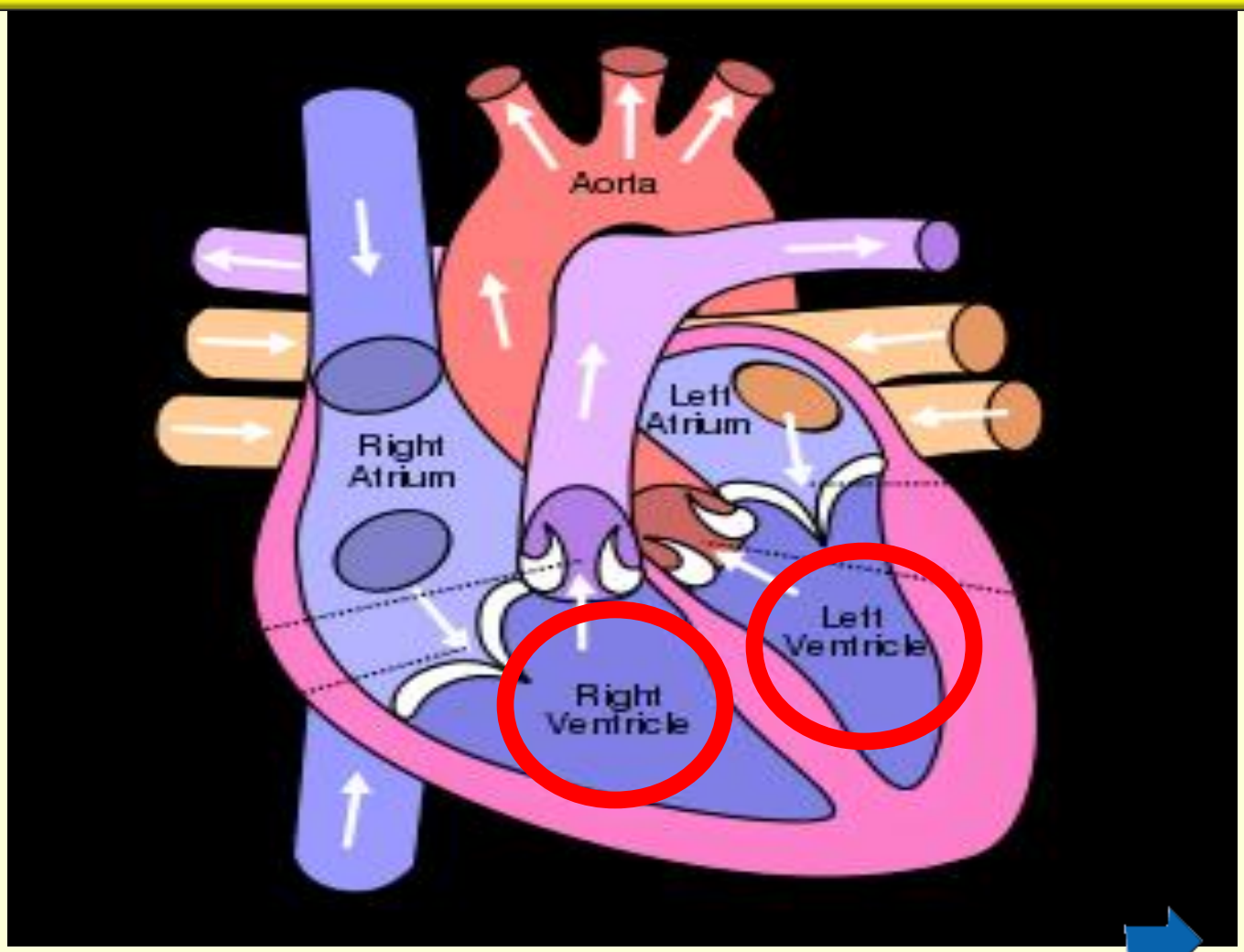
- Human heart situated between the two lungs in the thoracic cavity.
- It contains 4 chambers:-
- Two upper chambers – **Atria**
- Two lower chambers – **Ventricles**

STRUCTURE OF A HUMAN HEART

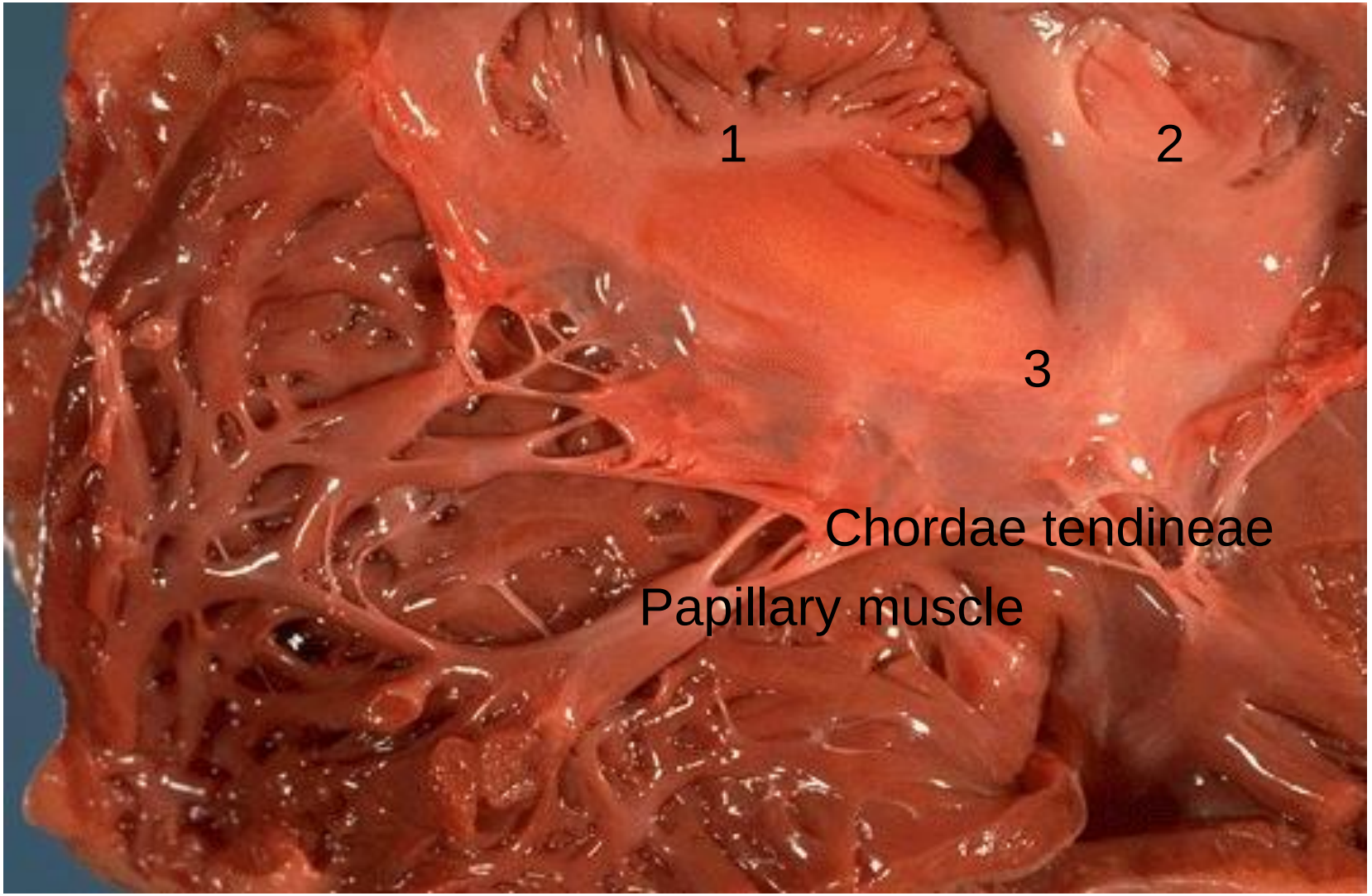


- Atria – receive blood returning to the heart

STRUCTURE OF A HUMAN HEART



- Ventricles – pump blood out of the heart.
- Muscular wall of the left ventricle is thicker than the wall of the right ventricle.
- Right ventricle pump blood to the lungs.
- Left ventricle pump blood to all parts of the body.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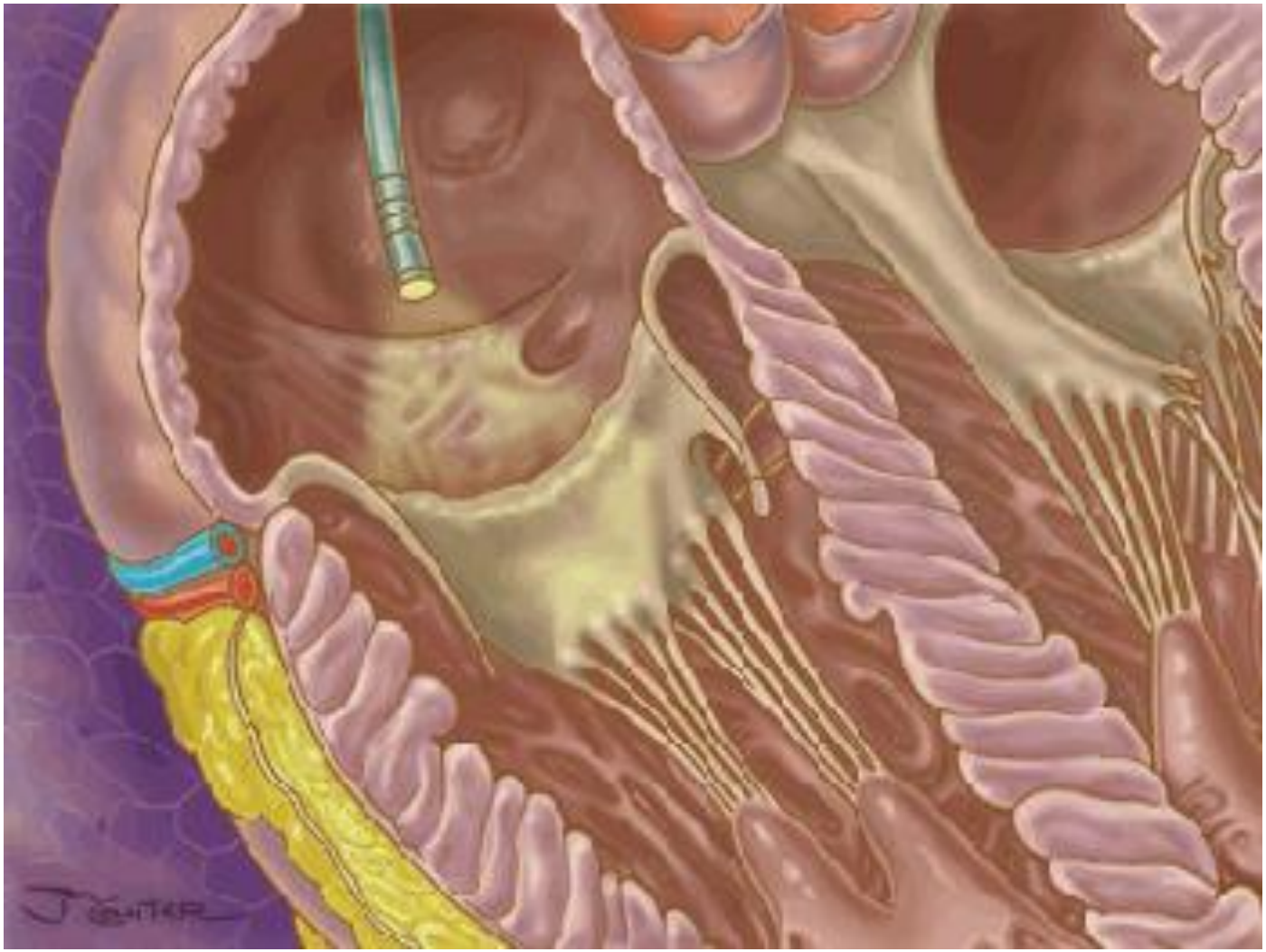
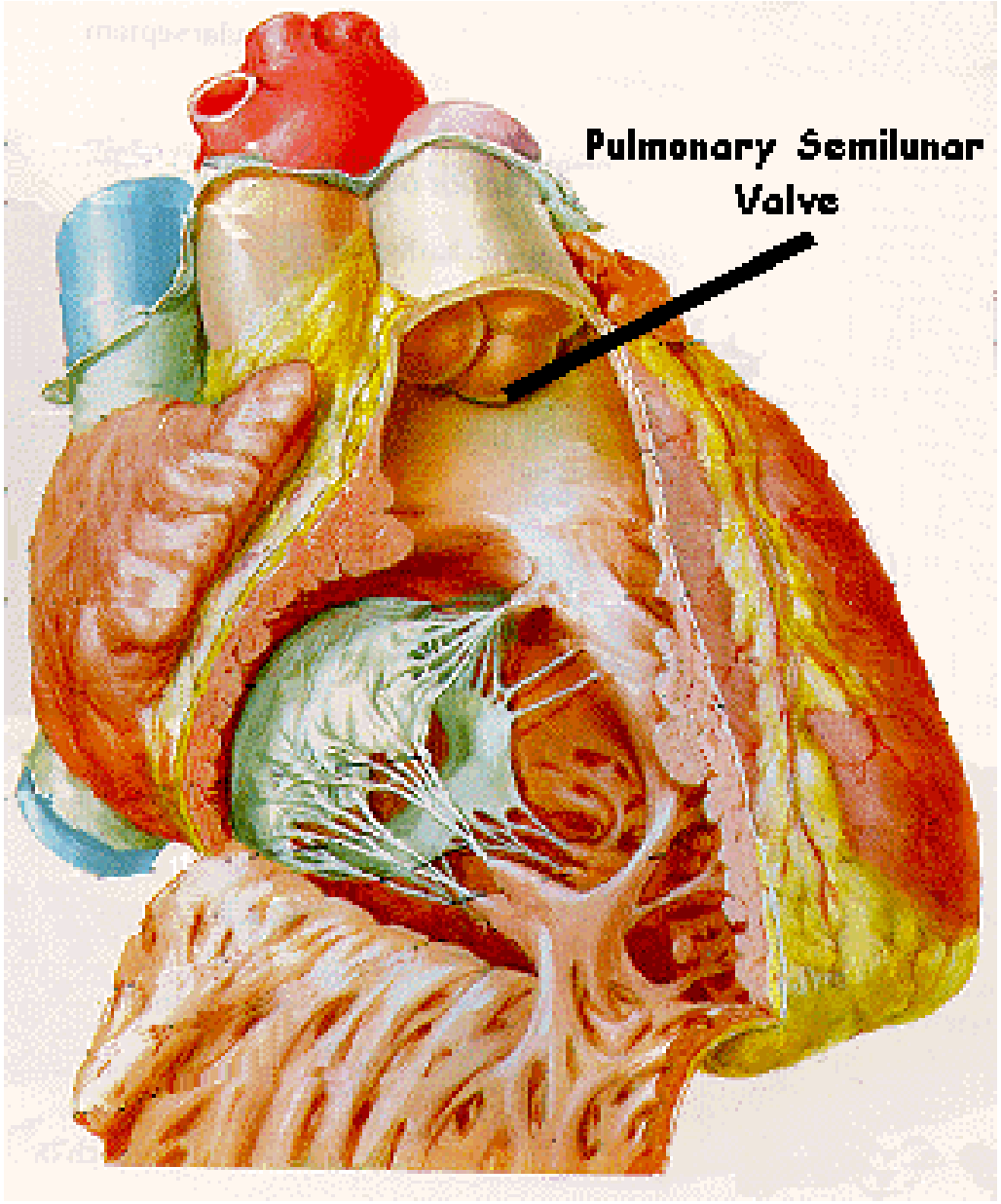
Chordae tendineae
Papillary muscle



Tricuspid Valve

Remember you are looking at the right side of the heart.



FUNCTION OF A HUMAN HEART

- Carries all vital minerals that helps the body function.
- Pumps blood which carries waste products that the body does not need.

DIFFERENT PARTS OF A HUMAN HEART

Valves

a)i) **Tricuspid valve** – between the right atrium and the right ventricle.

ii) **Bicuspid valve** – between left atrium and left ventricle.

- Function of these two valves:-

  Prevent blood from flowing back into the atria.

Atrioventricular Valves

- Prevent backflow of blood from the ventricles back into the atria.
- Chordae tendineae and papillary muscles play an important role in this process.
- Ventricular *diastole* the ventricles relax and the ventricles refill.
- The chorae tendineae are loose and offer no resistance to the flow of blood.

During ventricular *systole* the ventricles begin to contract blood moving back towards the atria swings the cusps together closing the valves.

The chordae tendineae and papillary muscles stops the cusps from swinging into the atria.

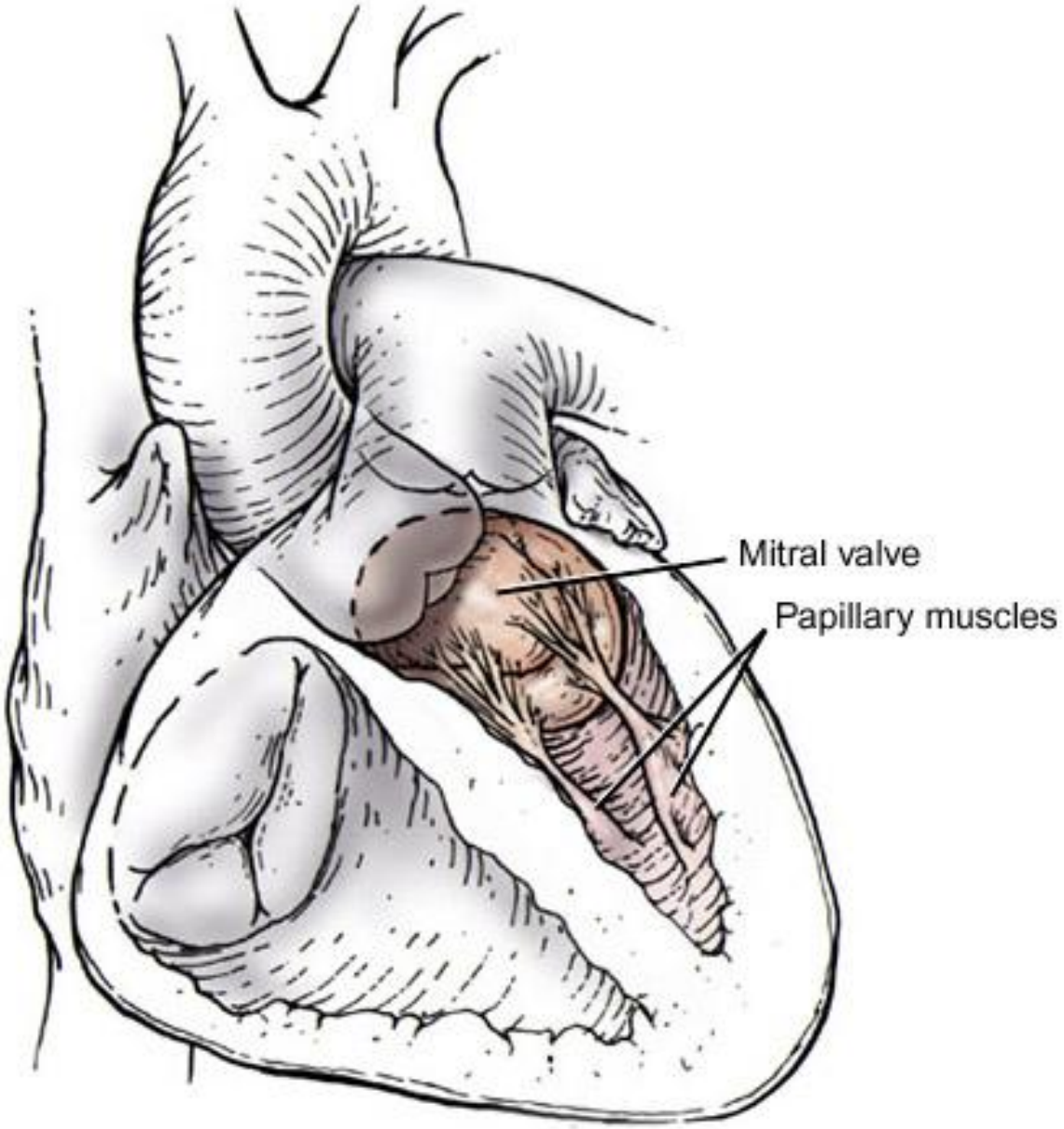
If those two structures are cut or damaged the valves act as swinging doors, and there is backflow, or *regurgitation.*

Mitral valve damage can especially occur in women after pregnancy.

