

# Cardiovascular Physiology

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# Objectives

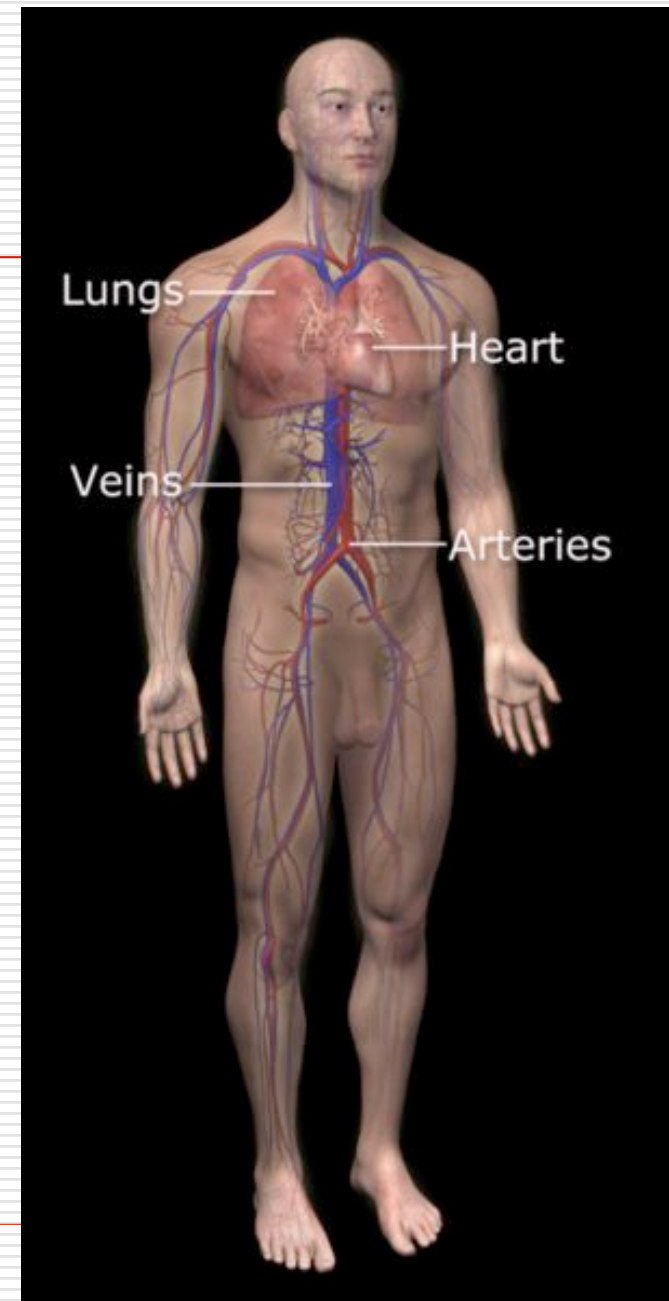
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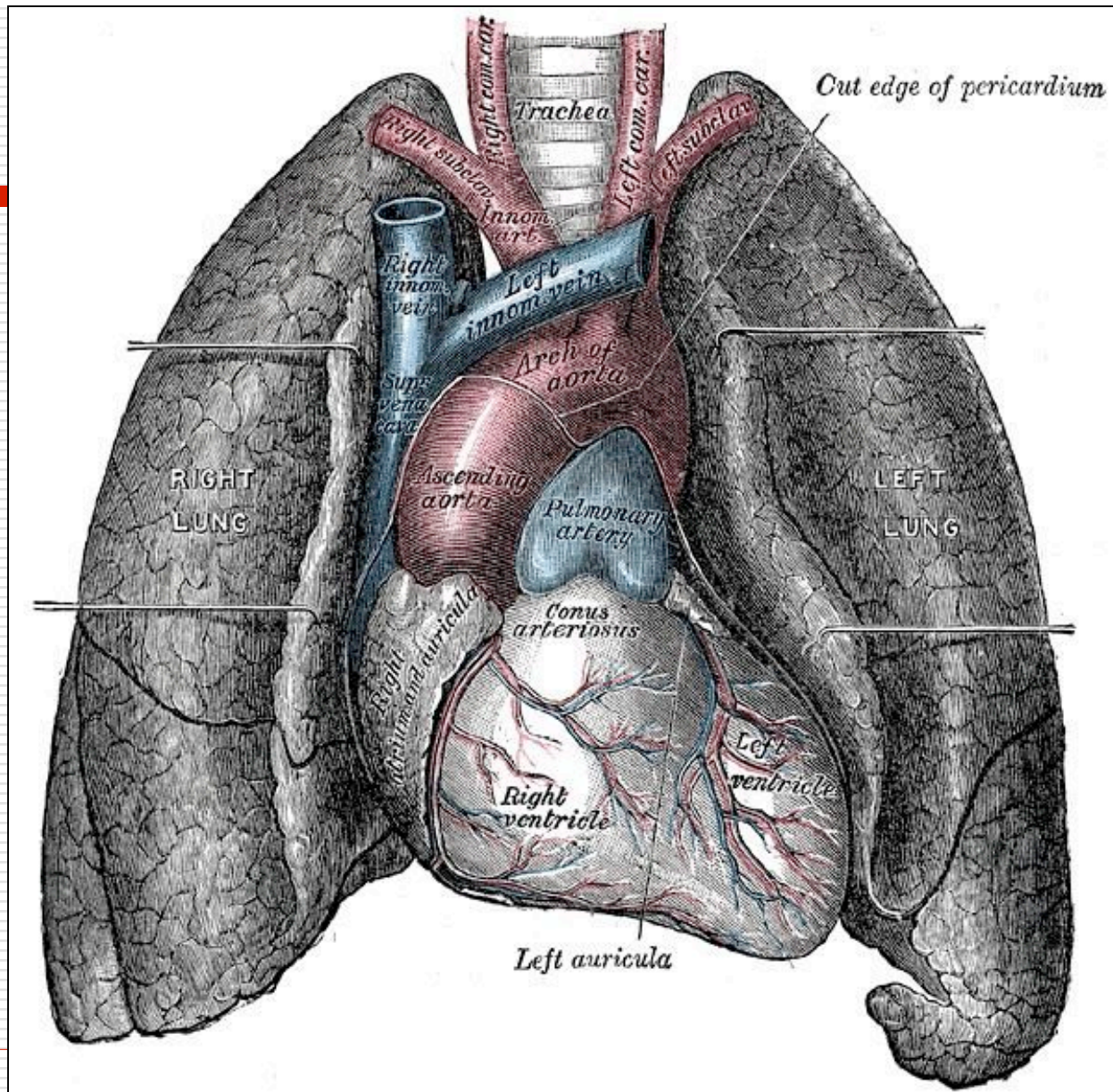
- Adult Circulation
  - Fetal Circulation
  - Cardiac myocyte
  - Electrical conduction in the heart
  - Cardiac Imaging
-