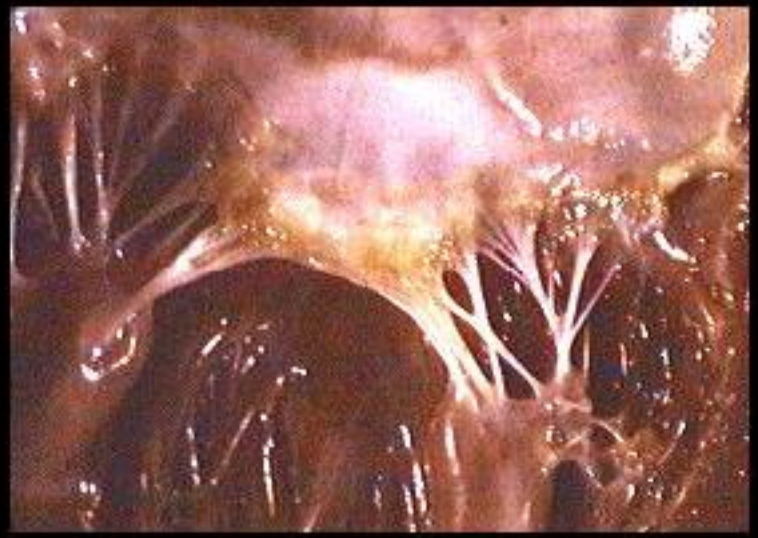
DIFFERENT PARTS OF A HUMAN HEART

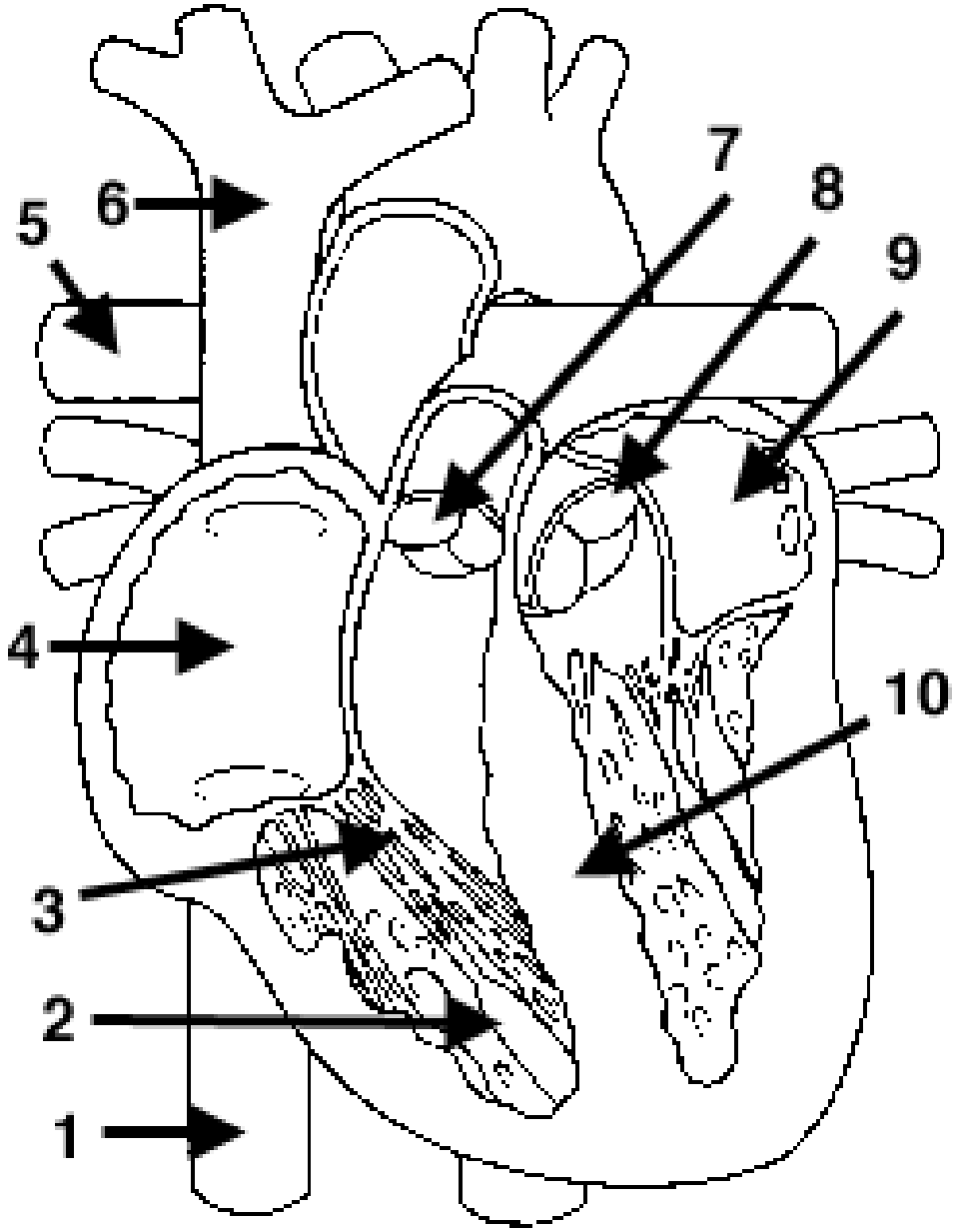
b) **Semi-lunar valve** – located at the point where the pulmonary artery and aorta leave the heart and along the vein.

- Function of semi-lunar valves:- Prevent backflow of blood.


Mitral valve
Papillary muscles

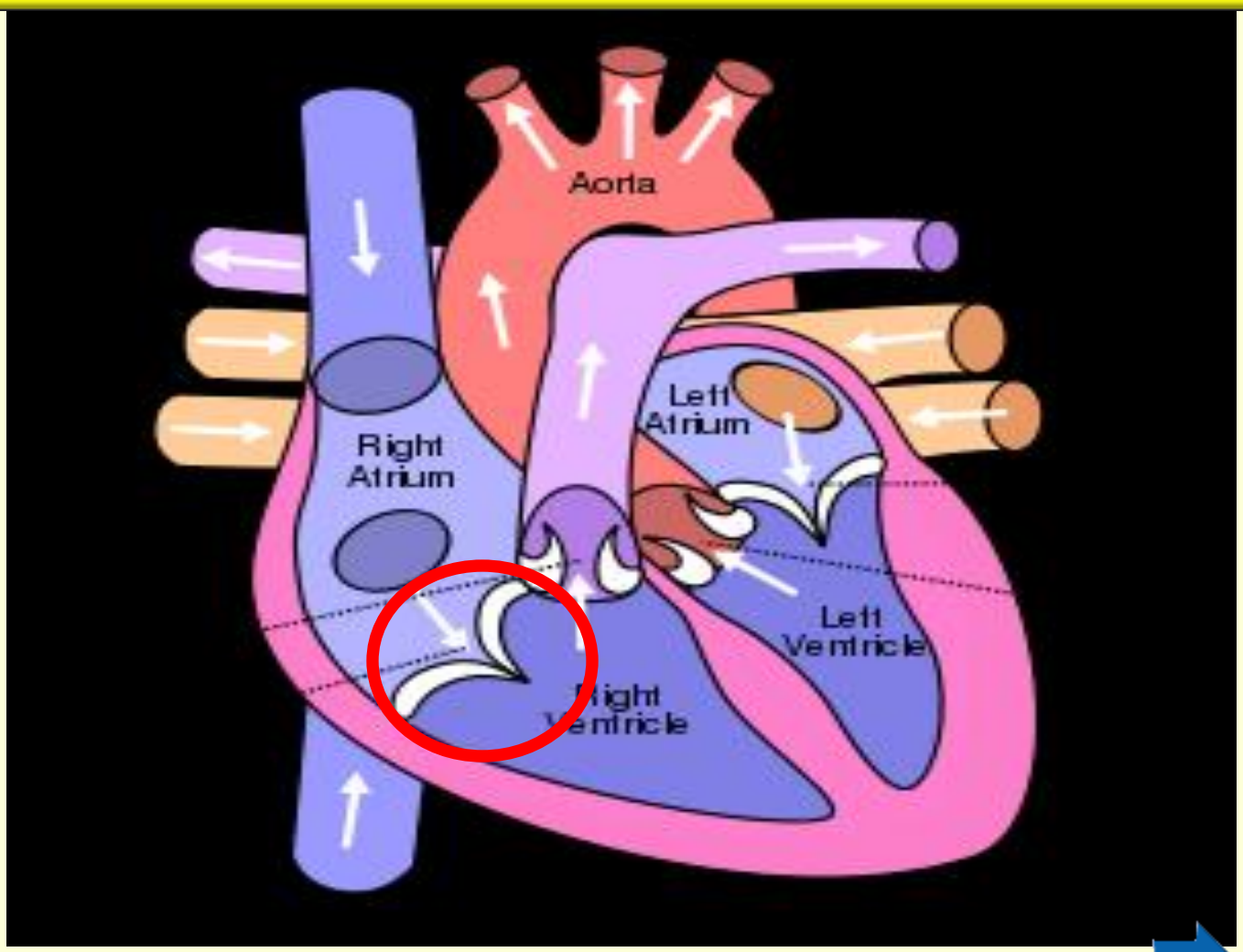
Left Atrium, Mitral Valve, and Left Ventricle





#8 is the aortic semilunar valve

STRUCTURE OF A HUMAN HEART



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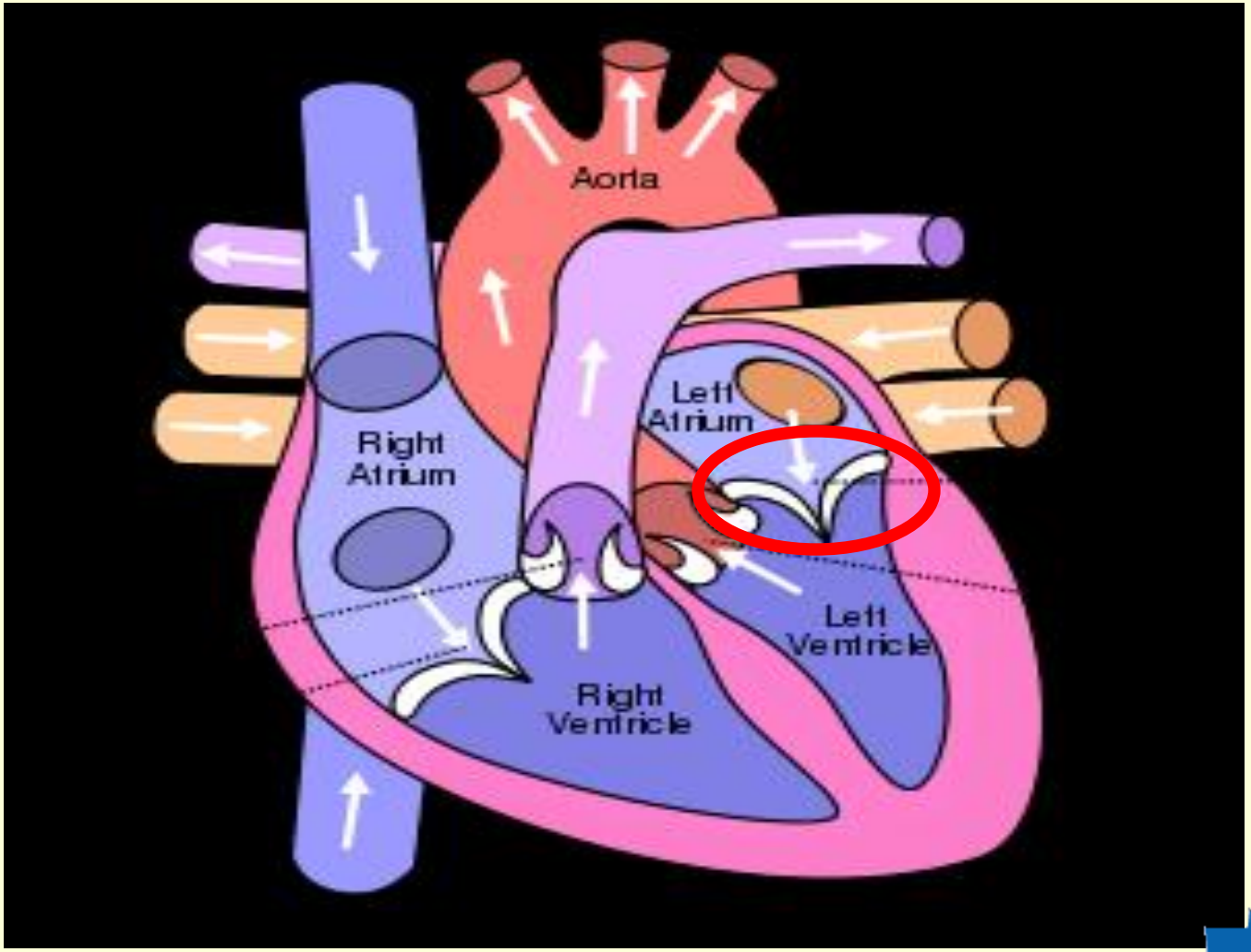

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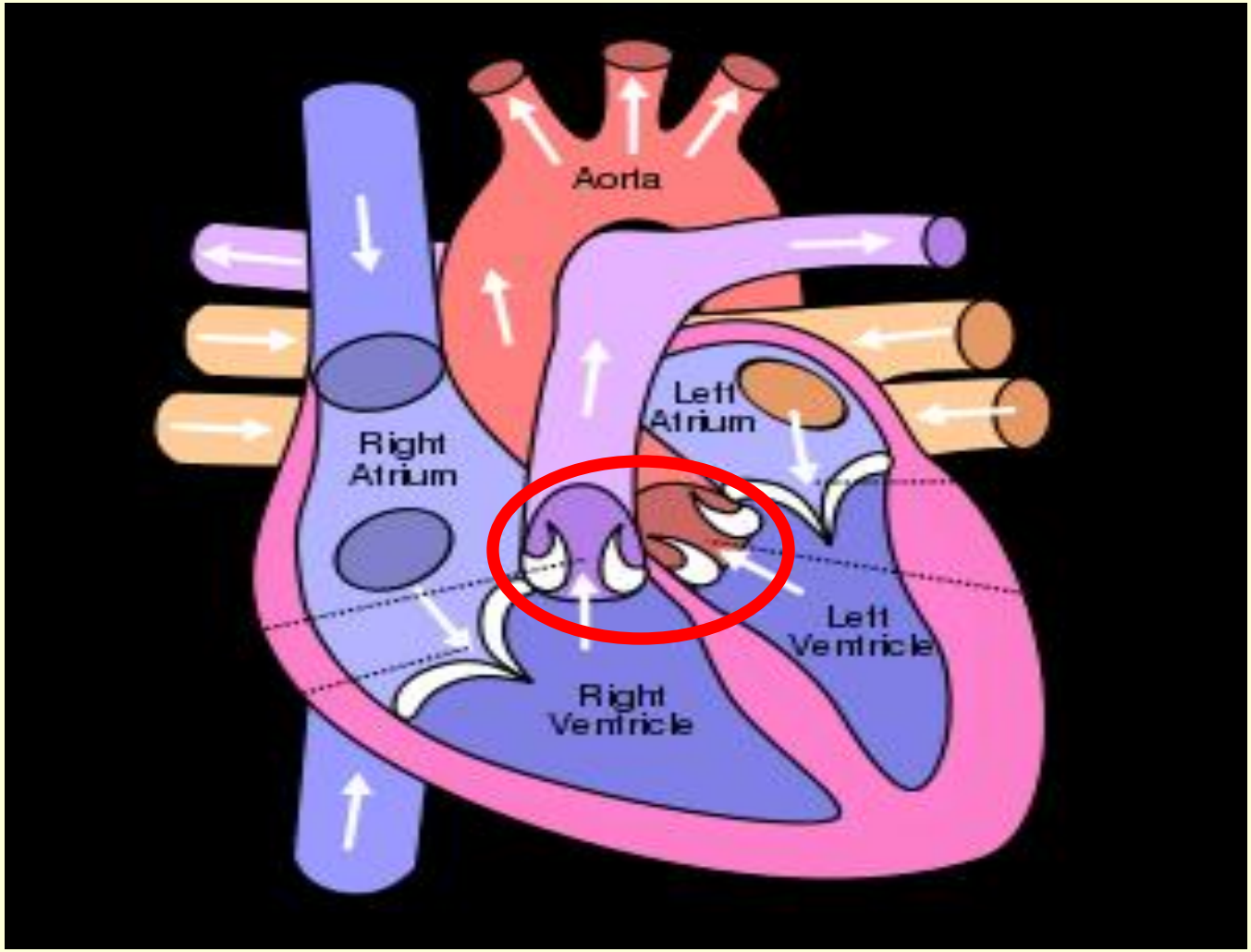
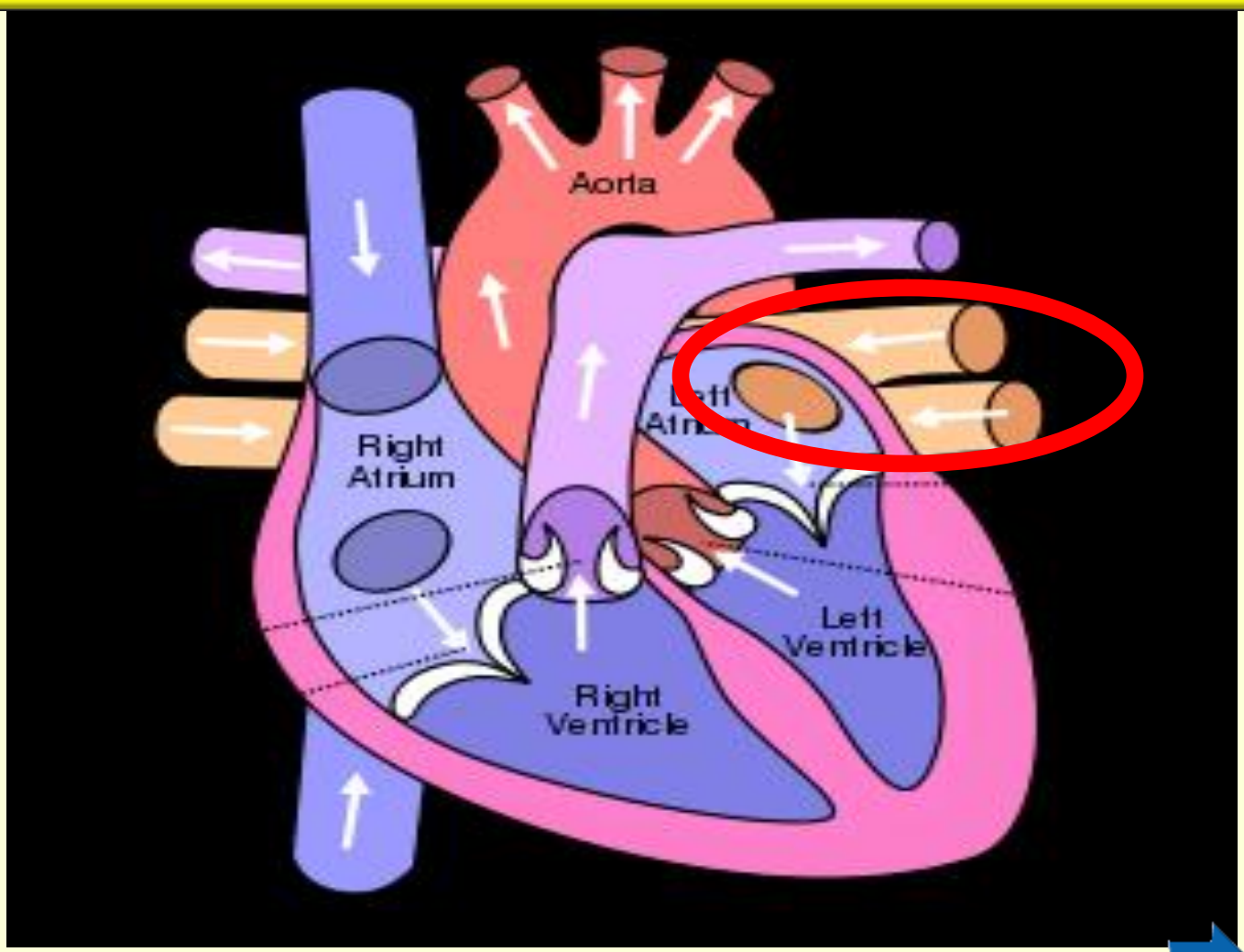


DIFFERENT PARTS OF A HUMAN HEART

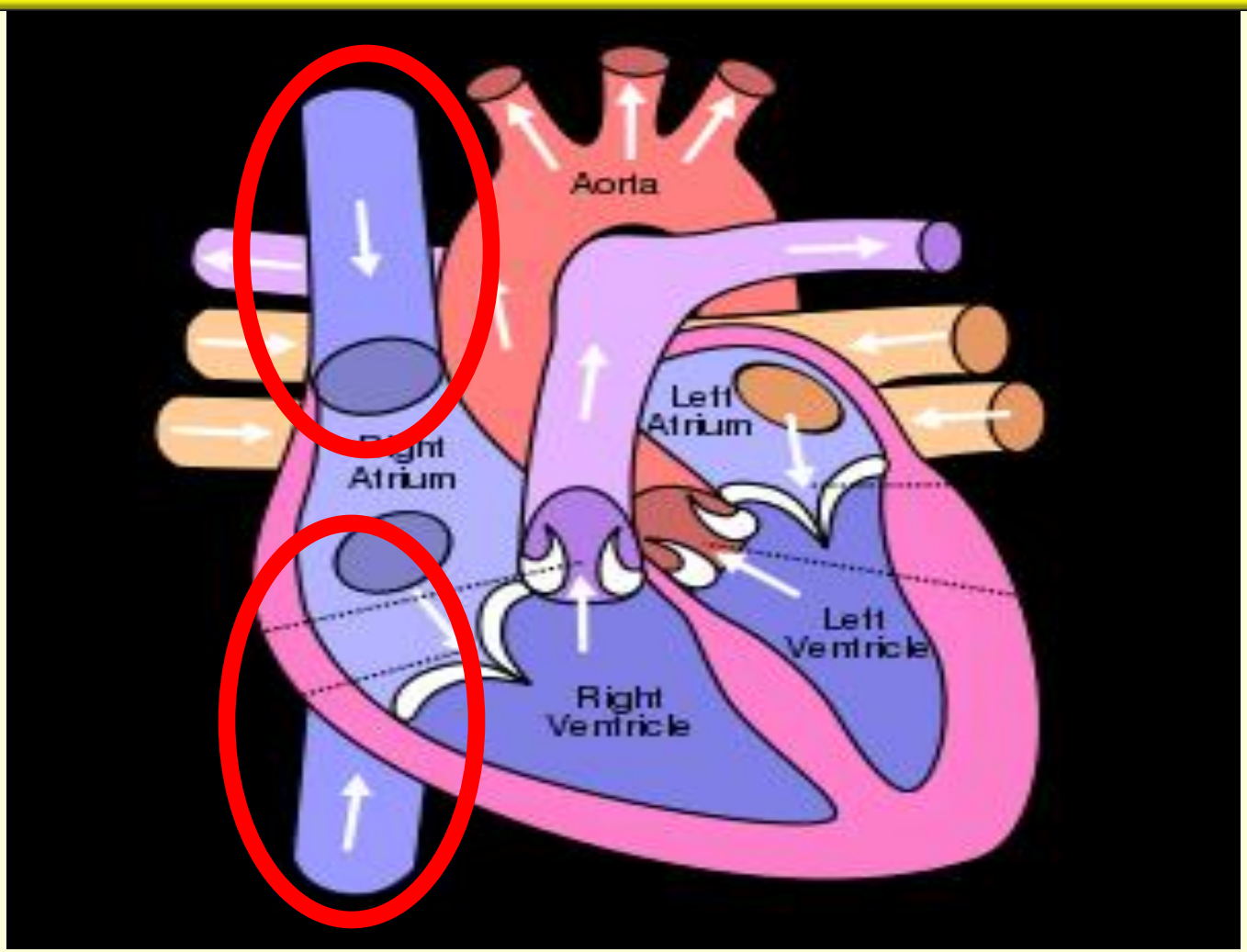
- **Pulmonary vein -** oxygenated blood from lungs enters the left atrium via the pulmonary vein.

- **Vena cava -** deoxygenated blood from the left of the body enters the right atrium via the vena cava.

STRUCTURE OF A HUMAN HEART



STRUCTURE OF A HUMAN HEART

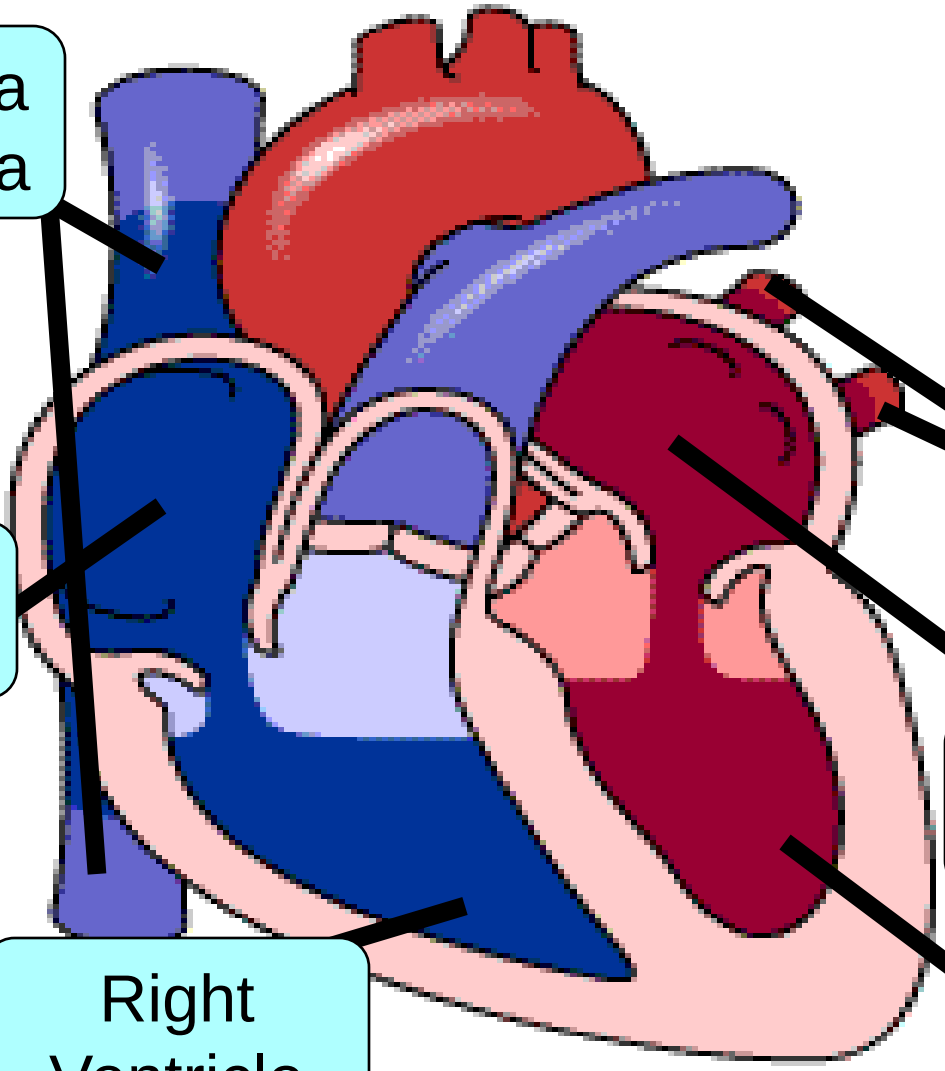


MECHANISM OF THE HEART

- When blood fills the atria, atria contract, blood pushed into the two ventricles.

- When ventricles contract - bicuspid and tricuspid valves will close, blood pushed out though semi-lunar valve into the pulmonary arteries and aorta.

MECHANISM OF THE HEART



Vena Cava

Right Atrium

Right Ventricle

Deoxygenated Blood

Oxygenated Blood

Pulmonary Vein

Left Atrium

Left Ventricle

MECHANISM OF THE HEART

Cardiac muscle cells are:-

- interconnected.
- myogenic - contracts and relaxes without the need to receive impulse from the nervous system.

Control of heart rate

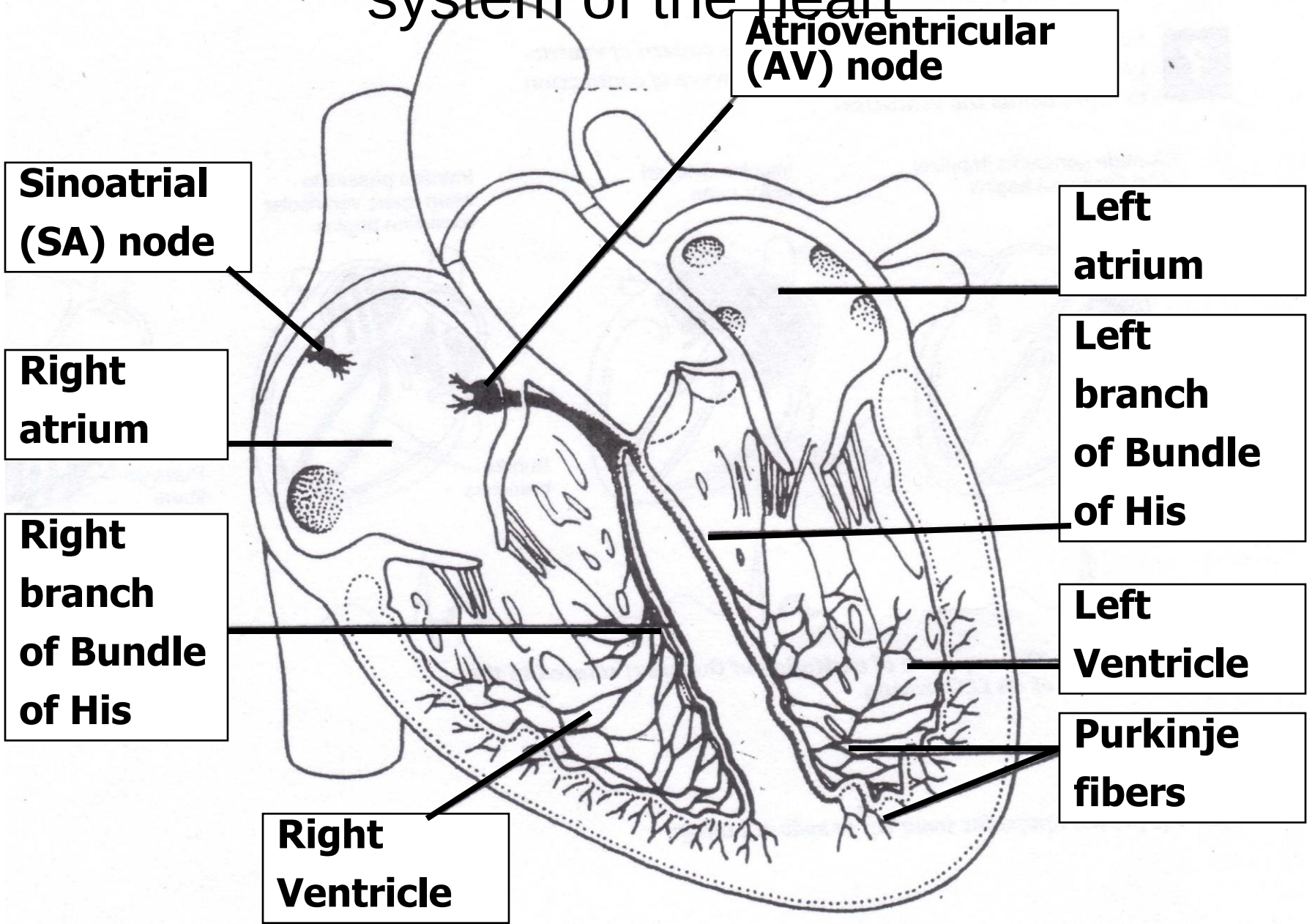
Heart rate is controlled by 2 separate systems

- Intrinsic control :- Autorhythmic
  (pacemaker cells)
  Conduction system

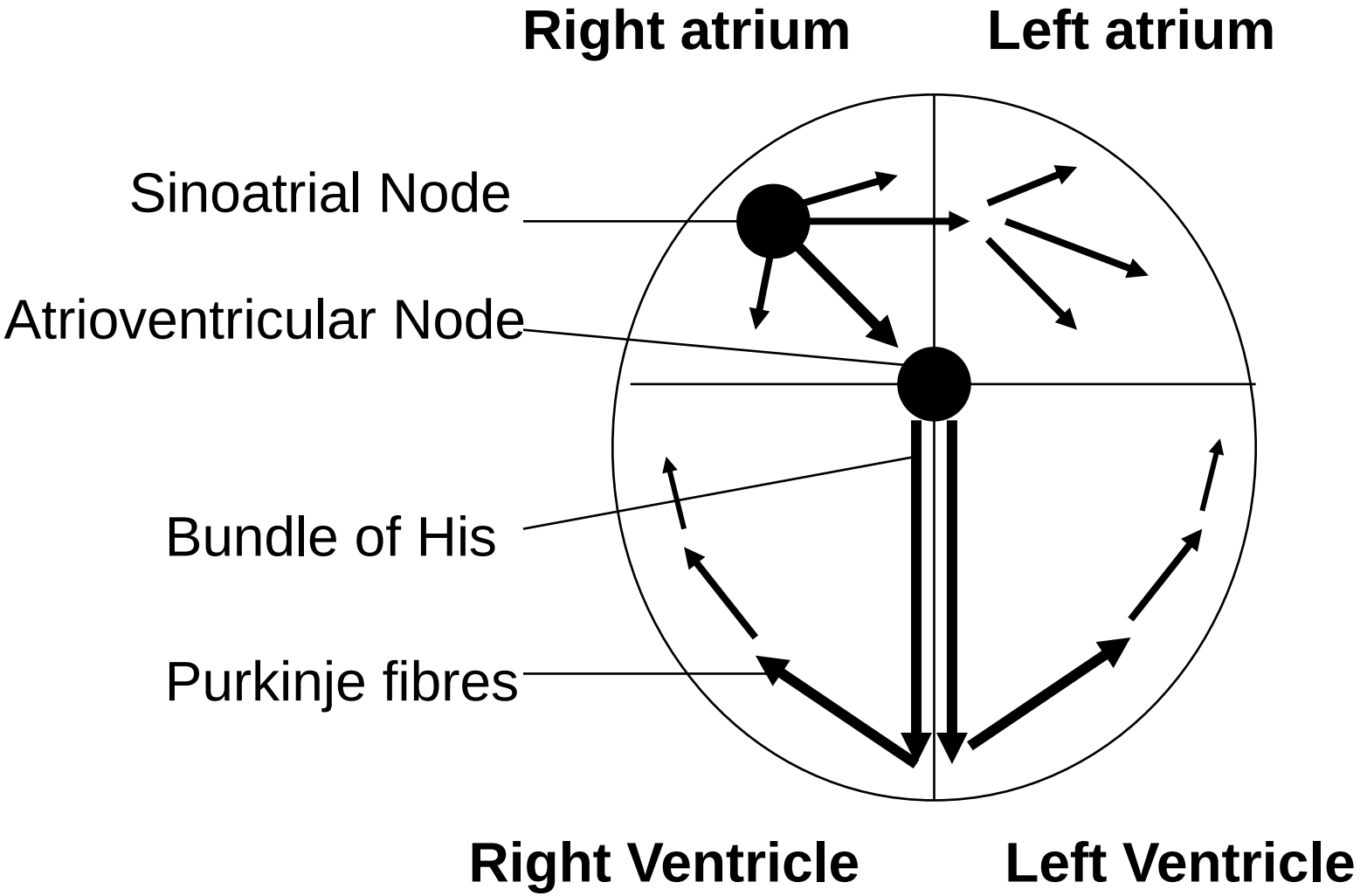
  HR = excitation rate of SAN

- Extrinsic control:- Nerves (autonomic)
  Hormones

Intrinsic Control:- Specialised conduction system of the heart



Spread of Cardiac Excitation



Animation of spread of intrinsic activity.
http://www.aboutkidshealth.ca/HowTheBodyWorks/default.aspx

?

Knowing that ventricular contraction follows the pattern of ventricular excitation, describe the path you expect the contraction wave to follow across the ventricles.

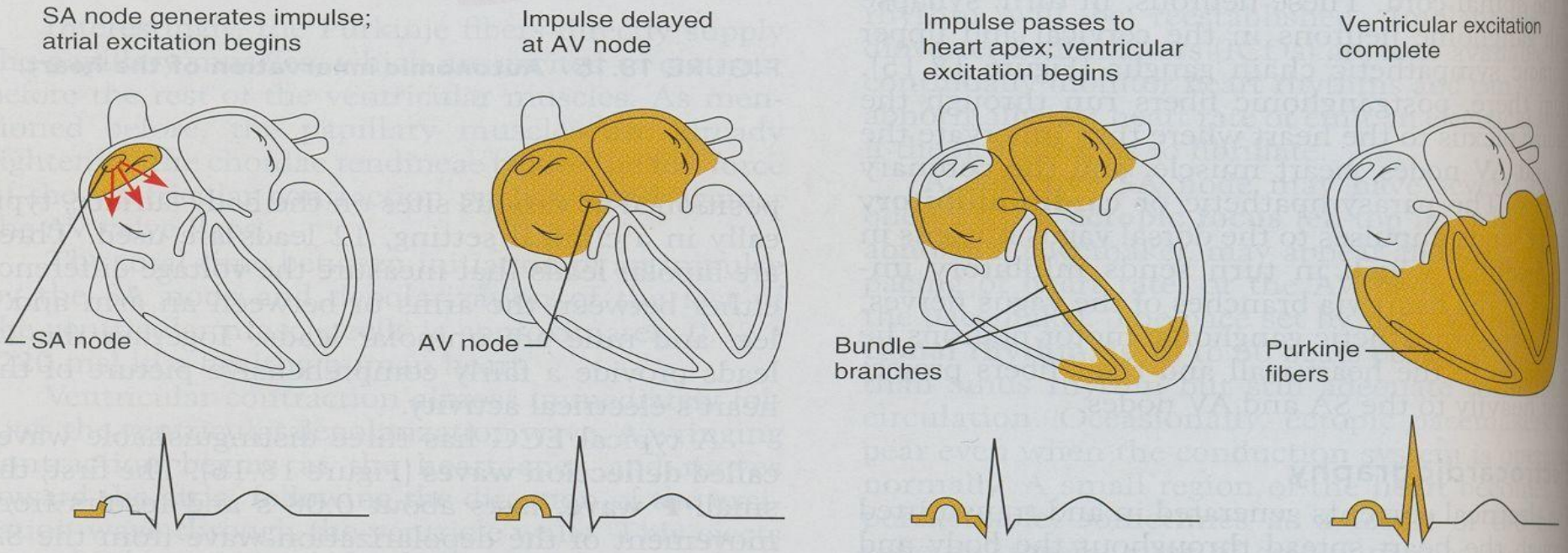


FIGURE 18.17 **The sequence of excitation of the heart related to the deflection waves of an ECG tracing.**

Marieb E. N (2007) Human Anatomy and physiology. 7th Edition. San Francisco : Pearson/Benjamin Cummings. p696.

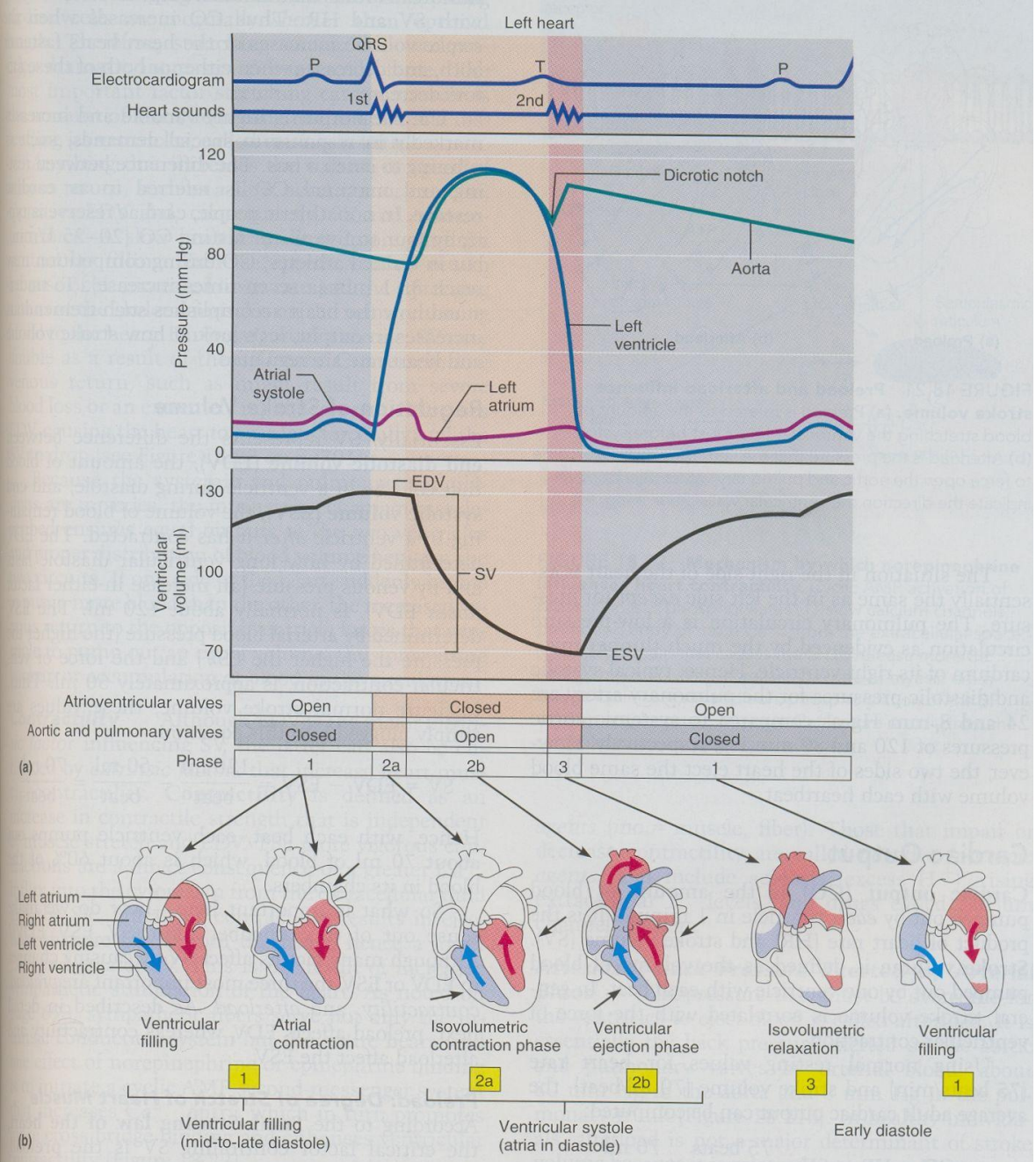


FIGURE 18.20 **Summary of events during the cardiac cycle in the left side of the heart.** **(a)** An ECG tracing correlated with graphs of pressure and volume changes. Time occurrence of heart sounds is also indicated. **(b)** Events of phases 1 through 3 of the cardiac cycle.