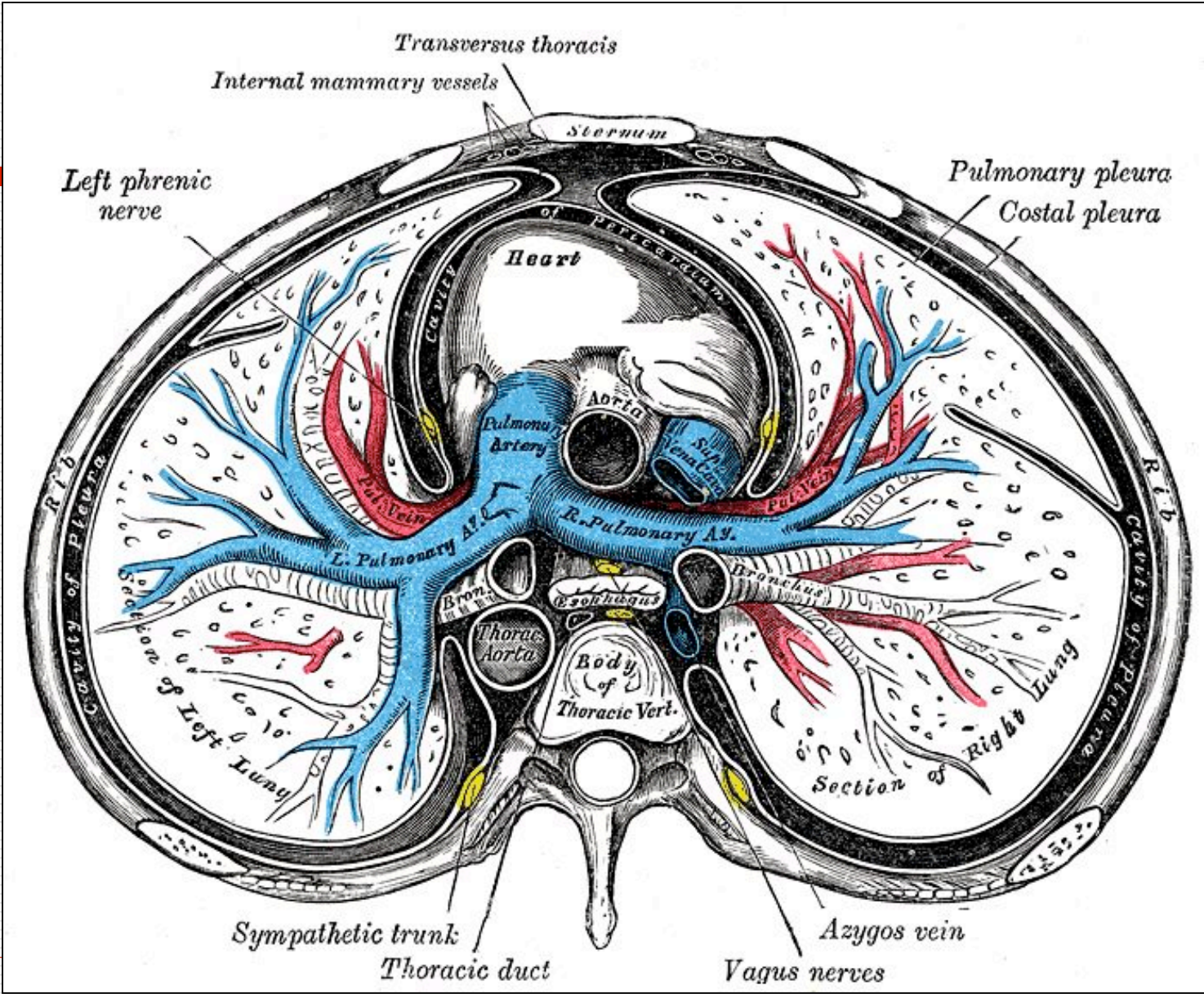
# Cardiovascular Anatomy

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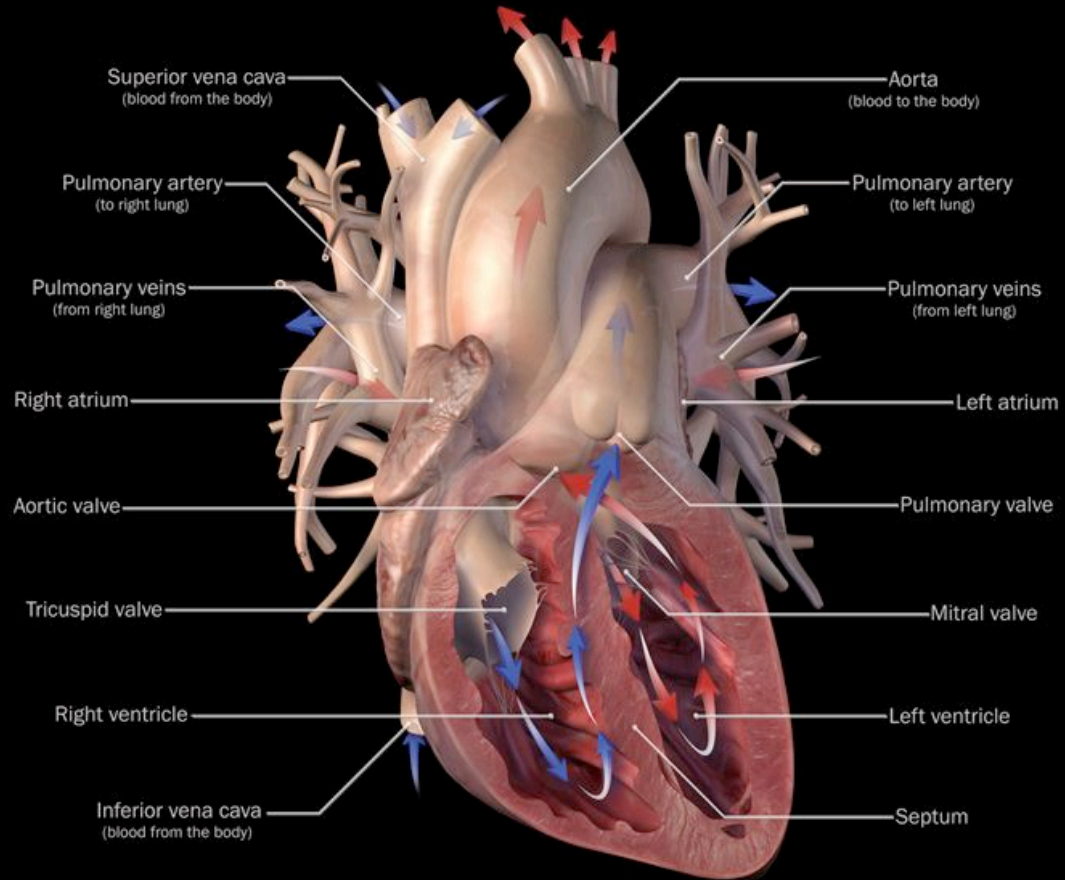
- ❑ Heart
  - ❑ Lungs
  - ❑ Arteries
    - Carry blood away from the heart
    - Usually oxygenated
    - Exception: Pulmonary arteries
  - ❑ Veins
    - Carry blood towards the heart
    - Ususally deoxygenated
    - Exception: Pulmonary veins
- 