Marieb E. N (2007) Human Anatomy and physiology. 7th Edition. San Francisco : Pearson/Benjamin Cummings. p699.

Extrinsic Control

See diagram: - Control of the heart by the sympathetic and parasympathetic systems

- The chemoreceptors in the aortic arch and carotid sinus monitor:- O_2, CO_2 and pH of the blood leaving the heart.
- The glossopharangeal nerve carries information from the carotid sinus to the brain
- The vagus nerves carries information from the aortic arch to the brain
- The autonomic nervous system modifies the heart rate to meets the bodies demands:-

1. Which division increases heart rate?

2. Which division decreases heart rate?

These autonomic nerves modify the heart rate to meet the demands of the body

MECHANISM OF THE HEART

Contraction of heart is coordinated by a pacemaker. Pacemaker:-

- A specialized heart muscle that sets the rate at which the heart contracts.
- Located in right atrium.
- Generate electrical impulses that cause the atria to contract in a rhythmical pattern. Primary pacemaker is called sinoatrial (SA) node.

MECHANISM OF THE HEART

From SA mode, impulses reach the atrioventricular (AV) node. AV node located at the floor of the right atrium.

MECHANISM OF THE HEART

From AV node,

- the bundle of His fibres
- bundle branches
- Purkinje fibres

-conduct signals to the apex of the heart thoughout the walls of the ventricles causing the ventricles to contract and push blood out to the lungs and body.

MECHANISM OF THE HEART

Pacemaker regulated by two sets of nerves:-

- The parasympathetic nerve slows down the pacemaker.

- Sympathetic nerve speeds up the pacemaker.

MECHANISM OF THE HEART

Heartbeat also control by hormone adrenaline or epinephrine which increases heartbeat during moments of fear or threat.

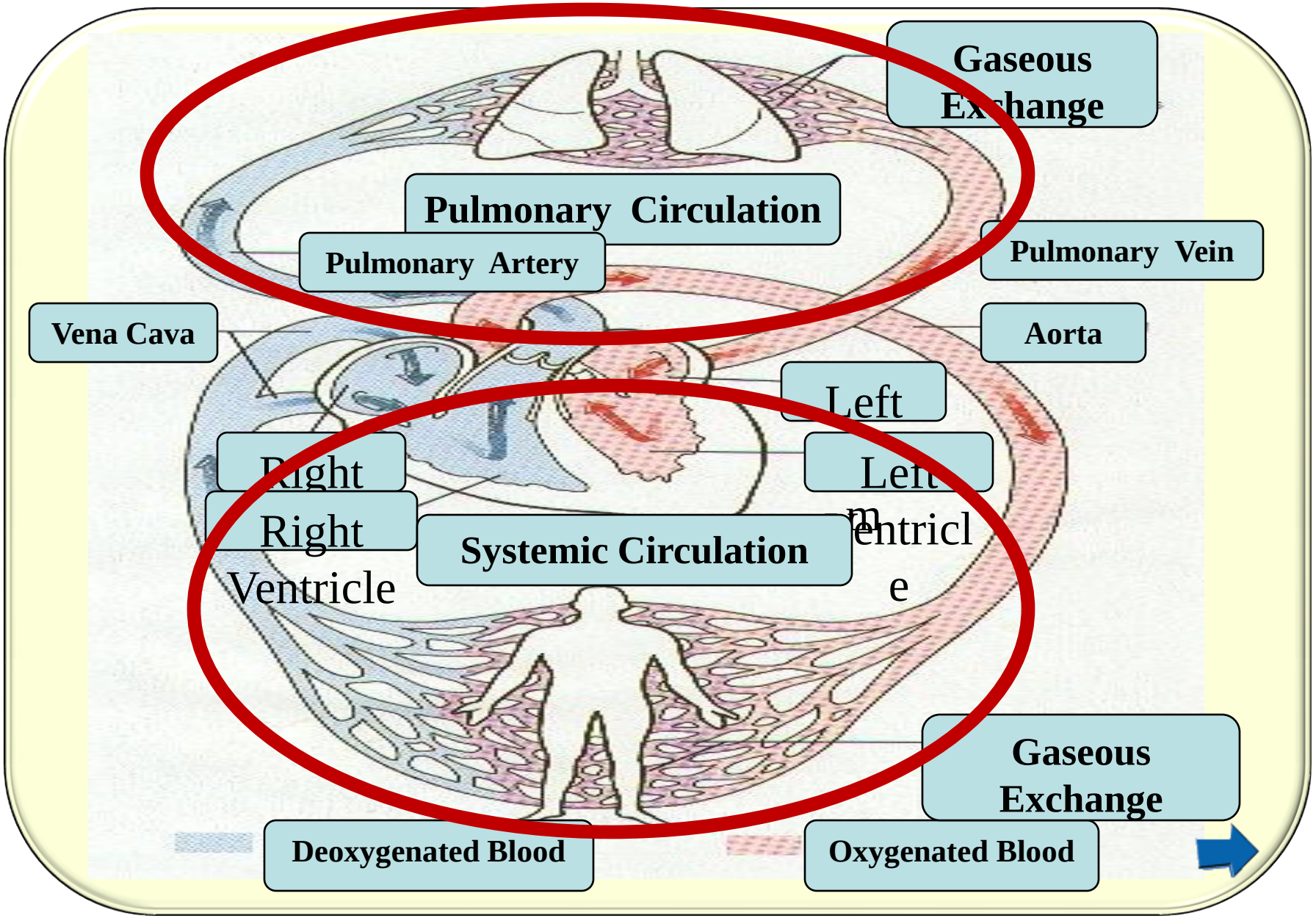
What's the Lub Dub?

- The first heart sound (lub) is caused by the acceleration and deceleration of blood and a vibration of the heart at the time of the closure of the tricuspid and mitral valves.
- The second heart sound (dub) is caused by the same acceleration and deceleration of blood and vibrations at the time of closure of the pulmonic and aortic valves.

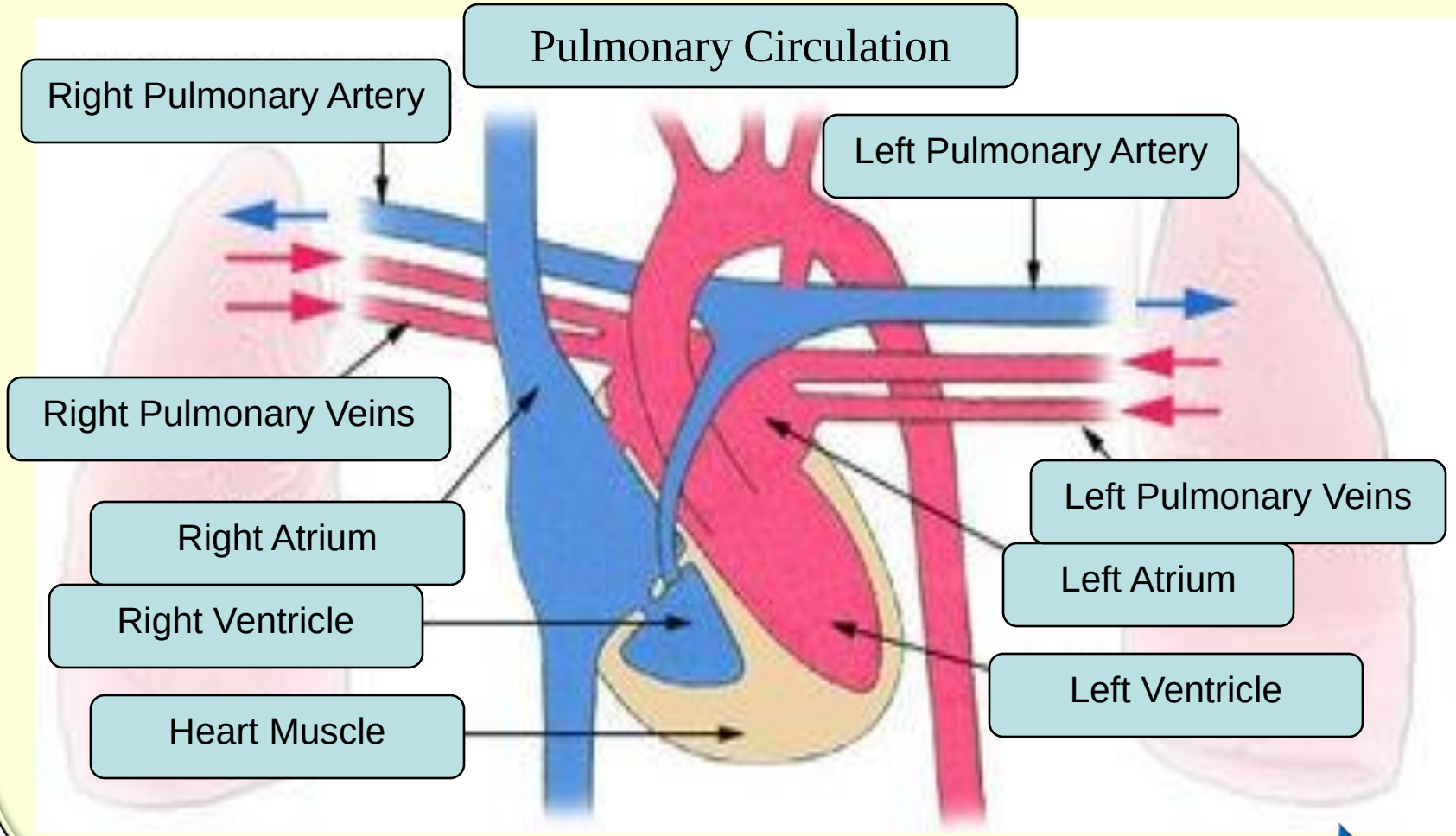
CIRCULATORY SYSTEM IN HUMAN

1. Human has a:-

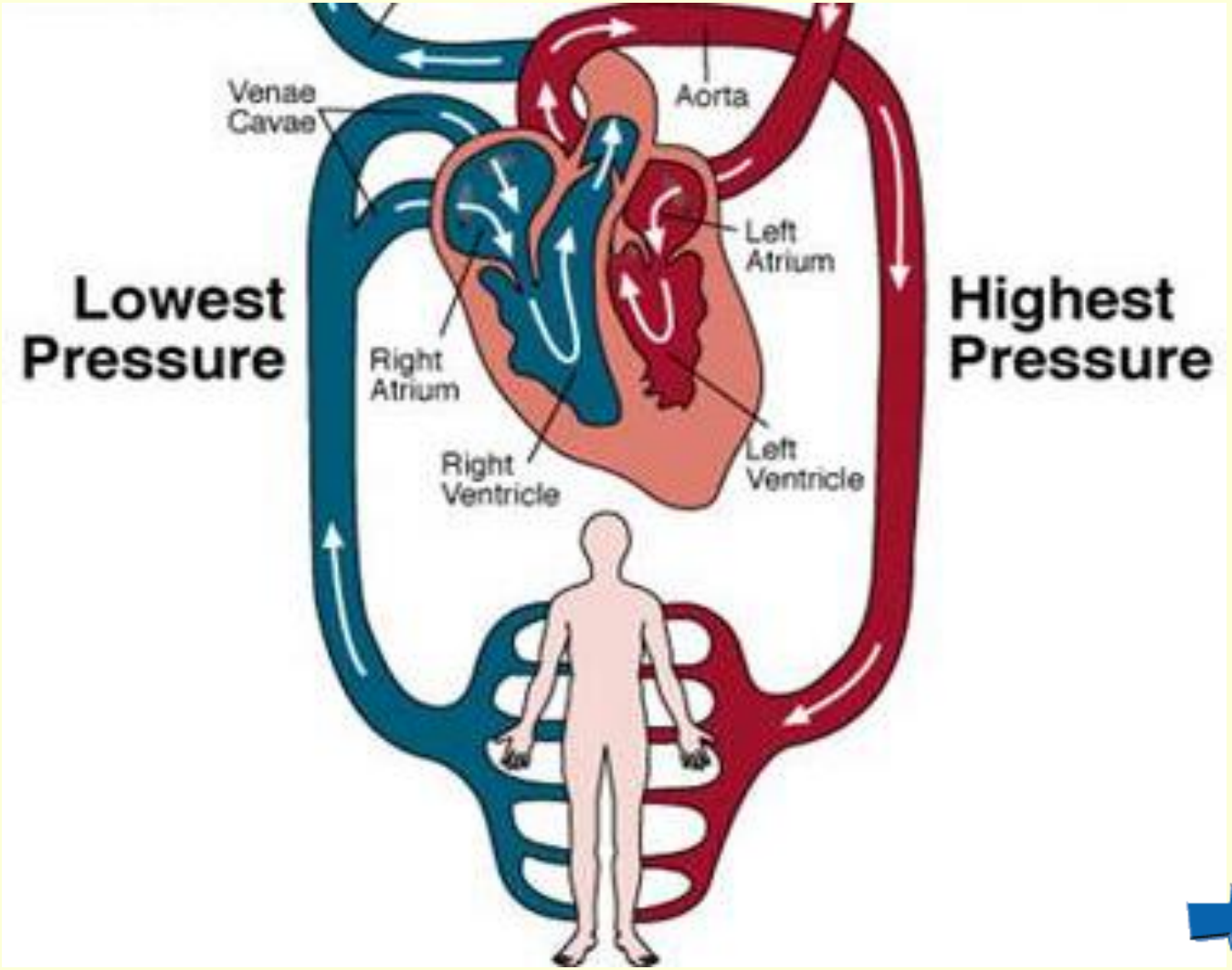
- double circulatory system ➡ which consists of the:-
- pulmonary circulation ➡
- systemic circulation ➡


Gaseous Exchange
Pulmonary Circulation
Pulmonary Artery
Pulmonary Vein
Vena Cava
Aorta
Left
Right
Left
Right Ventricle
Systemic Circulation
Gaseous Exchange
Deoxygenated Blood
Oxygenated Blood

CIRCULATORY SYSTEM IN HUMAN



CIRCULATORY SYSTEM IN HUMAN



CIRCULATORY SYSTEM IN HUMAN

The Pulmonary Circulation

- Deoxygenated blood from the right ventricle is pumped to the lungs via the pulmonary arteries.
- In the alveolus, carbon dioxide is released and oxygen is taken up. Oxygenated blood passes back to the left atrium via the pulmonary veins.

CIRCULATORY SYSTEM IN HUMAN

The Systemic Circulation

- Oxygenated blood passes at high pressure from the left ventricle to the aorta for distribution to the rest of the body (except the lungs).
- The deoxygenated blood returns to the right atrium via the superior vena cava (from the head and arms), and the inferior vena cava (from the legs and rest of the body).

CIRCULATORY SYSTEM IN HUMAN

2. In a double circulatory system, the blood passes through the heart twice for each circuit of the body.

3. The complete double circulatory system is made possible by the heart being divided in two.

CIRCULATORY SYSTEM IN HUMAN

4. The right side pumps deoxygenated blood to the lungs while the left side pumps oxygenated blood to the rest of the body (except the lungs).

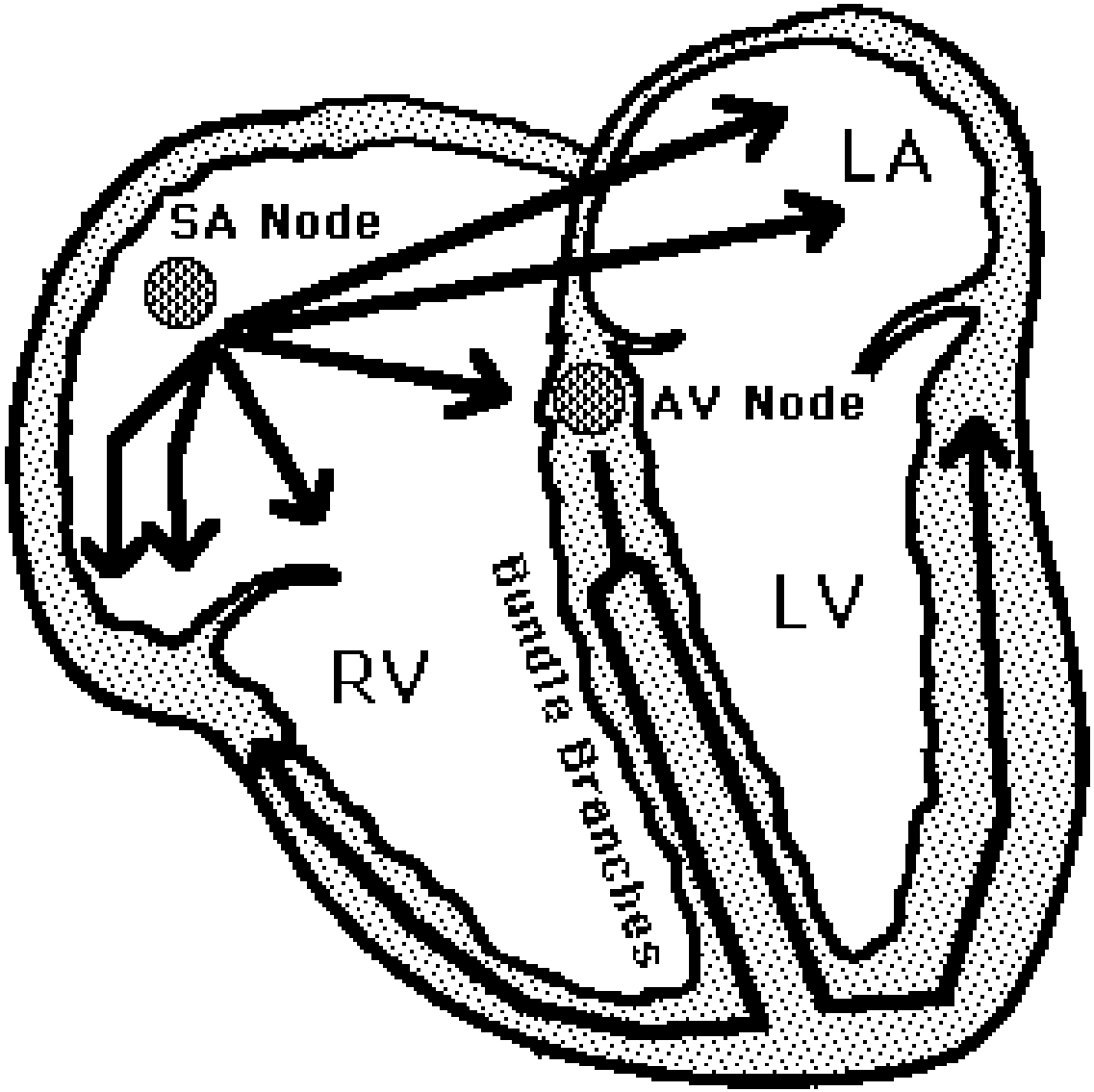
CIRCULATORY SYSTEM IN HUMAN

5. The advantage of the double circulatory system is that oxygenated blood returns to the heart to be pumped again before being distributed to the rest of the body.

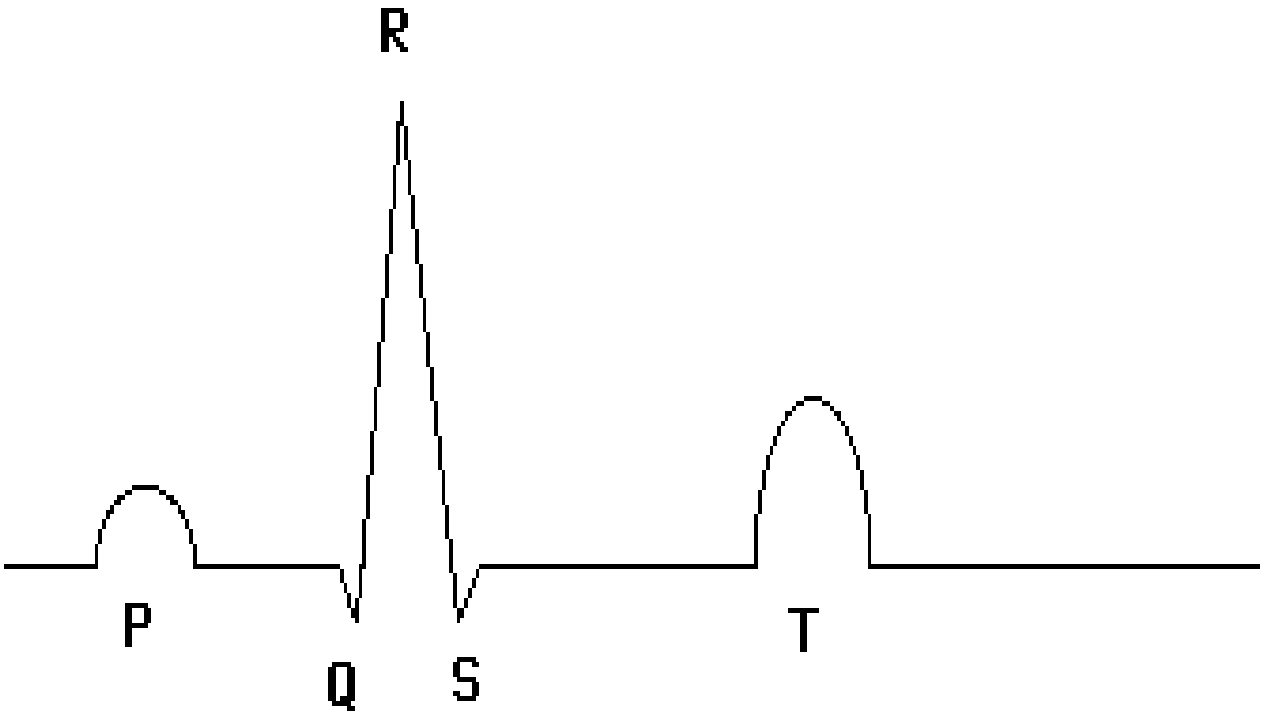
CIRCULATORY SYSTEM IN HUMAN

6. This action increases the pressure of the blood and the rate of flow, thereby speeding up the delivery of oxygen to the tissues and organs.

The SA and AV Nodes in Action

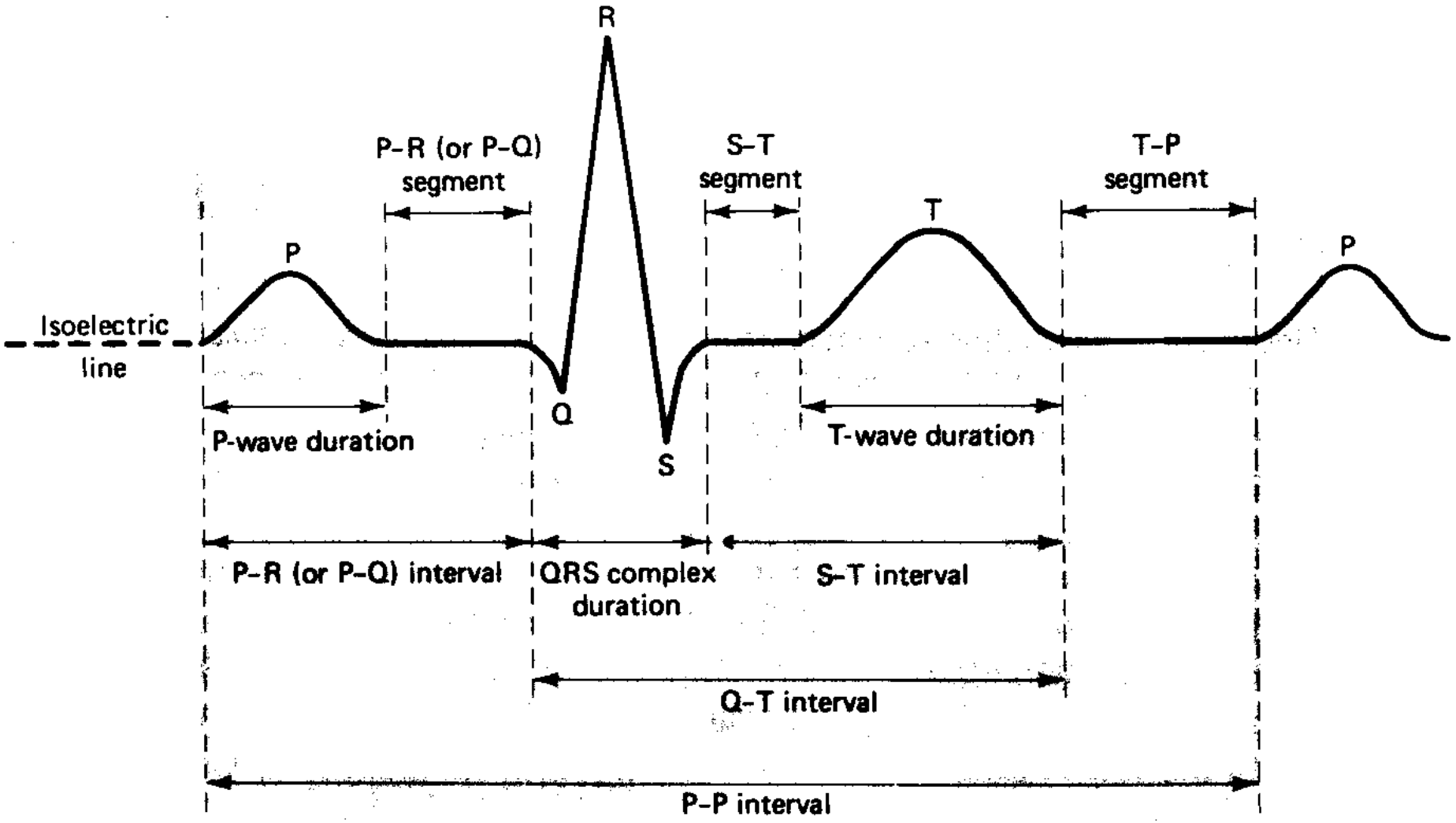


The Schematized EKG waveform

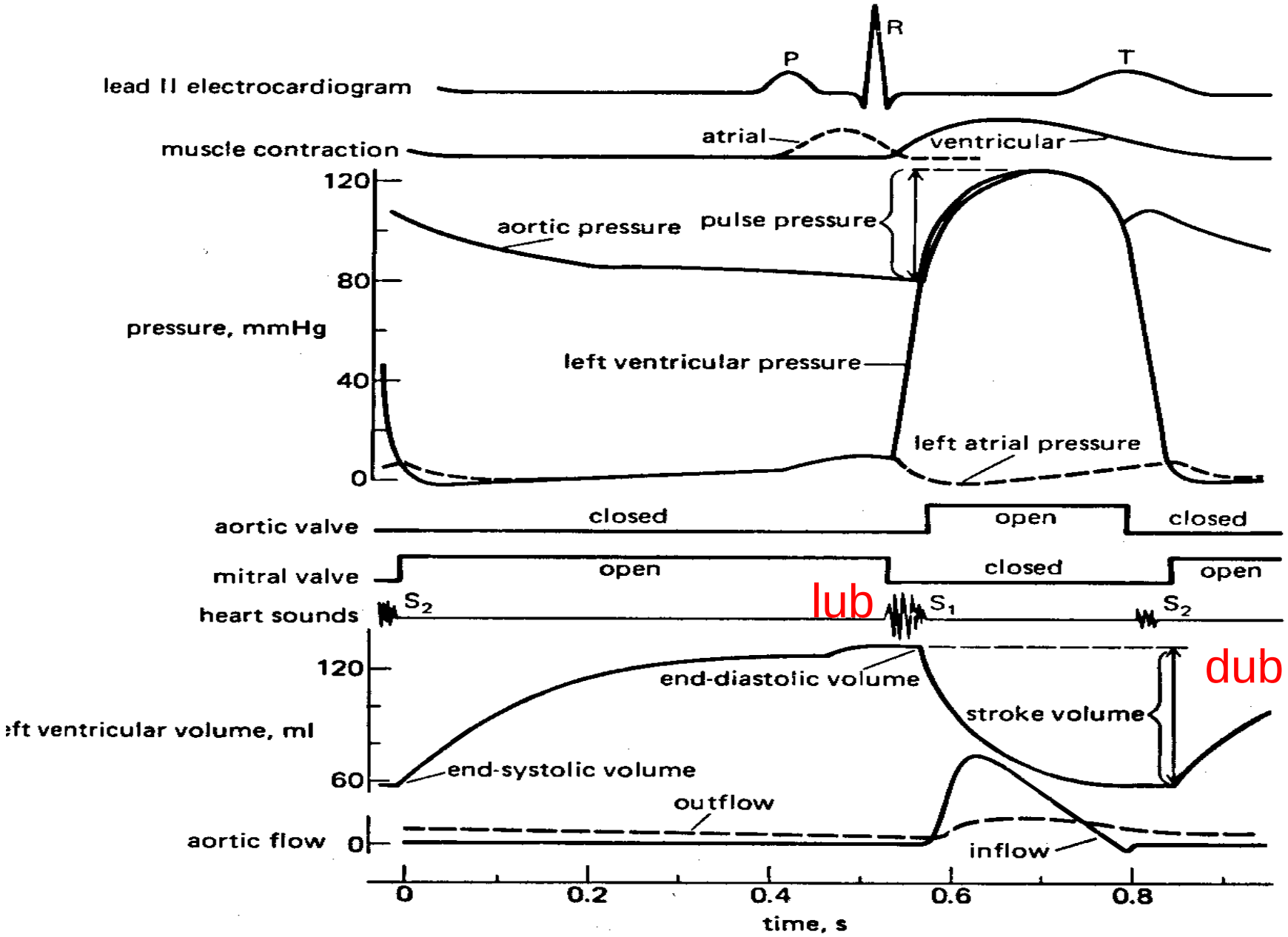


P = Atrial depolarization
QRS = Ventricular depolarization
T = Ventricular repolarization
Note that Atrial repolarization is not visible

The EKG waveform



The Cardiac Cycle

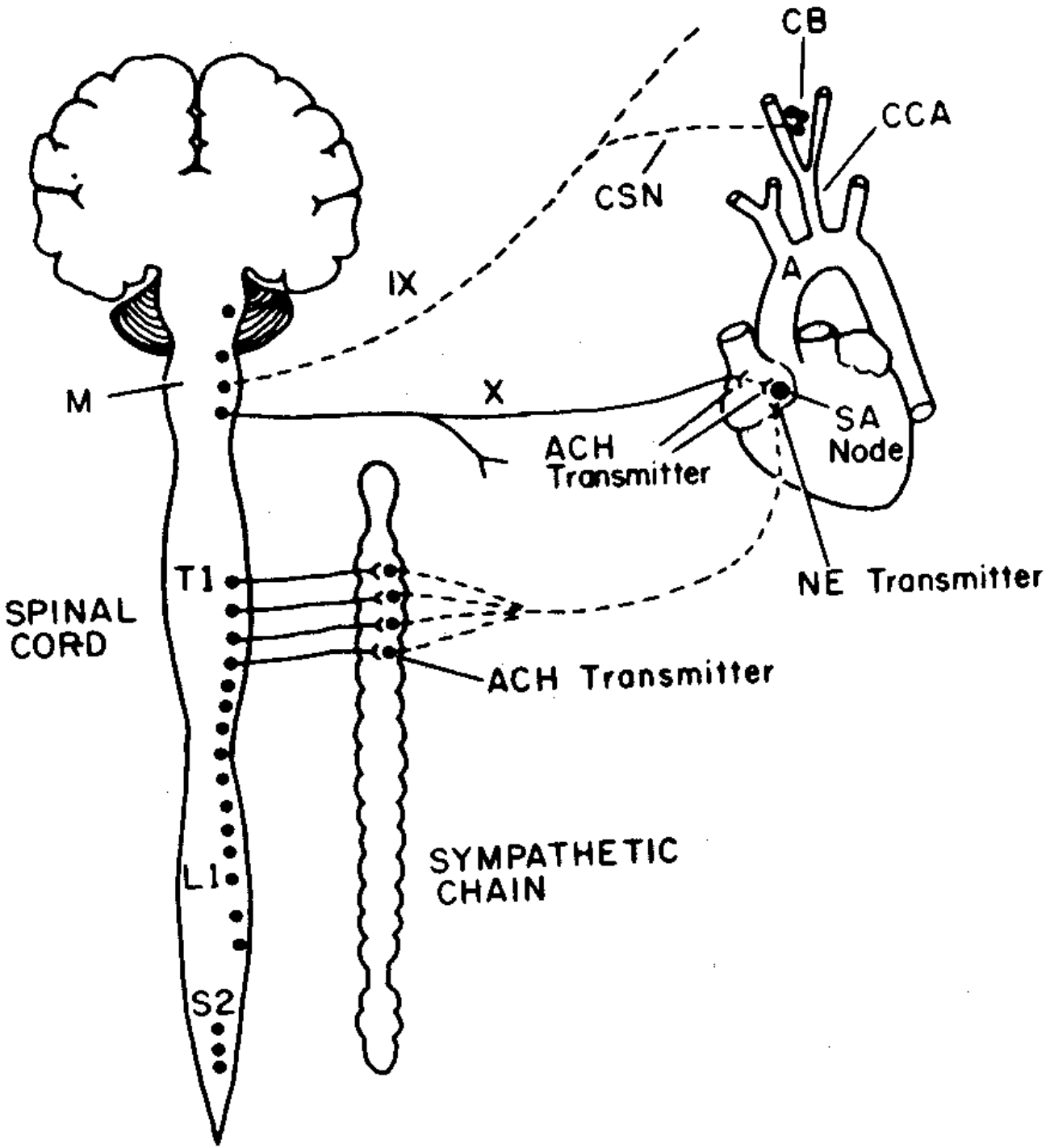


Cardiac Output

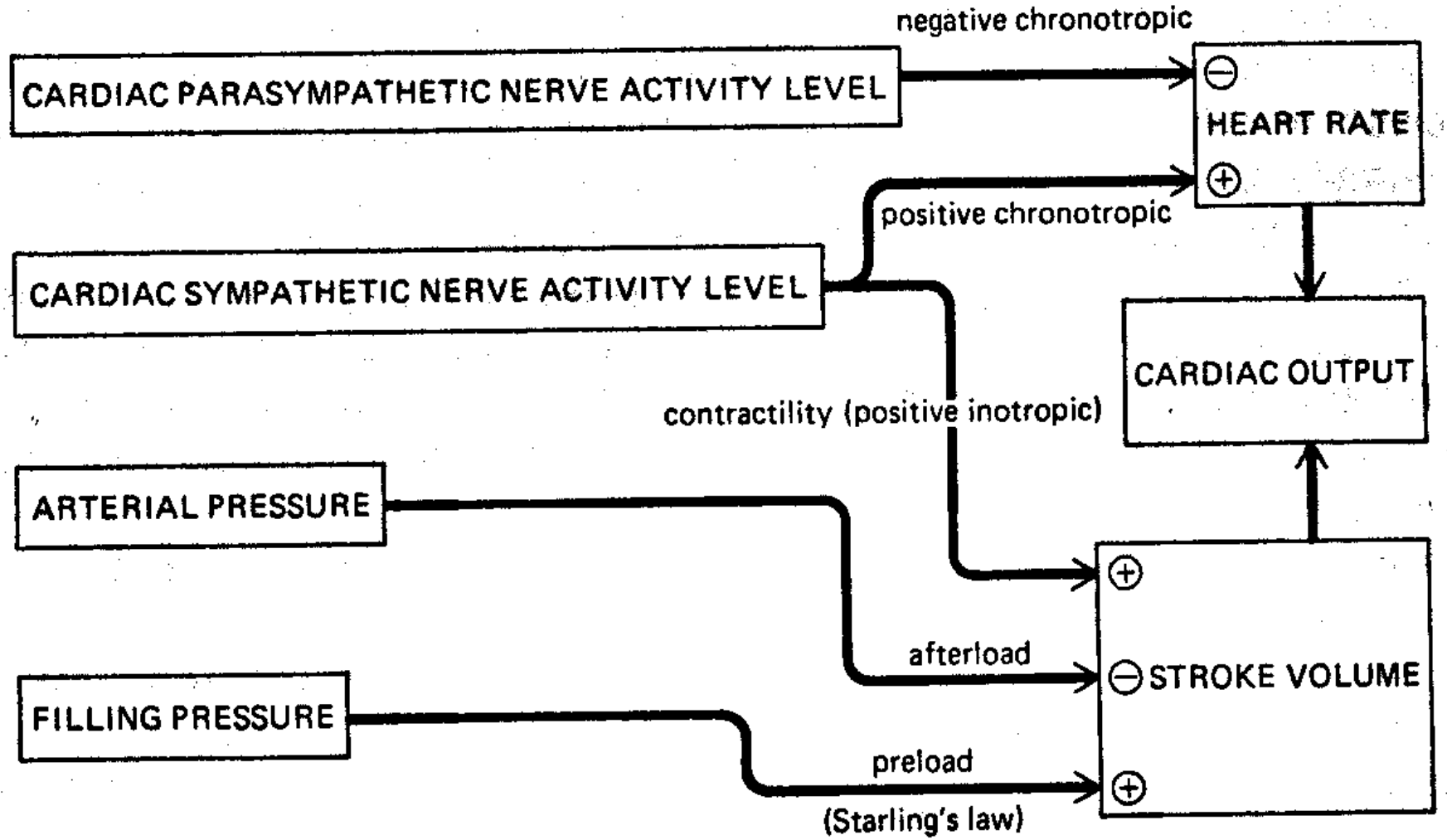
$$CO = HRxSV$$

Cardiac Chronoptropy

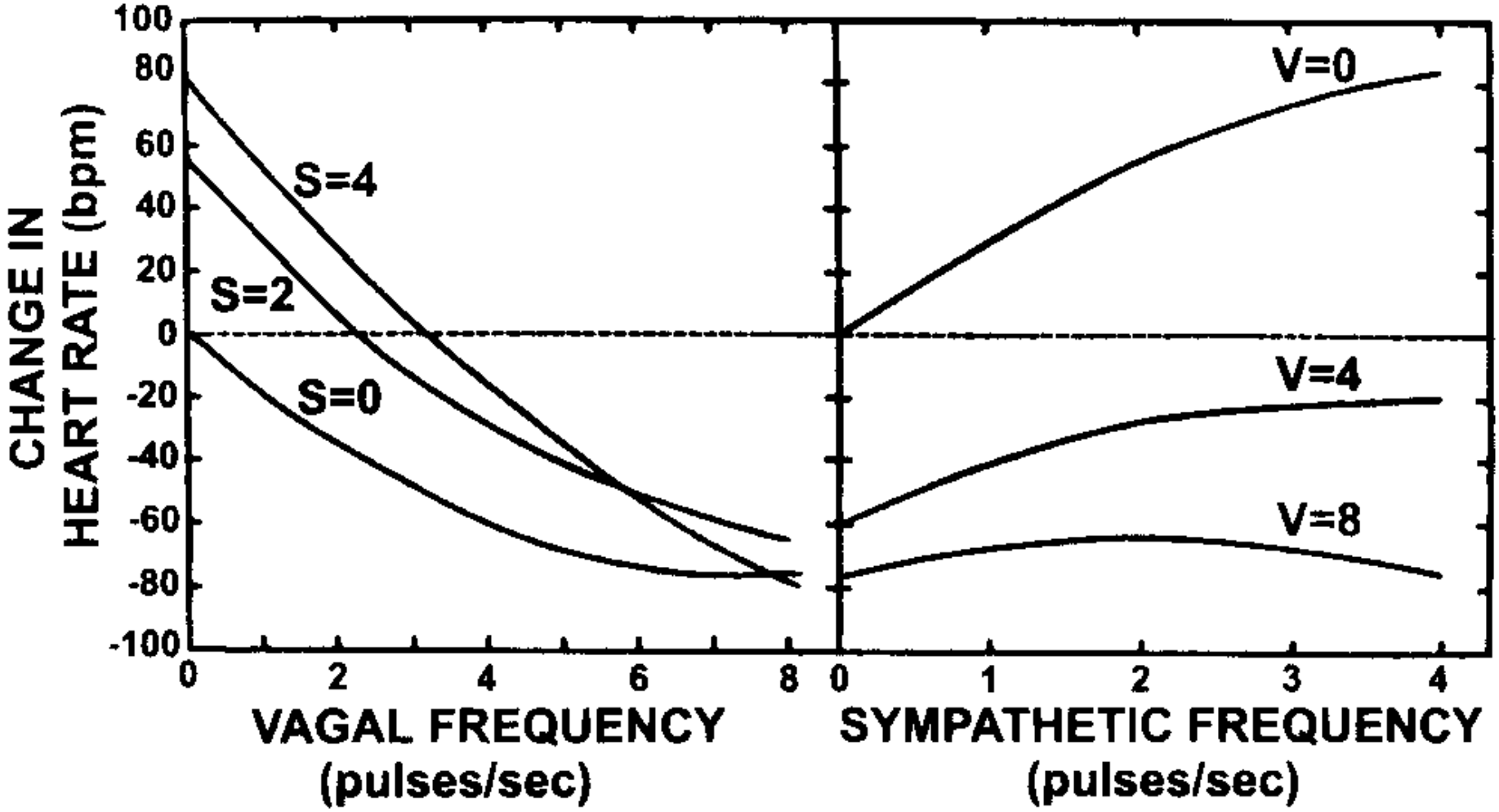
- Heart rate regulated extrinsically
- Vagal (PNS) influence
  - Slows HR
  - So too will dripping ACH on SA node ☺
  - Likely that all changes below 100 bpm are predominately vagally induced
- SNS influence
  - Speeds HR, but impact not as strong as PNS
  - Main effect is to increase contractility