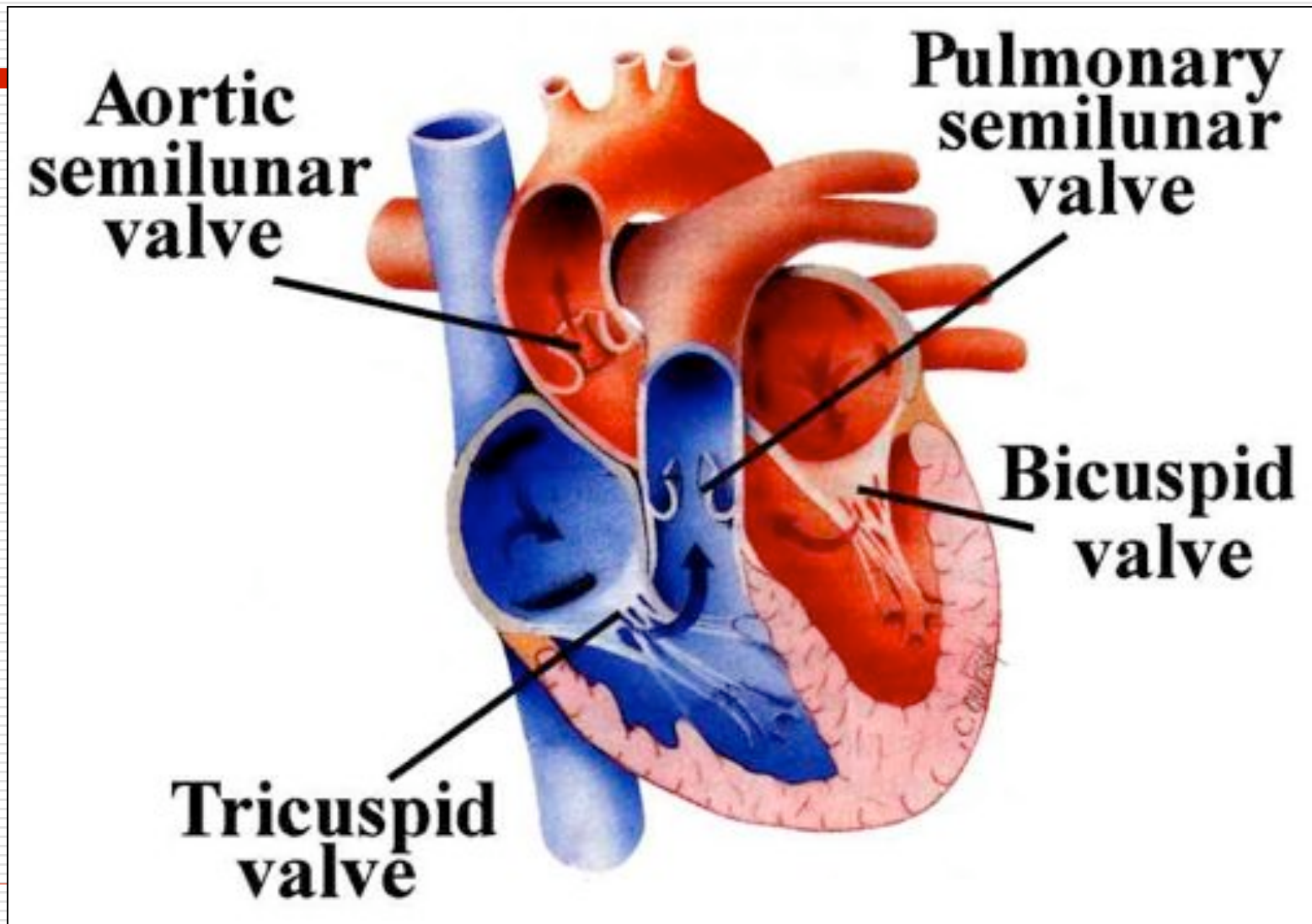




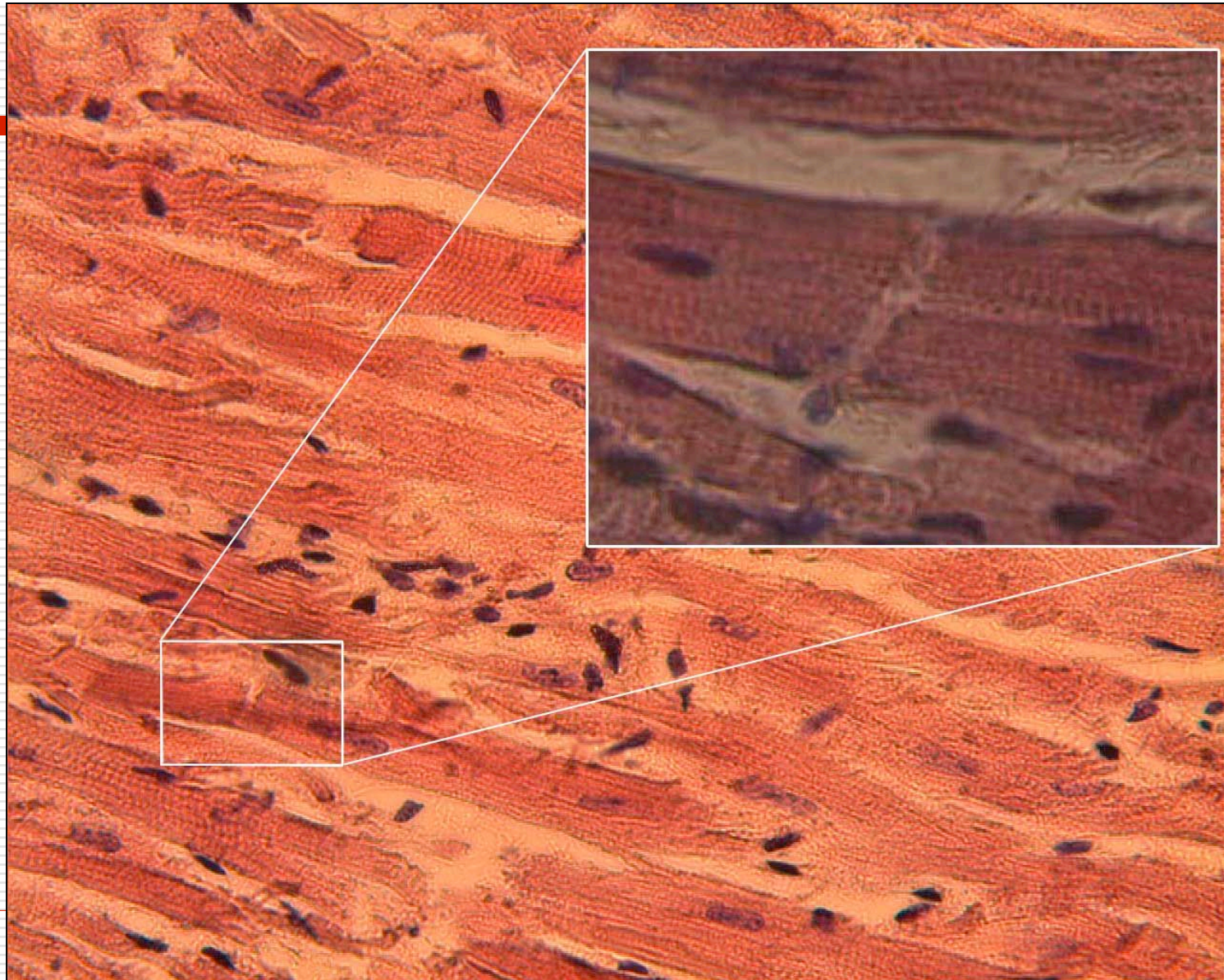
# Human Heart Diagram



Valves ensure one-way flow (if they work...)



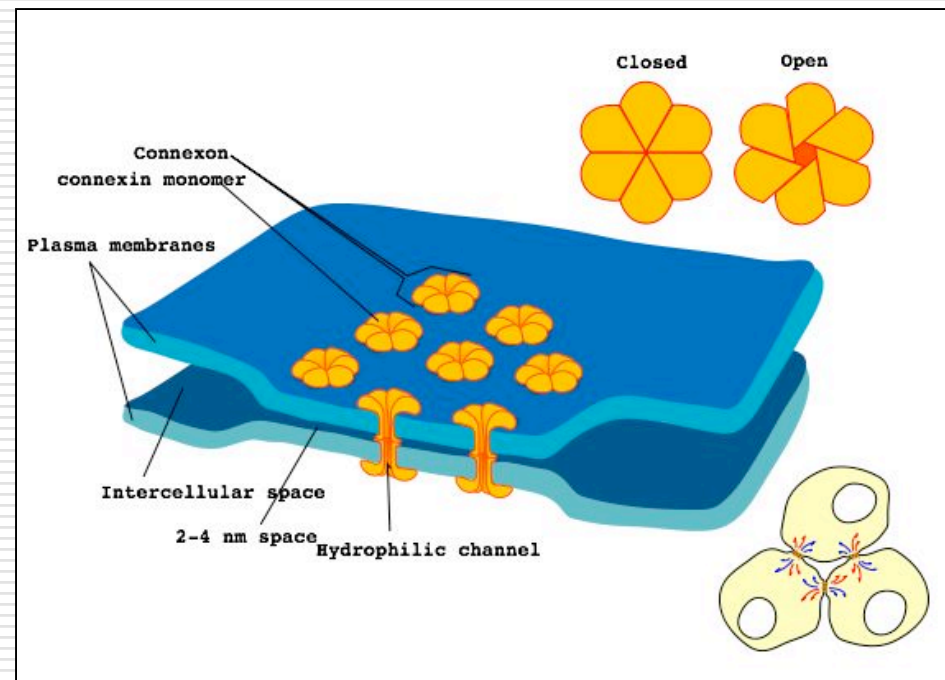
# Cardiac Muscle





# Gap Junctions

- ❑ Electrically, chemically, and biologically connect adjacent cells
- ❑ <1000 Dalton objects can pass through
  - Ions
    - ❑ Electricity
  - Other bio stuff
    - ❑ Not physics
      - Not as cool



# Cardiac Ions

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- Na<sup>+</sup>
- K<sup>+</sup>
- Cl<sup>-</sup>
- Ca<sup>2+</sup>

Intracellular and extracellular ion concentrations			
Ion	Extracellular concentration (mmol/L)	Intracellular concentration (mmol/L)	Ratio of extracellular to intracellular concentration
Na <sup>+</sup>	135 - 145	10	14:1
K <sup>+</sup>	3.5 - 5.0	155	1:16
Cl <sup>-</sup>	95 - 110	20 - 30	4:1
Ca <sup>2+</sup>	2	10 <sup>-4</sup> mmol/L	2 x 10 <sup>4</sup>

*Although intracellular Ca<sup>2+</sup> content is about 2 mM, most of this is bound or sequestered in intracellular organelles (mitochondria and sarcoplasmic reticulum).*

# Cardiac Myocyte Contraction

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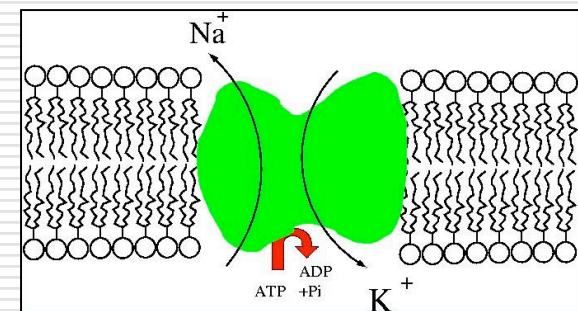
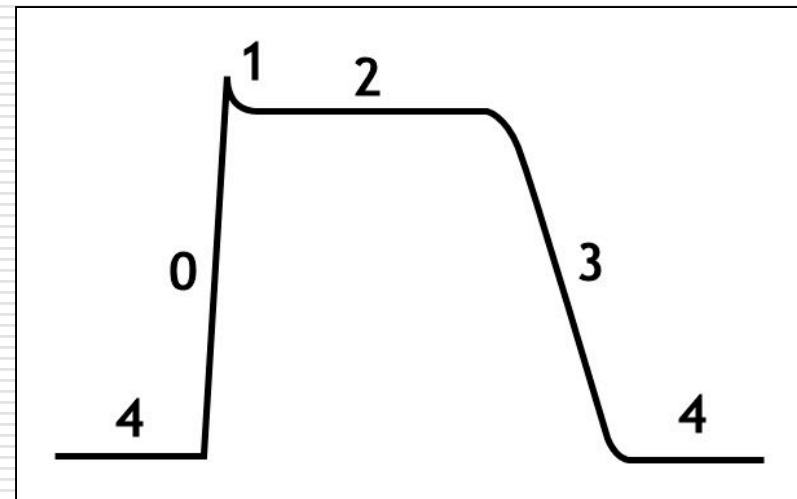
- Sarcomere / SR
  - $\text{Ca}^{2+}$ -mediated  $\text{Ca}^{2+}$  release
  - Troponin C / Tropomyosin
  - Actin / Myosin
-

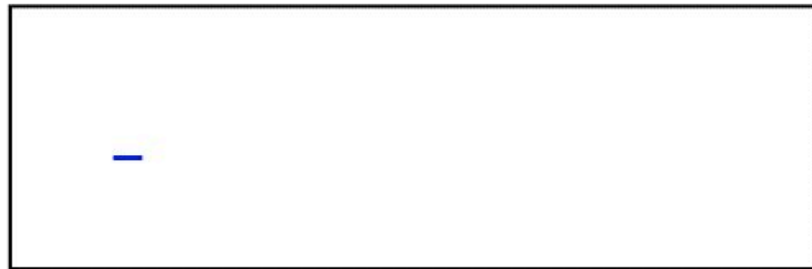
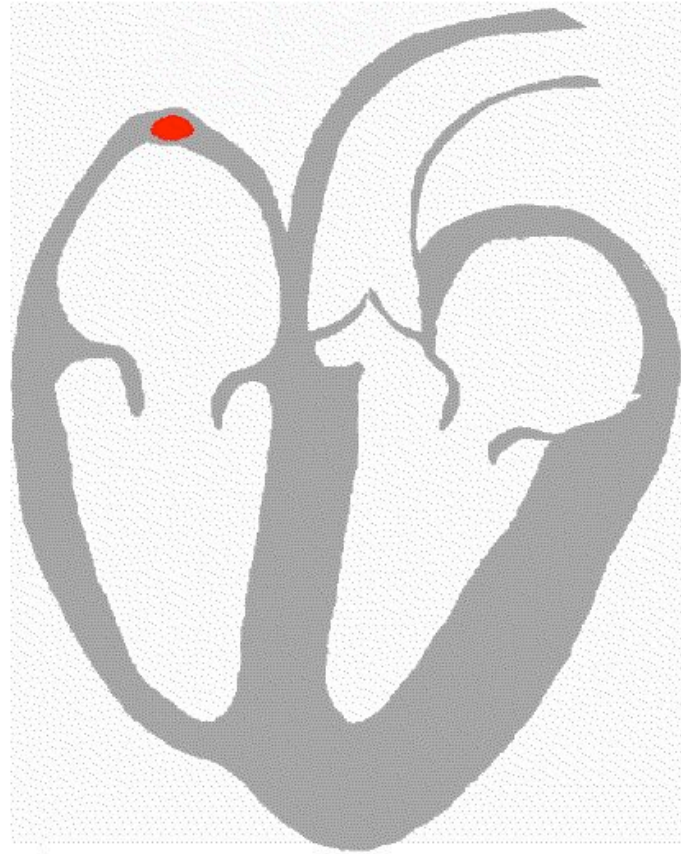
# Cardiac Currents

Major currents during the cardiac ventricular action potential				
Ion	Current	$\alpha$ subunit protein	$\alpha$ subunit gene	Phase / role
Na <sup>+</sup>	$I_{Na}$	Na <sub>v</sub> 1.5	<a href="#">SCN5A</a>	0
Ca <sup>2+</sup>	$I_{Ca(L)}$	Ca <sub>v</sub> 1.2	<a href="#">CACNA1C</a>	0-2
K <sup>+</sup>	$I_{to1}$	K <sub>v</sub> 4.2/4.3	<a href="#">KCND2</a> / <a href="#">KCND3</a>	1, notch
K <sup>+</sup>	$I_{Ks}$	K <sub>v</sub> 7.1	<a href="#">KCNQ1</a>	2,3
K <sup>+</sup>	$I_{Kr}$	K <sub>v</sub> 11.1 (hERG)	<a href="#">KCNH2</a>	3
K <sup>+</sup>	$I_{K1}$	K <sub>ir</sub> 2.1/2.2/2.3	<a href="#">KCNJ2</a> / <a href="#">KCNJ12</a> / <a href="#">KCNJ4</a>	3,4
Na <sup>+</sup> , Ca <sup>2+</sup>	$I_{NaCa}$	3Na <sup>+</sup> -1Ca <sup>2+</sup> -exchanger	<a href="#">NCX1 (SLC8A1)</a>	ion homeostasis
Na <sup>+</sup> , K <sup>+</sup>	$I_{NaK}$	3Na <sup>+</sup> -2K <sup>+</sup> -ATPase	<a href="#">ATP1A</a>	ion homeostasis
Ca <sup>2+</sup>	$I_{pCa}$	Ca <sup>2+</sup> -transporting ATPase	<a href="#">ATP1B</a>	ion homeostasis