CB
CCA
CSN
IX
A
M
X
SA
Node
ACH
Transmitter
NE Transmitter
T1
SPINAL
CORD
ACH Transmitter
SYMPATHETIC
CHAIN
L1
S2

SNS and PNS influences



HR change to simultaneous vagal and sympathetic stimulation



Integrated Control Mechanisms

- Baroreceptor Reflex
  - Pressure sensitive receptors
  - located in the arch of the aorta and carotid sinus nerves
  - Join Vagal and Glossopharangeal nerves
  - Terminate in regulatory centers in medulla
  - With increase in BP, causes compensatory decrease in HR, contractility, and SV
  - Quickly adjusts to maintain BP

Integrated Control Mechanisms

- Respiratory Effects
  - Respiratory Sinus Arrhythmia (RSA)
    - This arrhythmia is not a bad thing!
  - HR acceleration linked to inspiration
  - HR deceleration linked to expiration
- RSA
  - Indexes strength of Vagal influence
  - More later…

Cardiac Inotropy

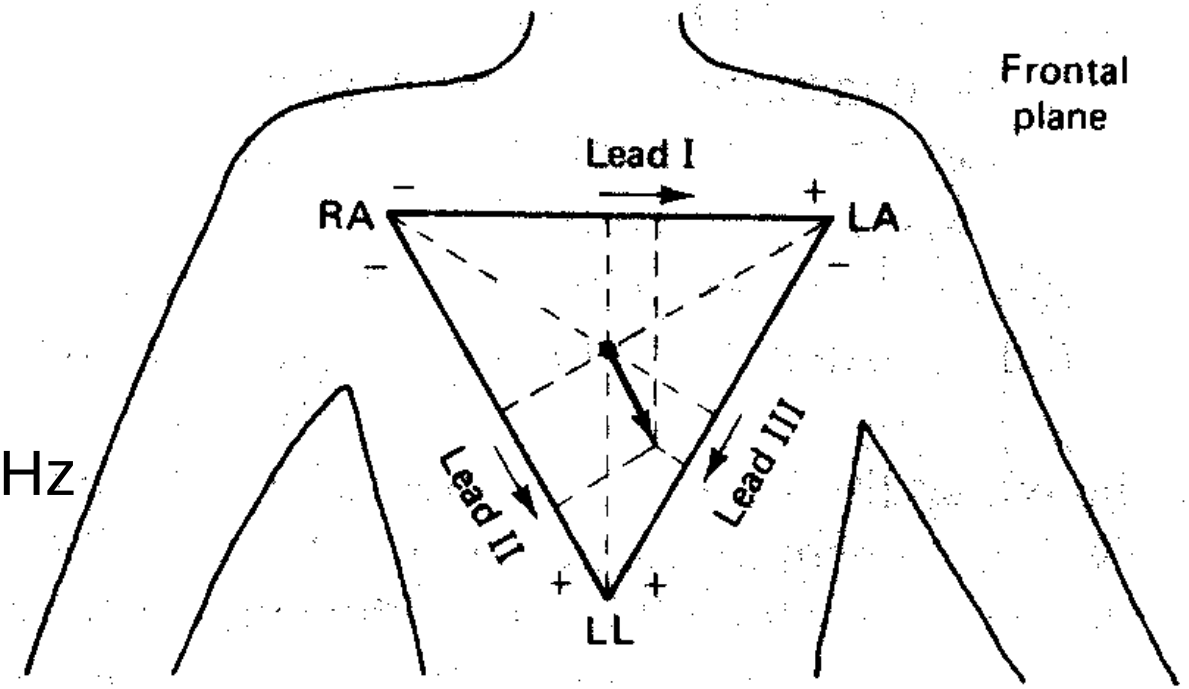
- Contractility is predominately Sympathetically mediated
- Often measured invasively, but can be measured noninvasively
  - EKG plus phonocardiogram
  - Impedance cardiography

Cardiovascular Measures

- Electrocardiogram (EKG)
- Phonocardiogram (PCG)
- Impedance cardiography
- Photoplethysmography
- Ballistocardiography
- Blood Pressure

EKG

AC signal
Sample 200-500 Hz

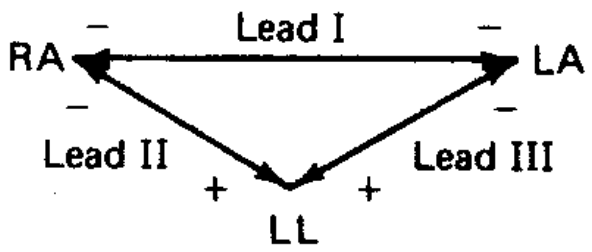


Bipolar

Bipolar limb leads: ECG voltage measurements between pairs of limbs:

Lead I:	between RA and LA
Lead II:	between RA and LL
Lead III:	between LA and LL

Einthoven triangle, showing relation of the bipolar limb leads



Which Time?

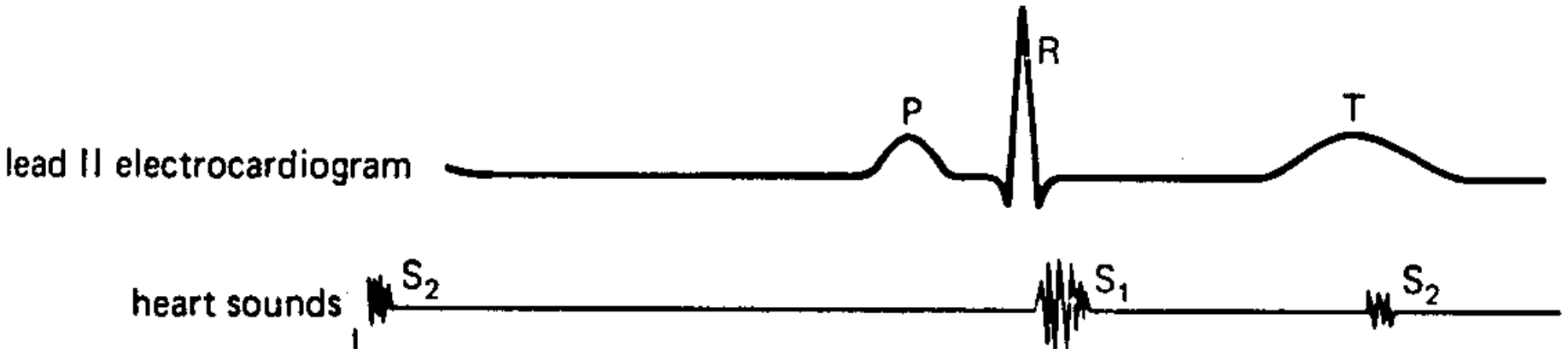
- Real time
  - Heart Rate
  - Expressed as beats per time (usually bpm)
- Cardiac time
  - Heart Period; interbeat interval (IBI)
  - Expressed in msec
- Converting

$$HR = \frac{1}{HP} x 60{,}000$$

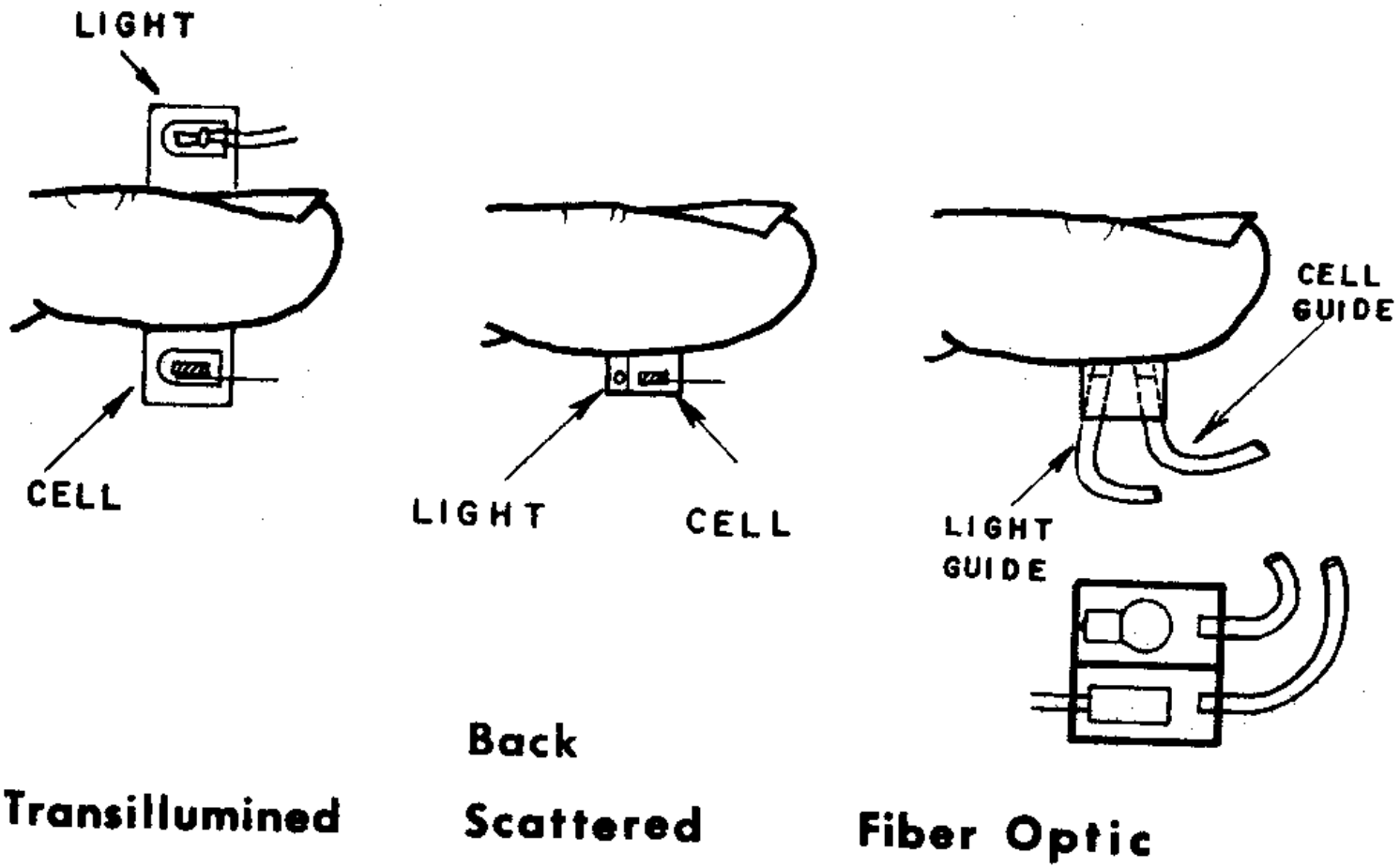
$$HR = \frac{1}{1000} X\, 60{,}000 = 60 bpm$$

Phonocardiography

- Position microphone over heart
- Lub-Dub is transduced to electrical signal

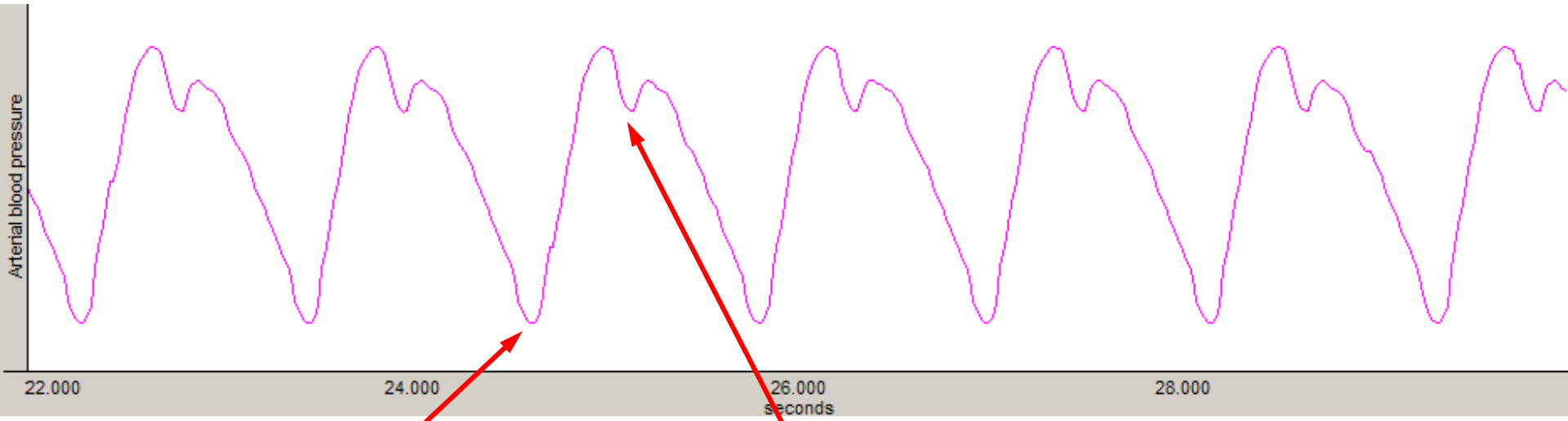


Photoplethysmography



Three methods, all involve measuring light absorbed by periph

The Photoplethysmographic Output

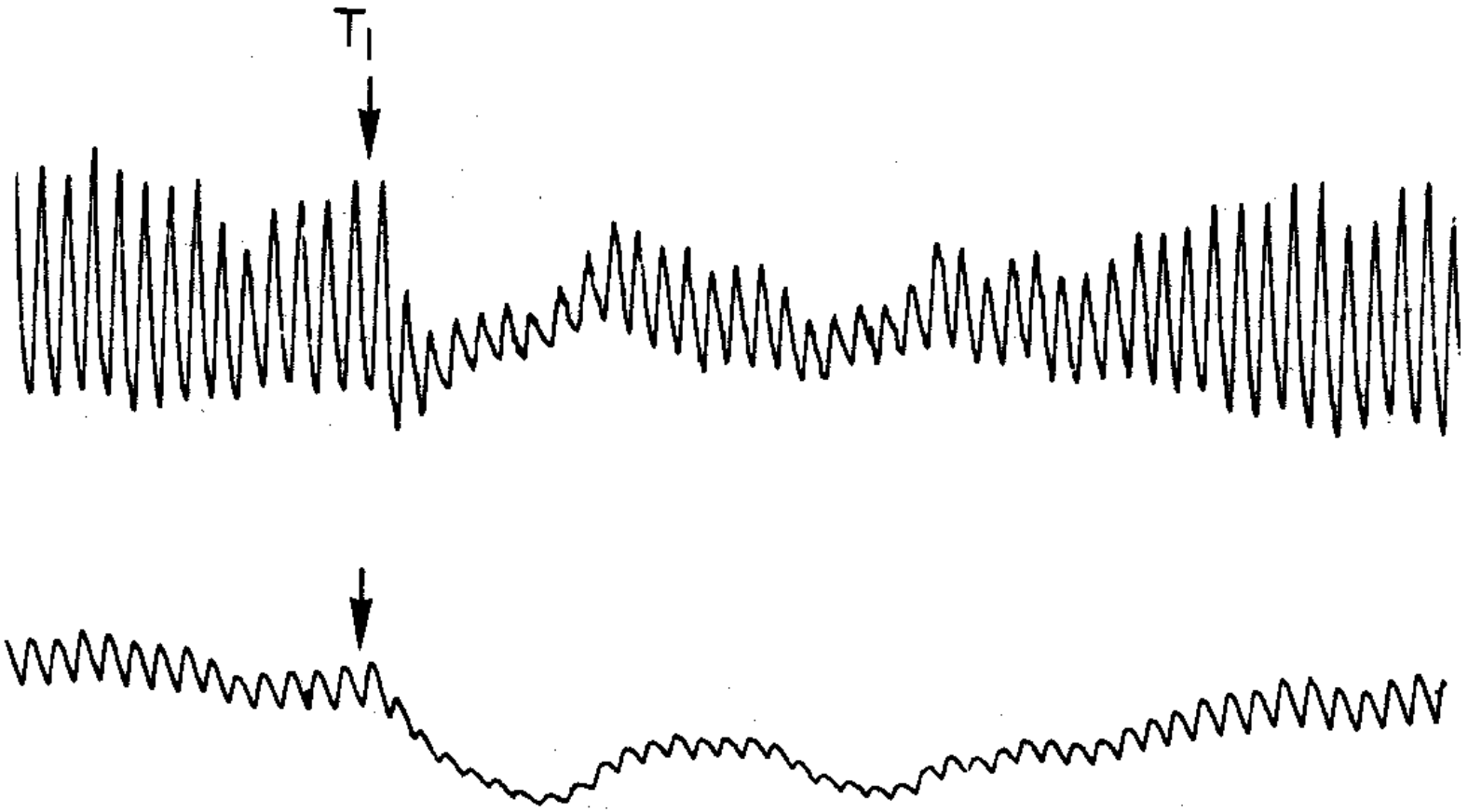


~LVET

Increase in Pressure due to opening of Aortic

Dichrotic Notch; closing of valve, end of ejection

Photoplethysmograph: Peripheral Vasoconstriction



T1 is onset of constriction
Top Panel: Pulse Volume (recorded with 1 sec time constant)
Lower Panel: Blood Volume (no filter)