# Cardiac Action Potential

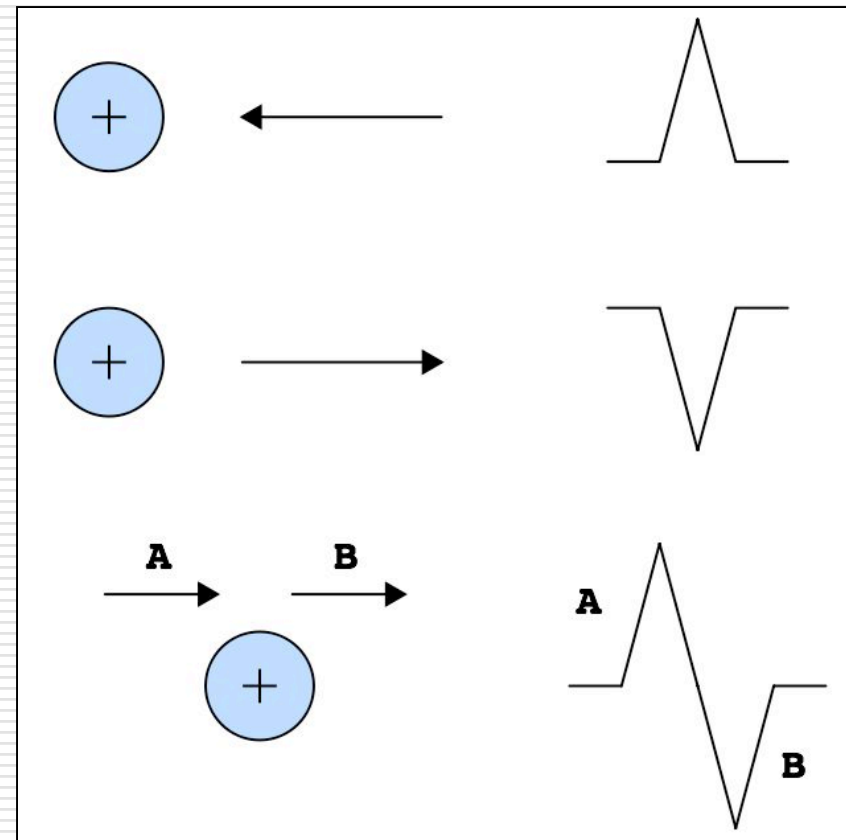
- **0: Upstroke**
  - $\text{Na}^{2+}$  in
- **1: Initial Repolarization**
  - $\text{K}^{+}$  out
- **2: Plateau**
  - $2 \text{ K}^{+}$  out =  $1 \text{ Ca}^{2+}$  in
- **3: Repolarization**
  - $\text{K}^{+}$  out
- **4: Rest**
  - $3 \text{ Na}^{+}$  out :  $2 \text{ K}^{+}$  in (NaK ATPase)





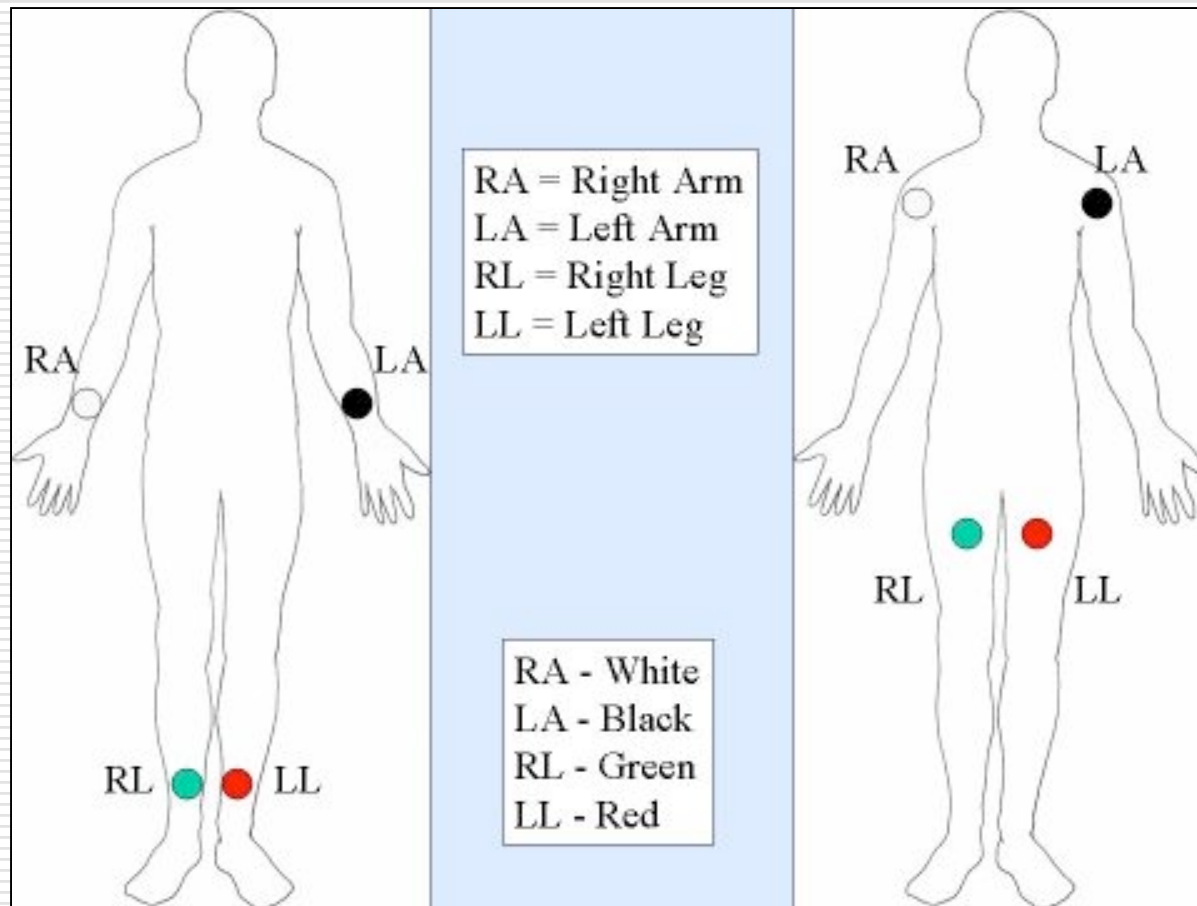
# Physics of Electrocardiography (ECG)

- Movement of current towards a positive electrode represented as “up”
- Movement of current away from a positive electrode represented as “down”



# ECG - Limb Leads

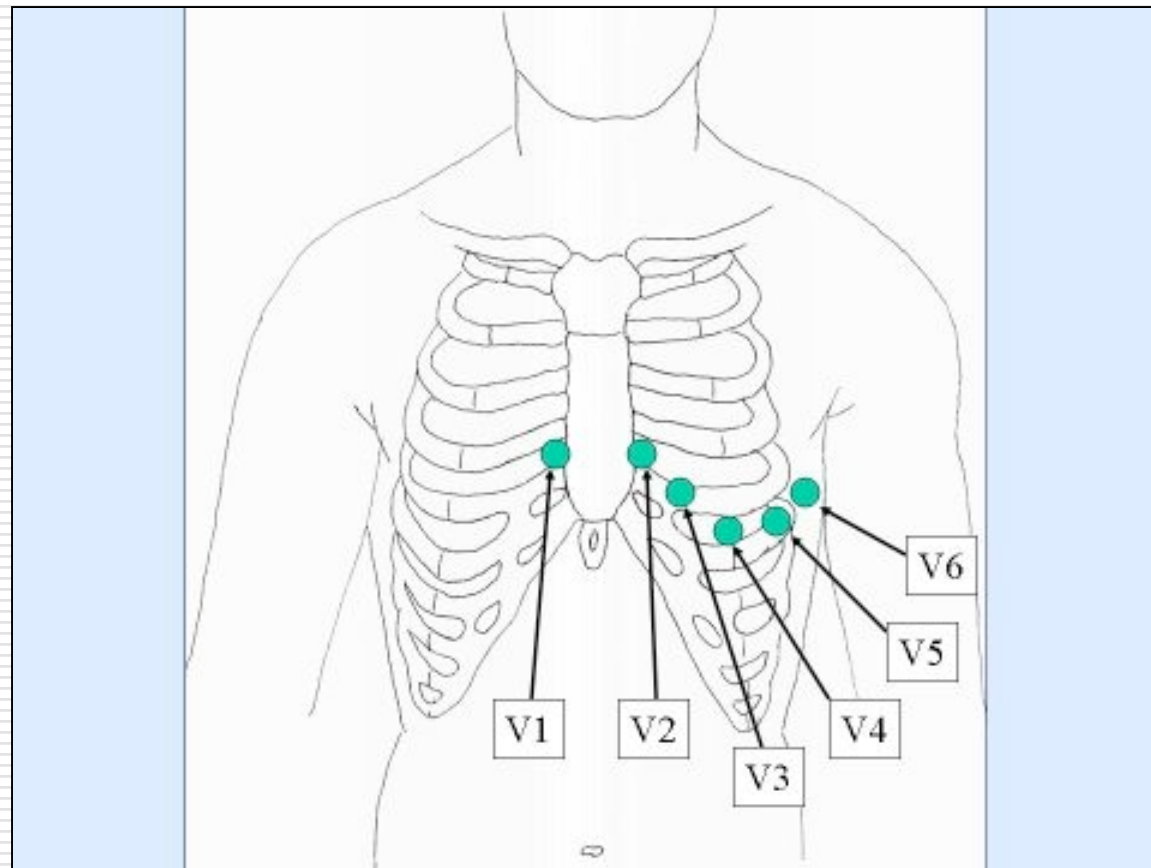
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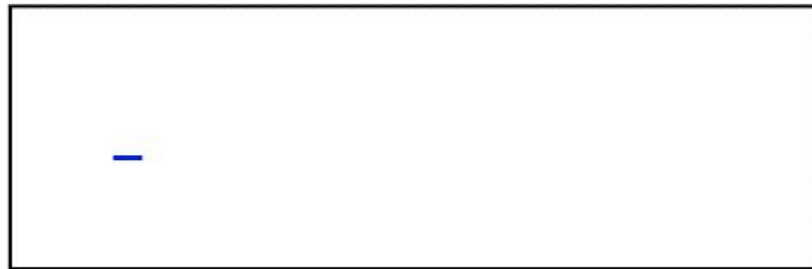
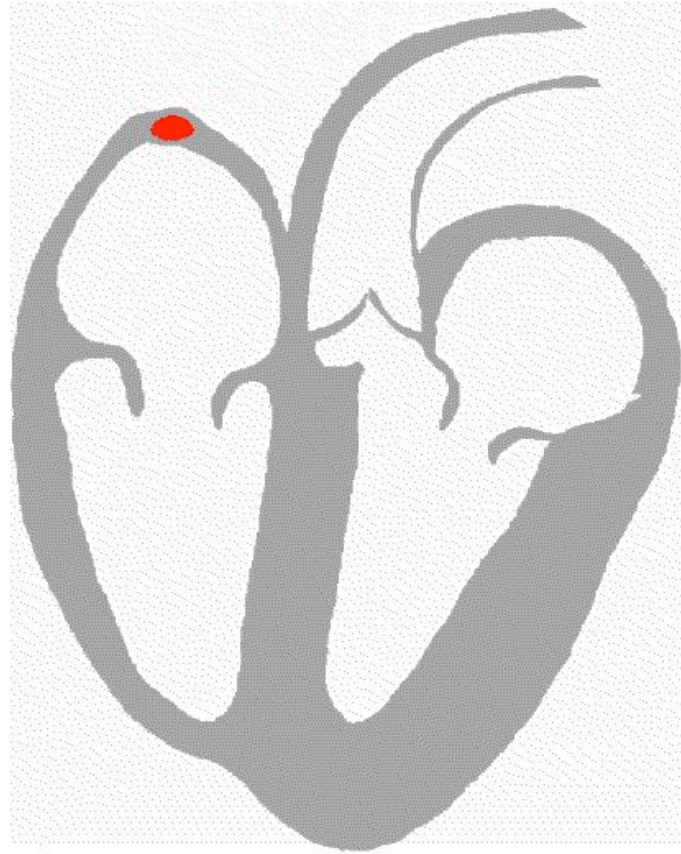




# ECG - Precordial Leads

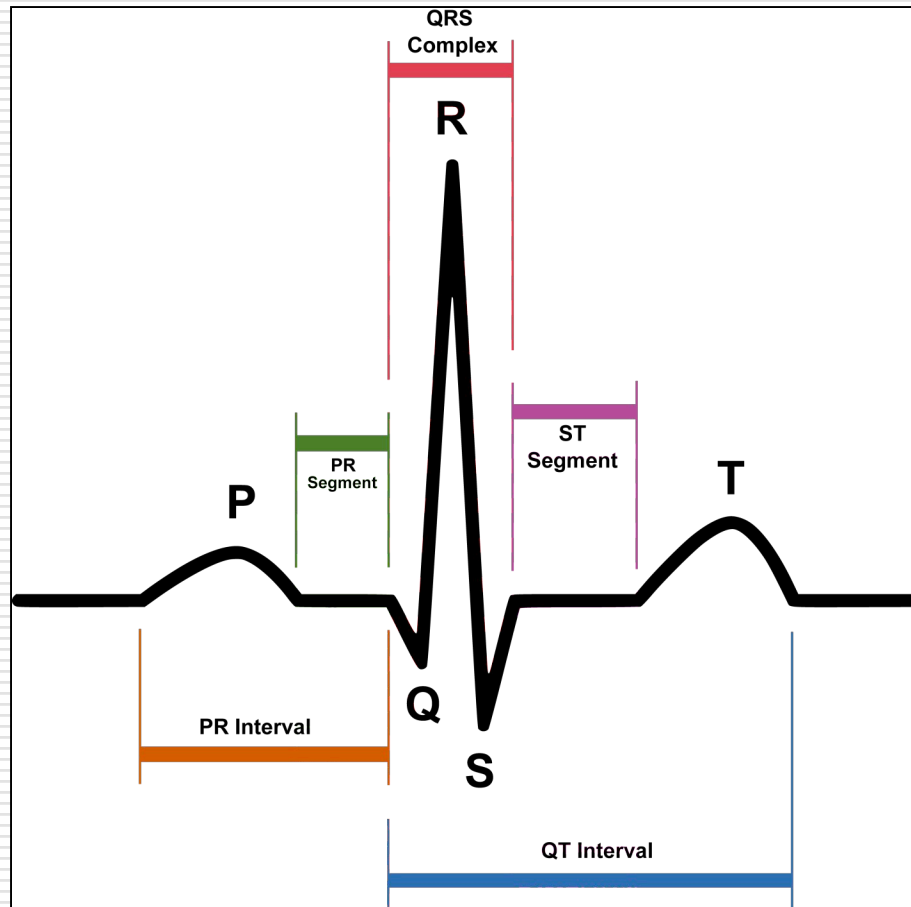
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# Normal Sinus Rhythm