Measuring contractility with EKG, PCG, and Photoplethysmography

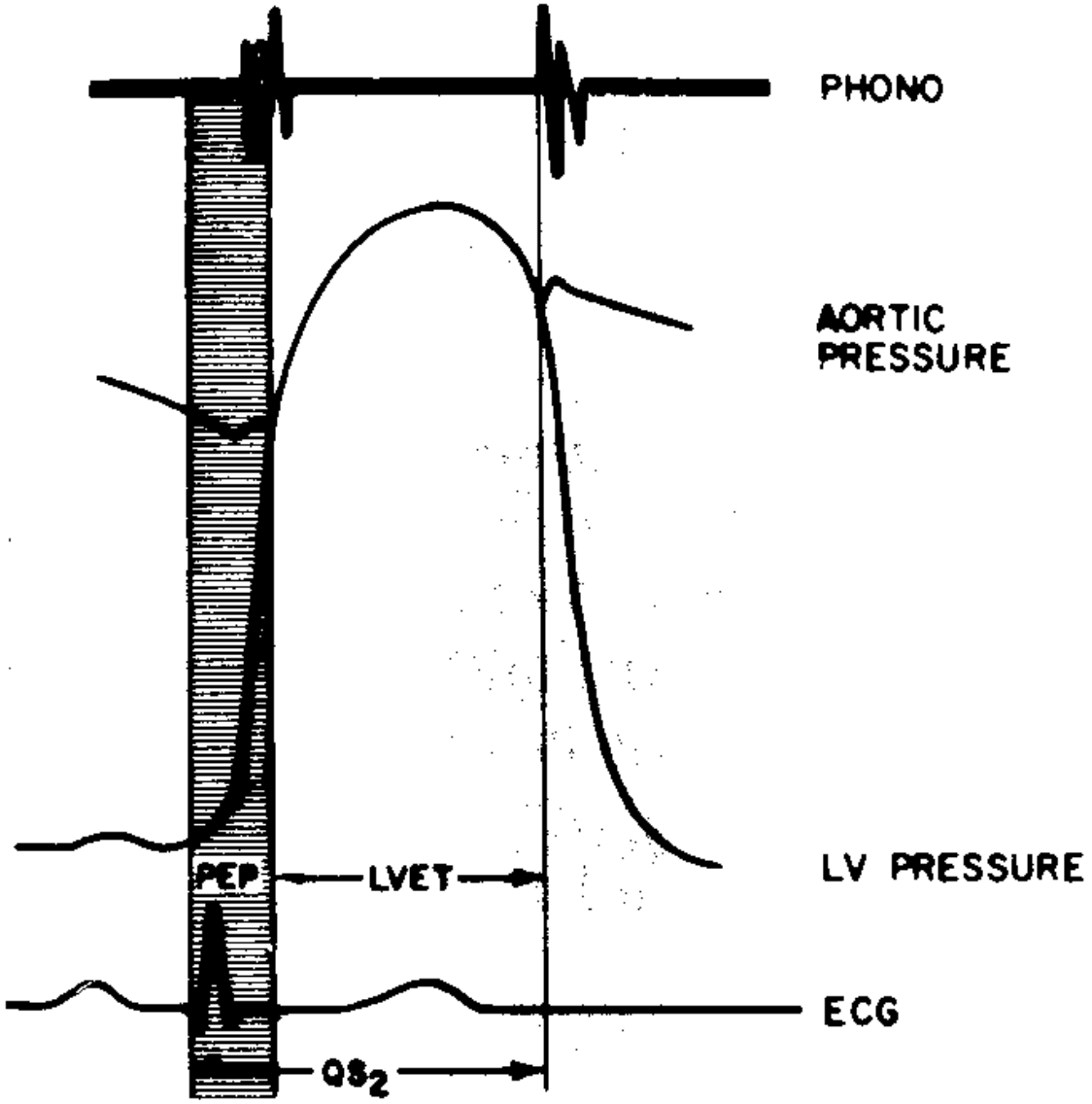
PEP = Pre-ejection period

LVET = Left Ventricular Ejection Time = Upswing of pressure wave to S2

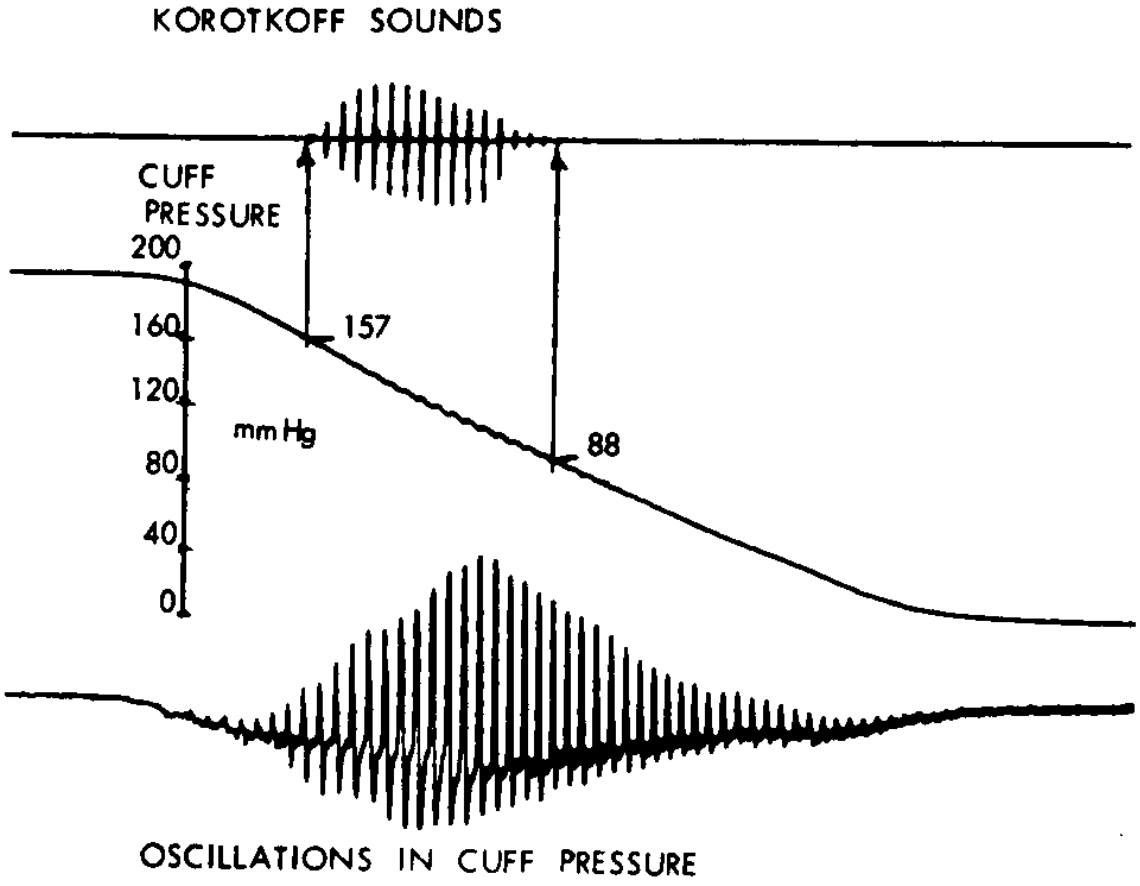
Electromechanical Systole = Q to S2

PEP = EMS – LVET

PEP reflects sympathetic influence on cardiac



Measuring Blood Pressure



Auscultatory Technique

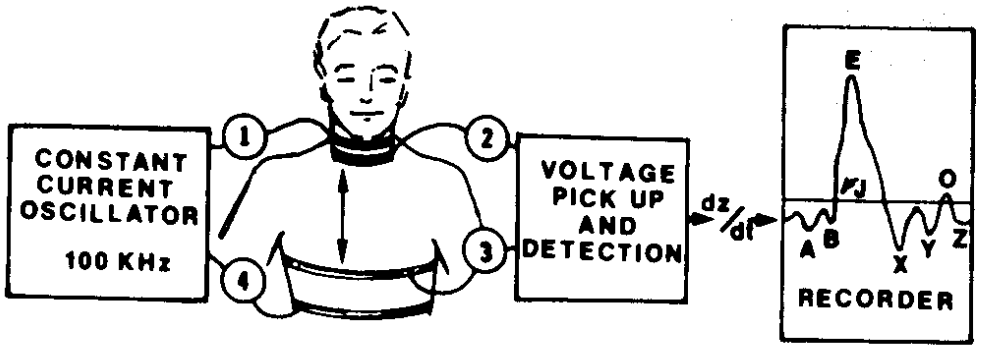
- Not good for instantaneous readings
- Not good for repeated readings

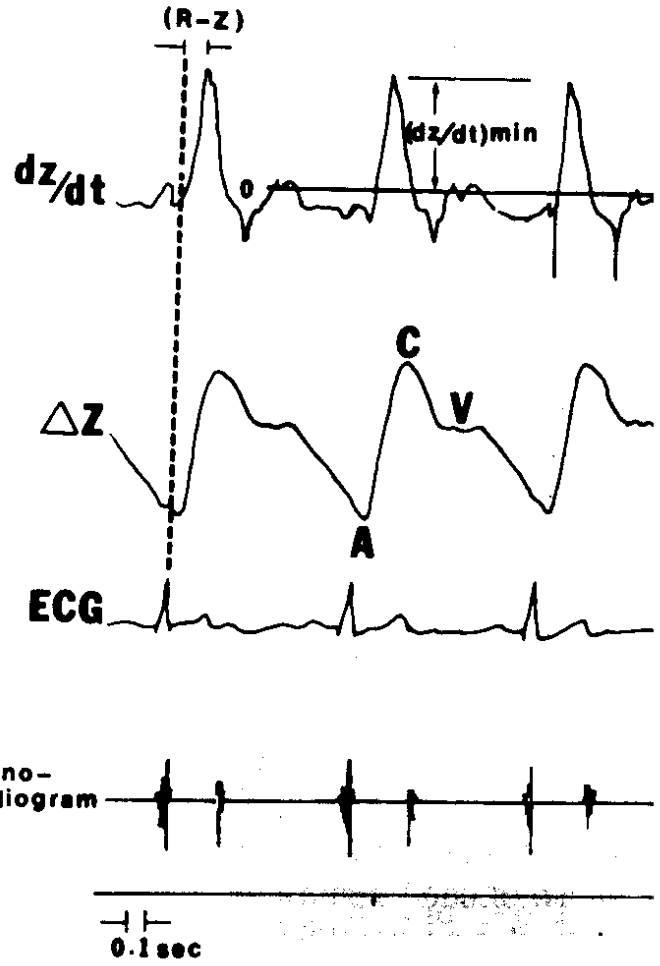
Ballistocardiography

- Imagine
  - On a chair on a platform on an air hockey table
  - Cardiac events cause movement of platform
- New applications:
  - Finding individuals hiding in vehicles
  - Finding individuals stuck in rubble

Impedance Cardiography

- Low energy high-frequency AC passed through thoracic region
- Changes in impedance to signal created by mechanical events of cardiac cycle
- ΔZ is change in impedance
- Dz/dt is 1st derivative of impedance signal Z
- R-Z is time from r-wave to peak ventricular contraction indicated in





Measuring Vagal Influence

- Descending Vagal Influence slows HR
- Respiration interrupts this vagal influence
- The size of periodic oscillations due to respiration will therefore index the strength of the Vagal influence
- Demo

Vagal Tone and Modulation

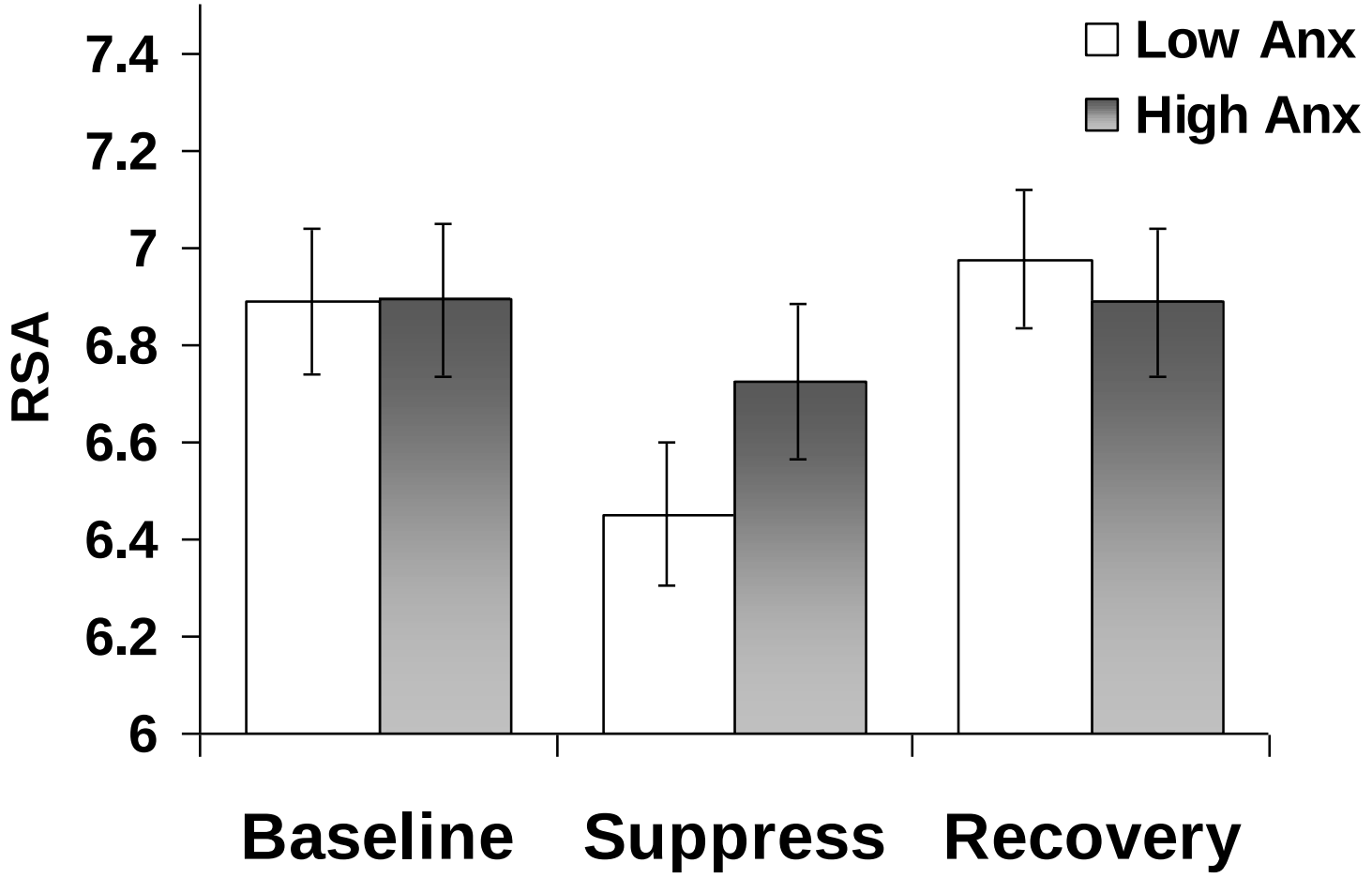
- Two Vagal Efferent Branches which terminate on SA Node
  - Reptilian “Dumb”: Dorsal Motor Nucleus
    - Massive reduction in HR & conservation of oxygen.
    - Dive reflex
  - Phylogentically newer “smart” Vagus
    - Orginates from Nucleus Ambiguous
    - Modualtes influence to:
      - Promote attentional engagement, emotional expression, and communication.
    - Mobilizes organism to respond to environmental demands
      - Phasicly withdraws inhibitory influence, increasing HR
      - Upon removal of the environmental stressor, resumes its efferent signal
        - » Slowing heart rate
        - » Allows the organism to self-sooth

Porges 1995, Beaucha

Tonic Vs Phasic

- Tonic Level indexes capacity
- Phasic change indexes actualization of that capacity
- Attention
  - higher vagal tone was associated with faster reaction time to a task requiring sustained attention
  - Hyperactive kids treated with Ritalin (Porges, Walter, Korb, & Sprague, 1975).
    - attentional skills improved
    - appropriate task-related suppression of heart rate variability was observed while performing the task requiring sustained attention
- Emotion
  - Beauchaine (2001):
    - low baseline vagal tone is related to negative emotional traits
    - high vagal withdrawal is related to negative emotional states

Task-related and Emotion-related modulation



Movius & Allen, 2001

Trait Vagal Tone

- Infants
  - Various sick infants have lower vagal tone (Respiratory Distress Syndrome, Hydrocephalic)
  - Infants with higher vagal tone (Porges, various years)
    - More emotionally reactive (both + & -)
    - More responsive to environmental stimuli (behaviorally and physiologically)
- Anxiety Disorders
  - Lower Vagal Tone in GAD (Thayer et al., 1996)
  - Lower Vagal Tone in Panic Disorder (Friedman & Thayer, 1998)
- Depression
  - Depression characterized by lower Vagal tone?
  - Gender may moderate (Thayer et al., 1998)
    - Note small sample: 15 depressed, 11 controls
  - State dependent? (Chambers & Allen, in press)

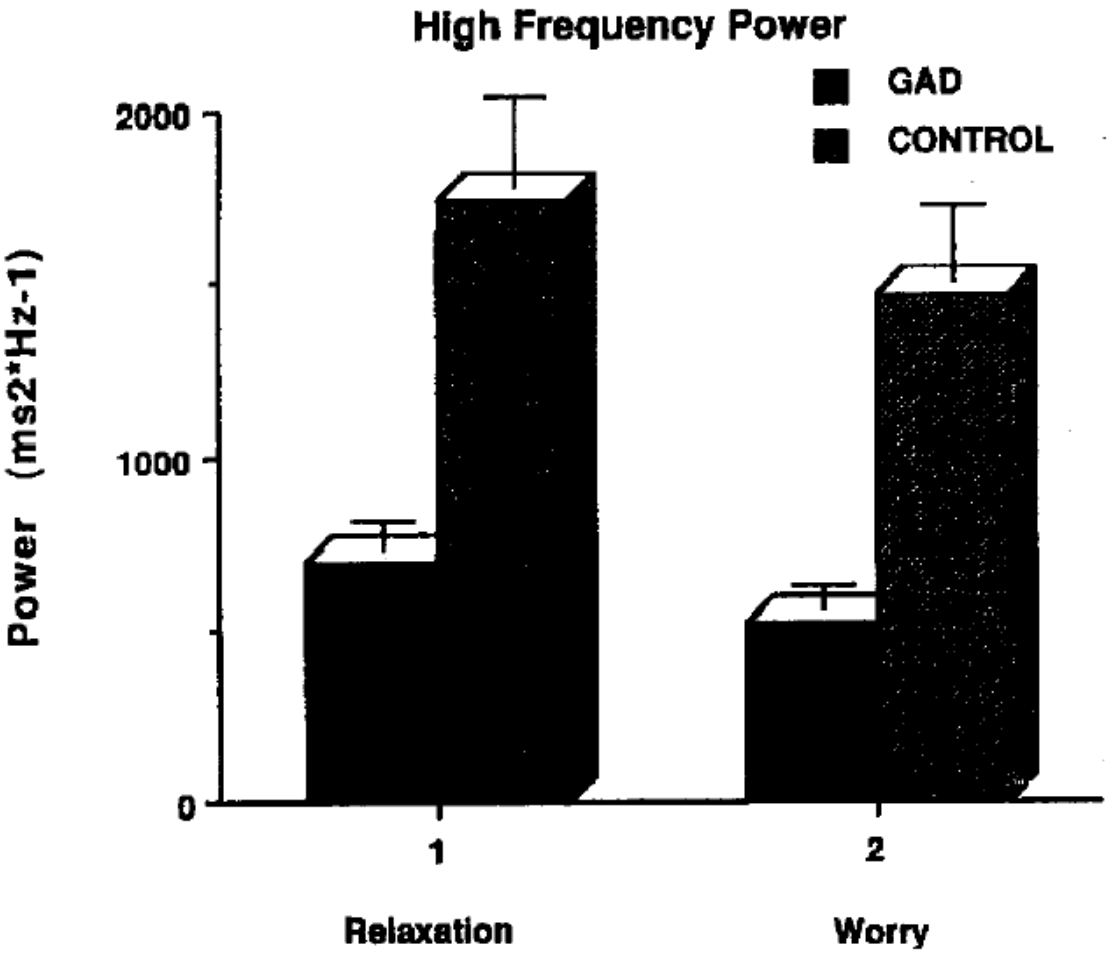
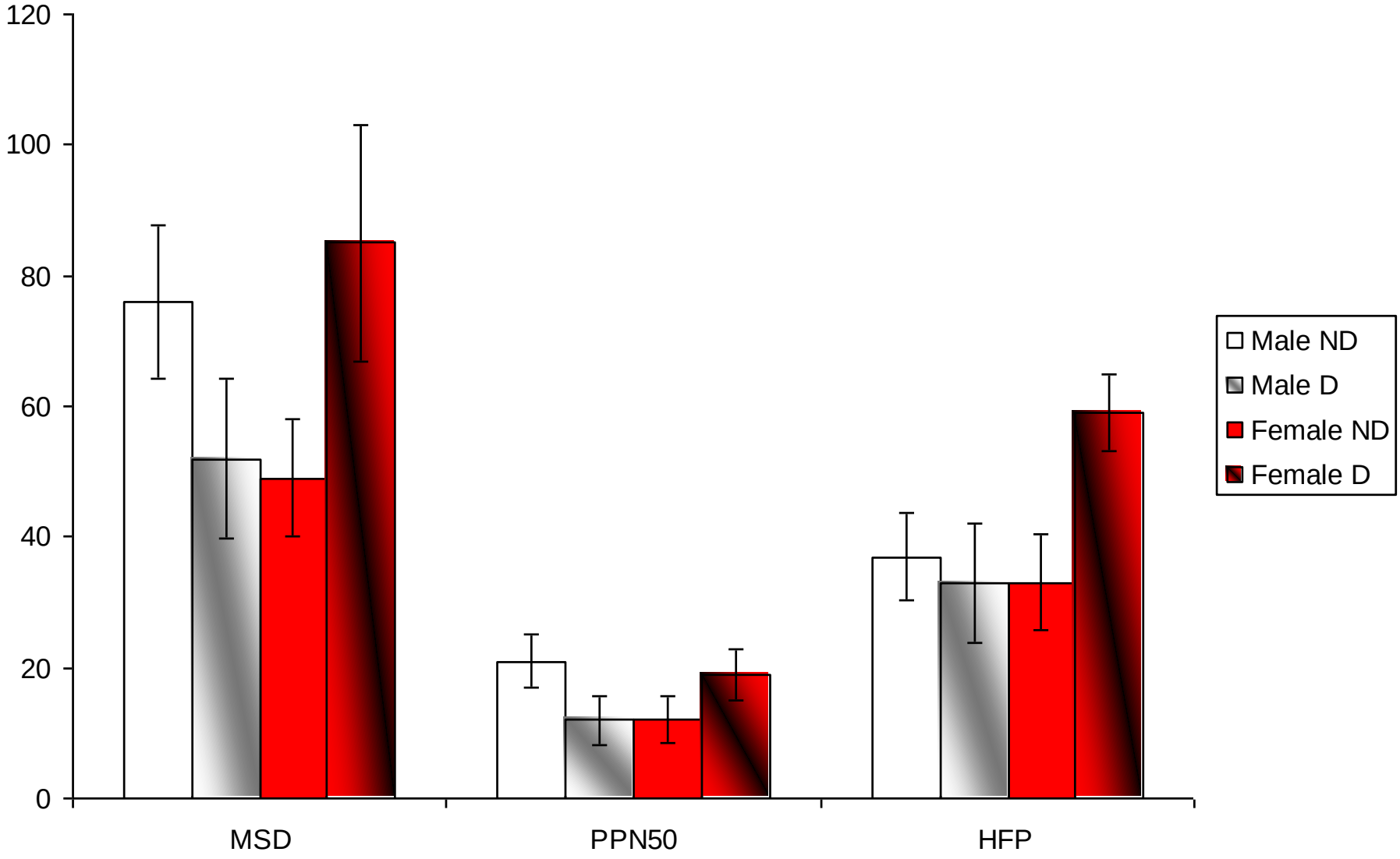


Figure 1. Power in the high frequency (respiratory) component of heart period variability in GAD patients and controls during relaxation and worry.