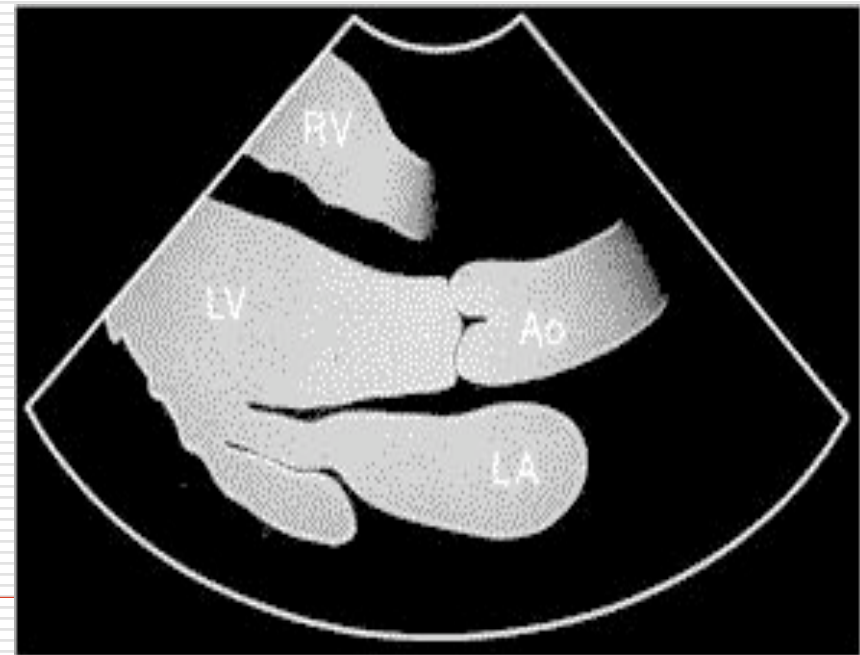
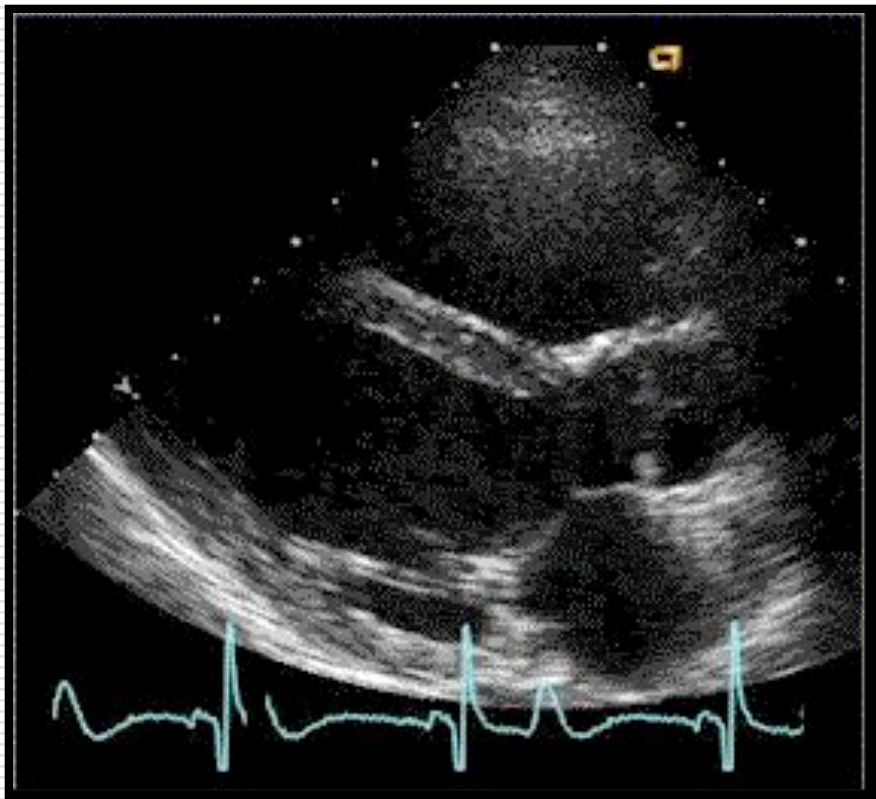
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# Echocardiography

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- ❑ Real-time ultrasound video of heart
- ❑ Shows valve function, blood flow, etc.



# Echocardiography

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## □ Doppler Effect

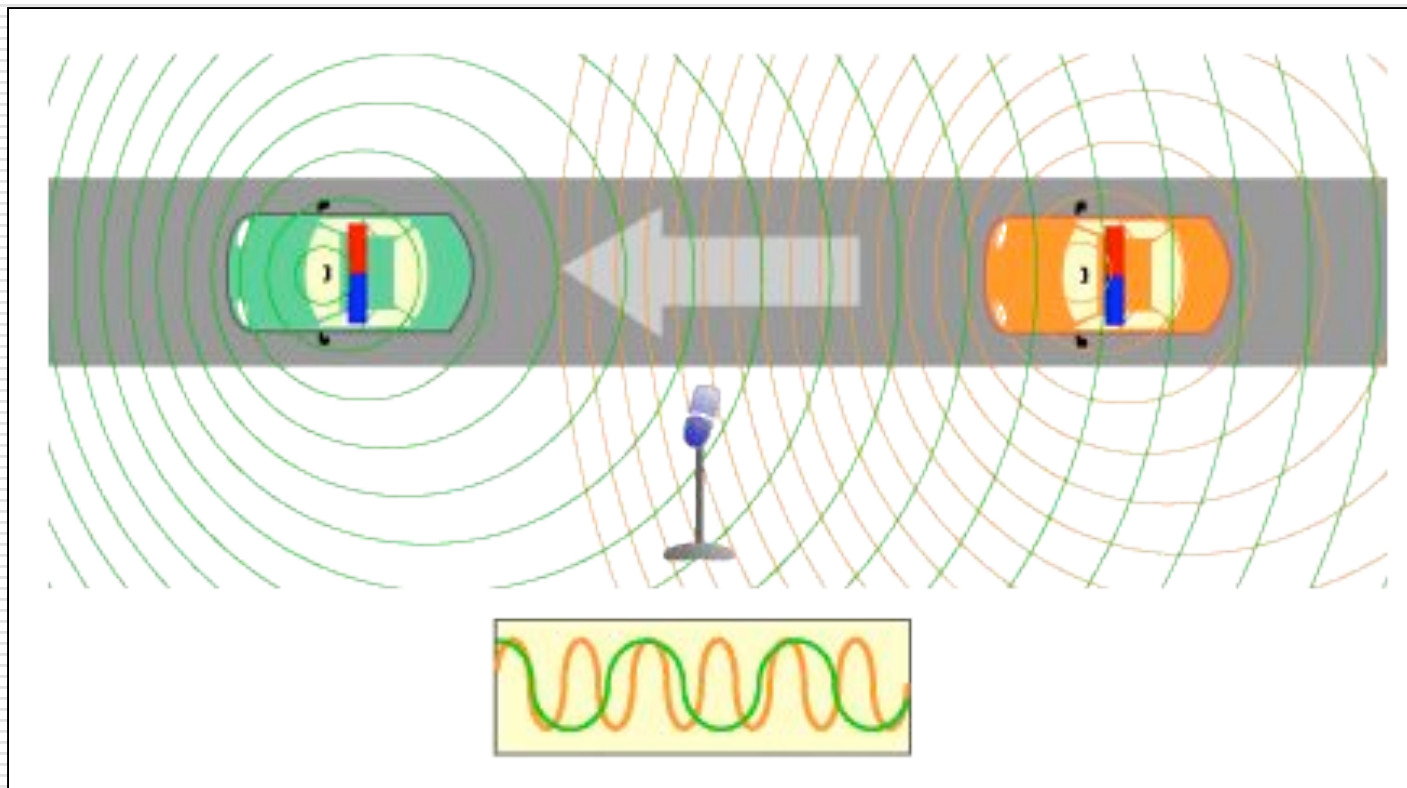
$$f' = \left( \frac{v}{v \pm v_s} \right) f$$