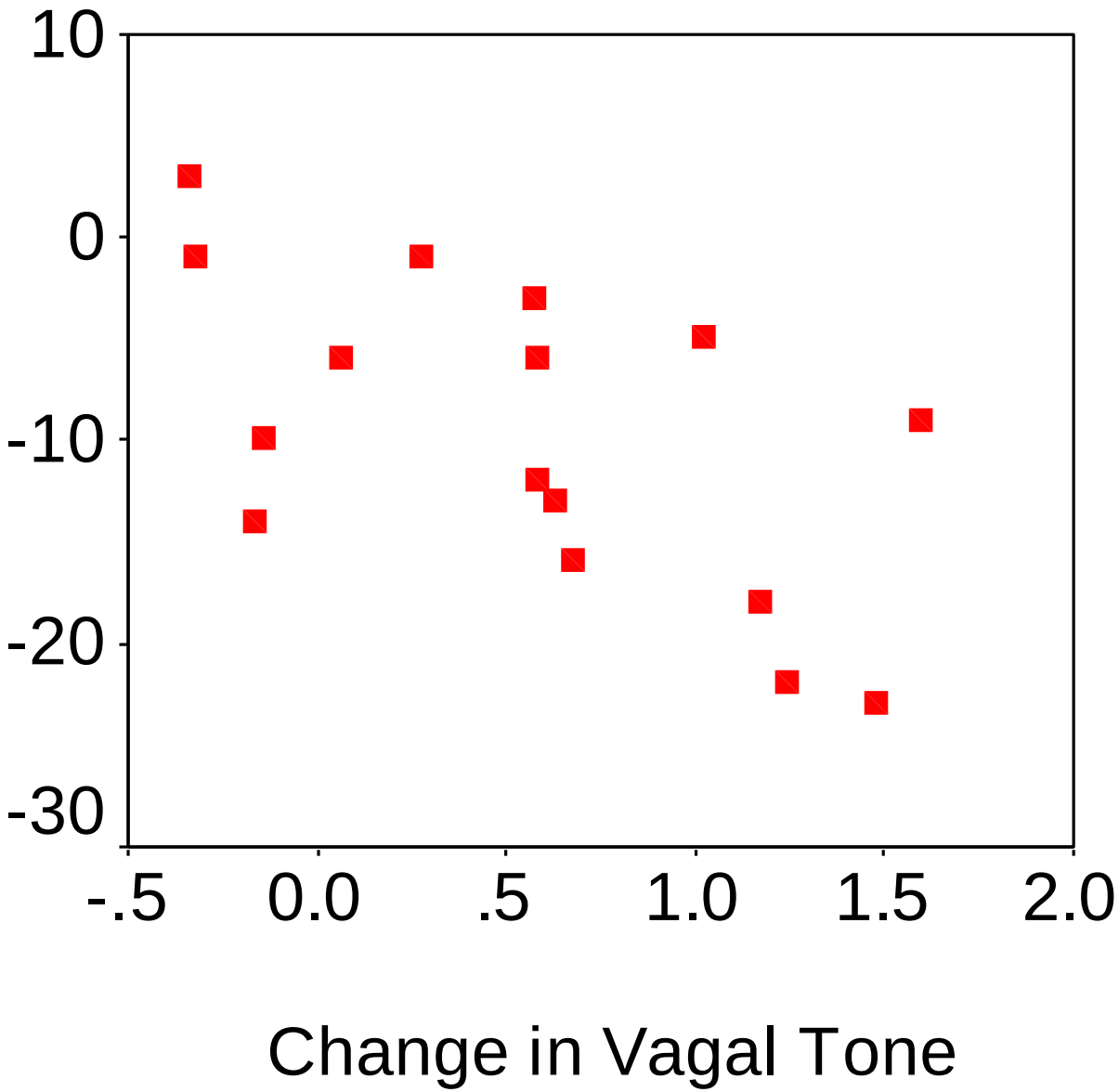
Table 1
Significant contrasts among panickers, blood phobics, and controls

Variable	Panic (mean, S.D.)	Blood phobic (mean, S.D.)	Control (mean, S.D.)	T ratio, df, p value
IBI (ms)	761.8 (141.0)	837.1 (92.4)	905.2 (132.5)	P < B 4.59 (215) $p < 0.001$ P < C 7.65 (214) $p < 0.001$ B < C 4.30 (207) $p < 0.001$
VAR (ms^2)	3942 (4009)	4334 (2663)	6112 (4563)	P < C 3.70 (214) $p < 0.001$ B < C 3.44 (207) $p < 0.001$ P = B N.S.
MSD (ms)	44.4 (31.2)	55.6 (22.7)	71.4 (32.1)	P < B 3.05 (215) $p < 0.001$ P < C 6.34 (214) $p < 0.001$ B < C 4.11 (207) $p < 0.001$
HF power (ms^2 Hz^{-1})	991 (1225)	1385 (1073)	2239 (1911)	P < B 2.49 (212) $p < 0.01$ P < C 5.67 (212) $p < 0.001$ B < C 3.90 (203) $p < 0.001$
LF/HF	2.1(2.5)	1.3 (1.8)	1.0 (1.5)	P < B 2.41 (209) $p < 0.005$ P < C 3.64 (203) $p < 0.001$ B = C N.S.

P, panic; B, blood phobic; C, control.



Data from Thayer et al., 1998, *Bio P*



Chambers and Allen, in

Trait Vagal Tone (cont')

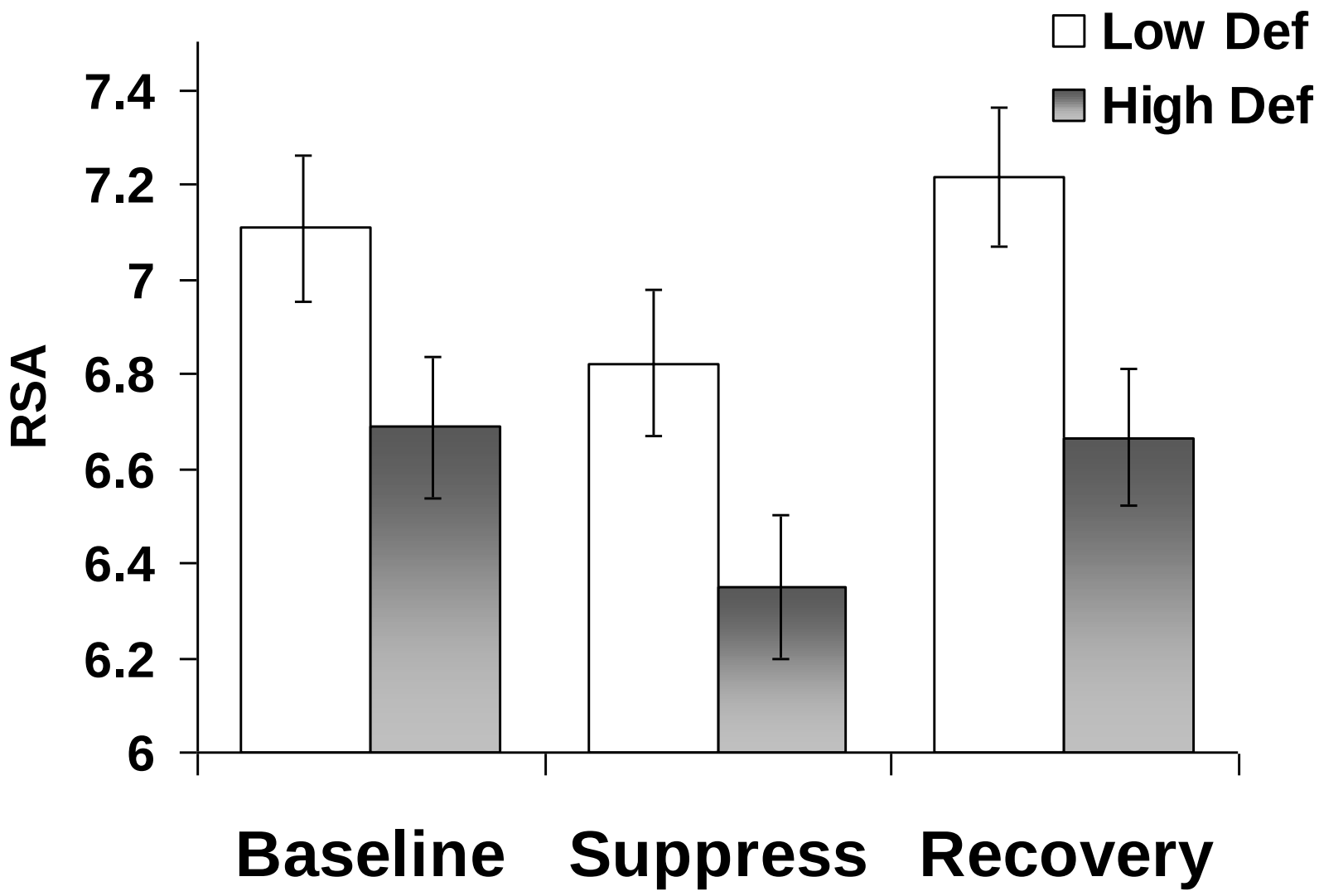
- Defensive Coping (Movius & Allen, 2001)
- Integrative Developmental Model

Beauchaine (2001)

Table 1. *Patterns of autonomic nervous system functioning in common psychopathologies and personality types*

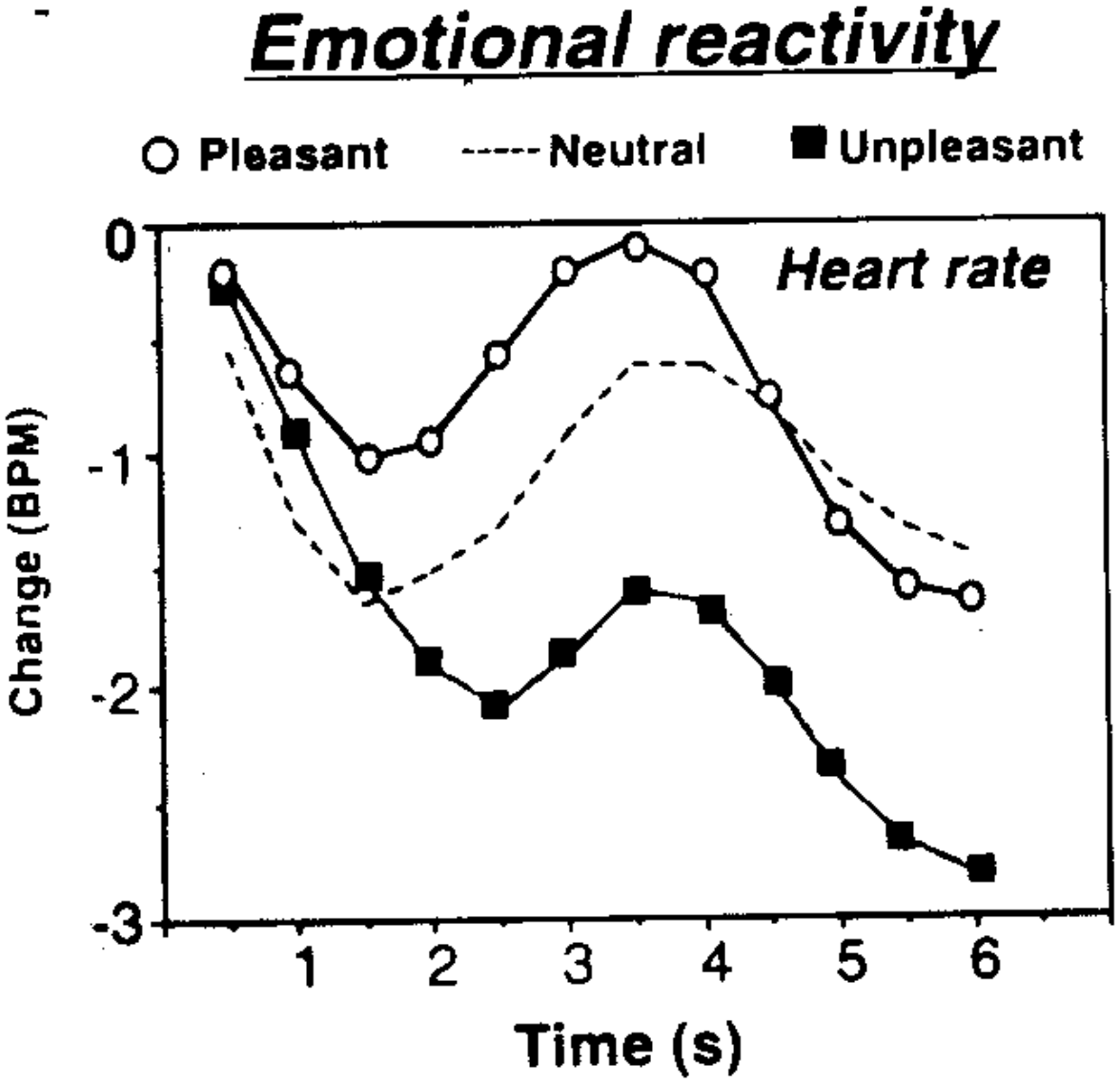
Motivational Predisposition	Behavioral Manifestation	Motivational System (SNS)		Regulational System (PNS)	
		Activation (BAS)	Inhibition (BIS)	Emotional Trait (RSA)	Emotional State (RSA Reactivity)
Disinhibition	Impulsivity (ADHD)	High	Low	—	—
	Aggression (UACD)	High	Low	Low	High
	Panic	High	High	Low	High
	Extraversion	High	—	—	—
Inhibition	Anxiety	—	High	Low	—
	Depression	Low	High	Low	—
	Panic	High	High	Low	High
	Introversion	—	High	—	—
None	Emotional stability	—	—	High	—
	Emotional lability	—	—	—	High

Note: High, atypically high activity; Low, atypically low activity. Dashes represent normal activity. Entries in the BIS, RSA, and RSA reactivity columns are supported by the literature reviewed herein. Entries in the BAS column are more speculative and require empirical confirmation.

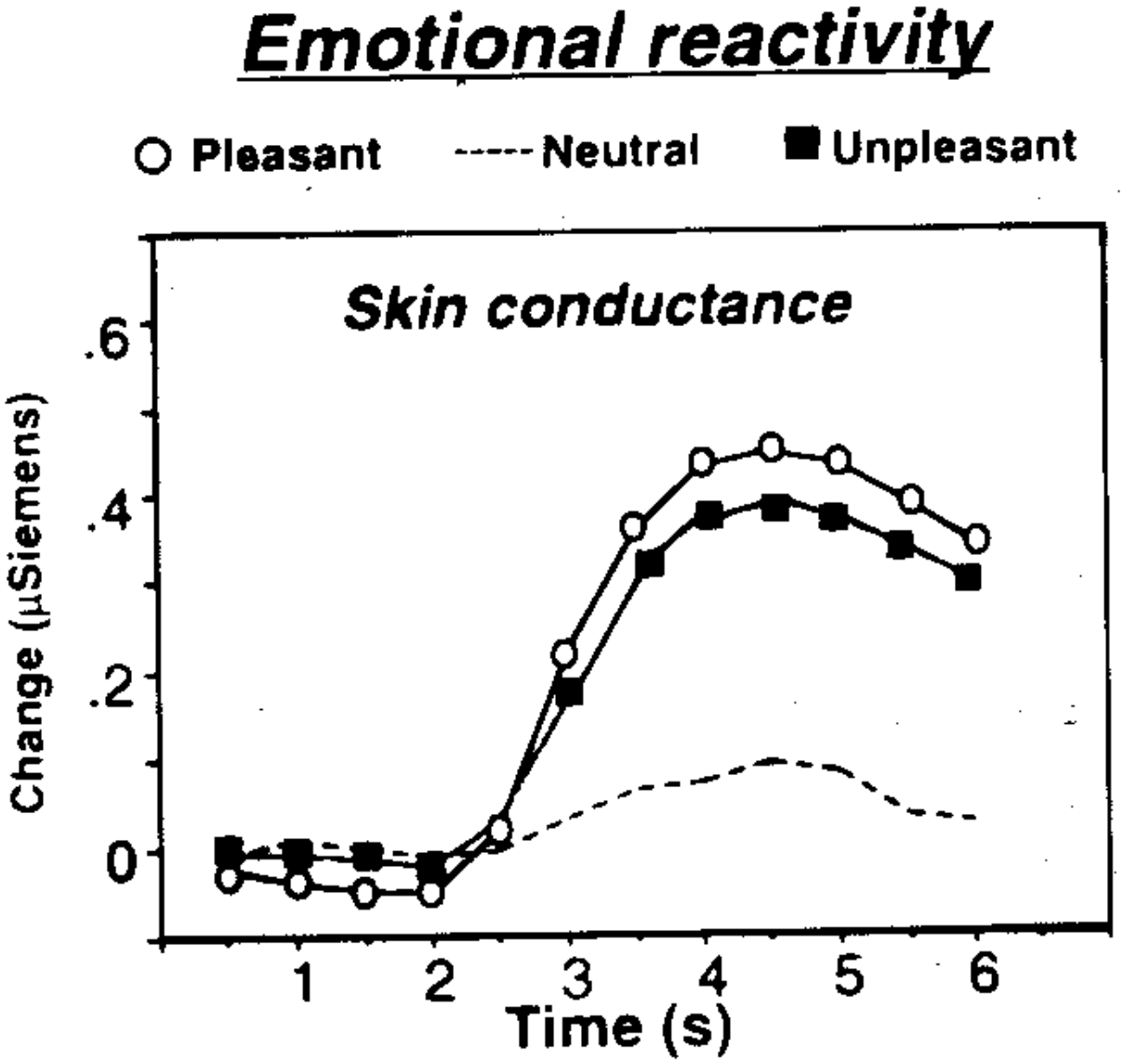


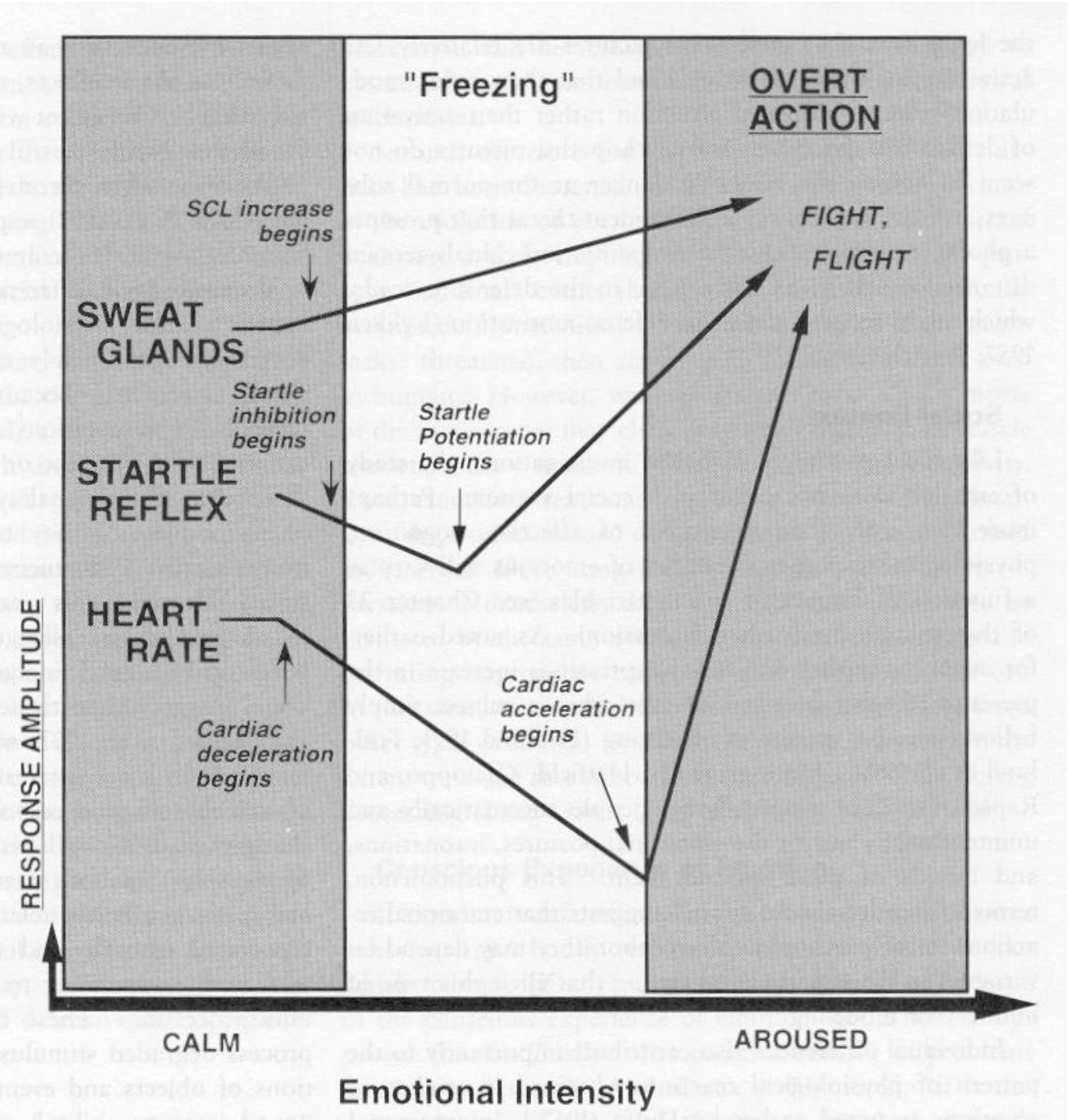
Movius & Allen, 2001

Orienting, Attention, and Defense



SCR (by contrast)




"Freezing"
OVERT ACTION
SCL increase begins
FIGHT, FLIGHT
SWEAT GLANDS
Startle inhibition begins
Startle Potentiation begins
STARTLE REFLEX
HEART RATE
Cardiac deceleration begins
Cardiac acceleration begins
RESPONSE AMPLITUDE
CALM
AROUSED
Emotional Intensity

OR Vs DR