- $f$  = emitted frequency
  - $f'$  = observed frequency
  - $v$  = velocity,  $v_s$  = speed of sound
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# Echocardiography

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## □ Doppler Effect



# Echocardiography

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## □ Doppler Echocardiography

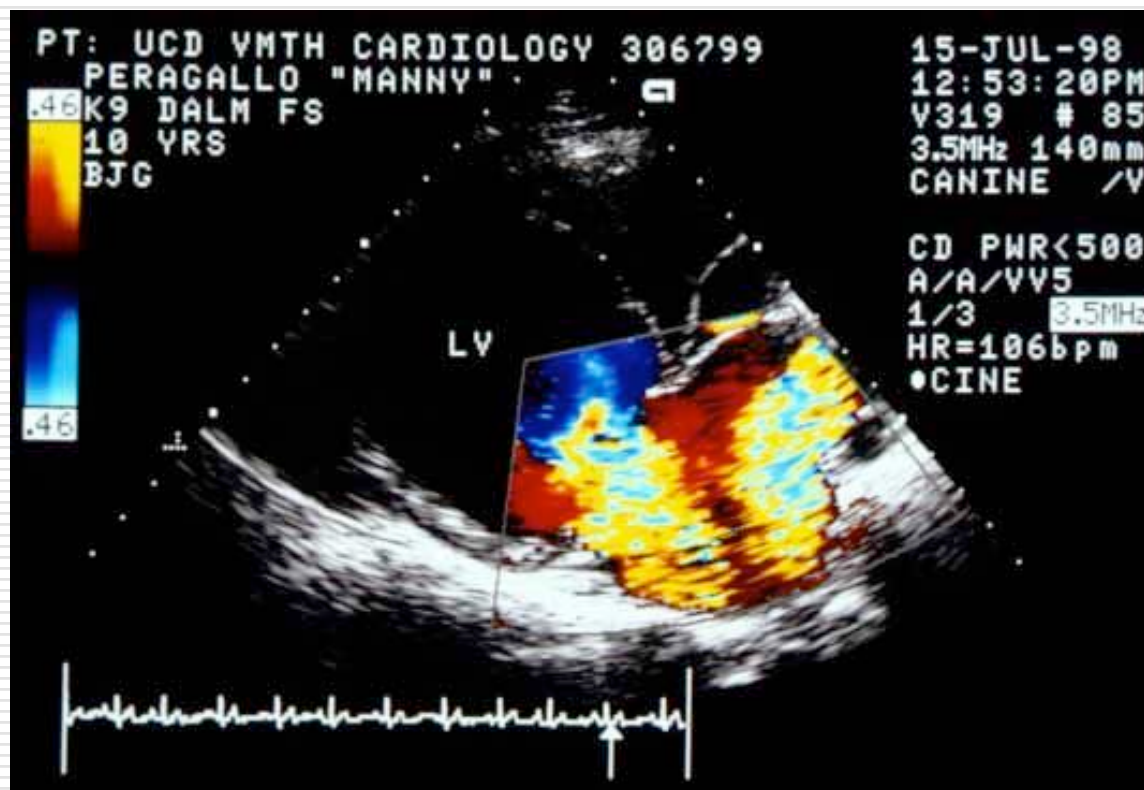
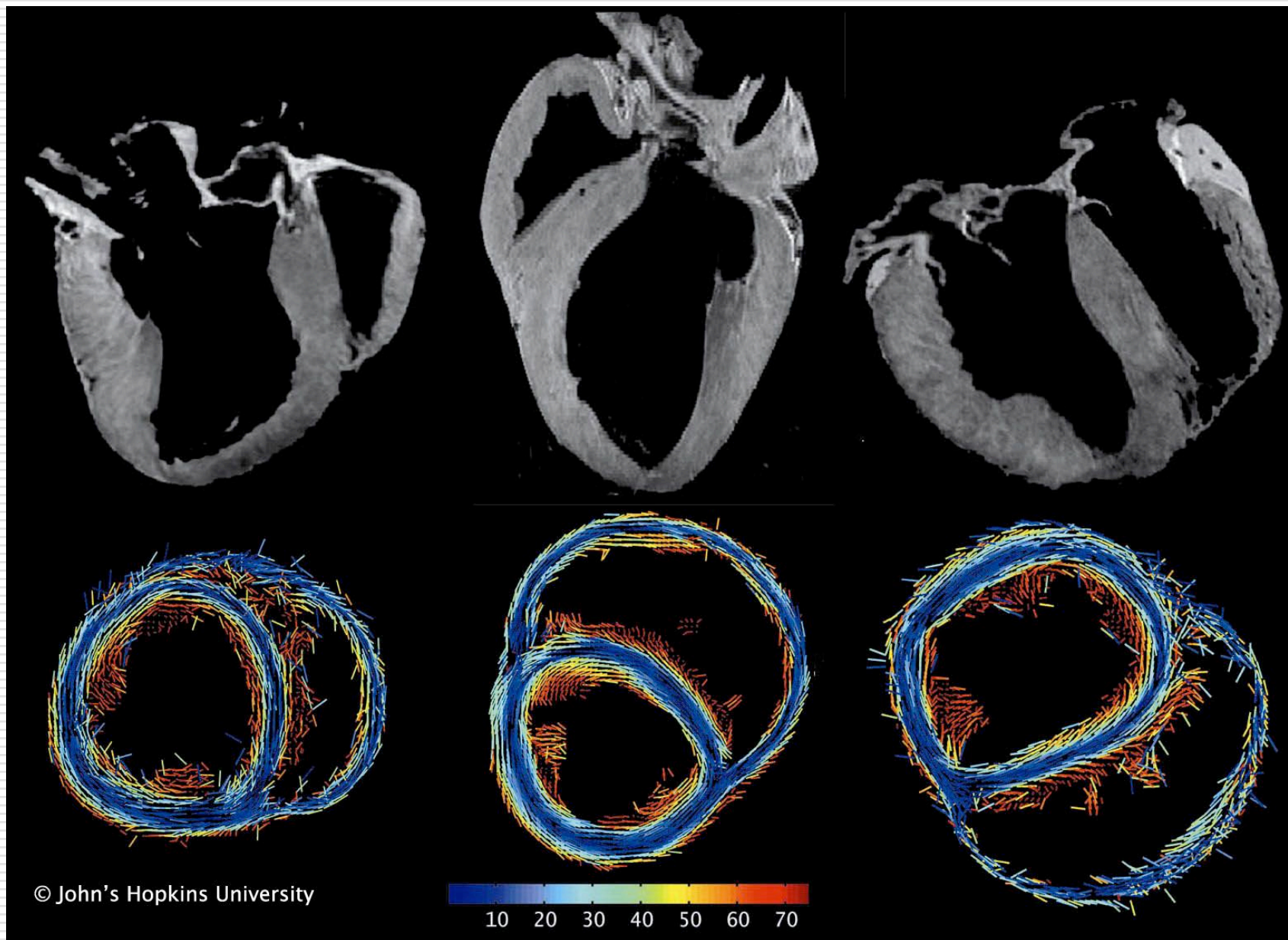


Image shamelessly stolen from <http://www.vmt.h.ucdavis.edu/Cardio/cases/case10/color.htm>

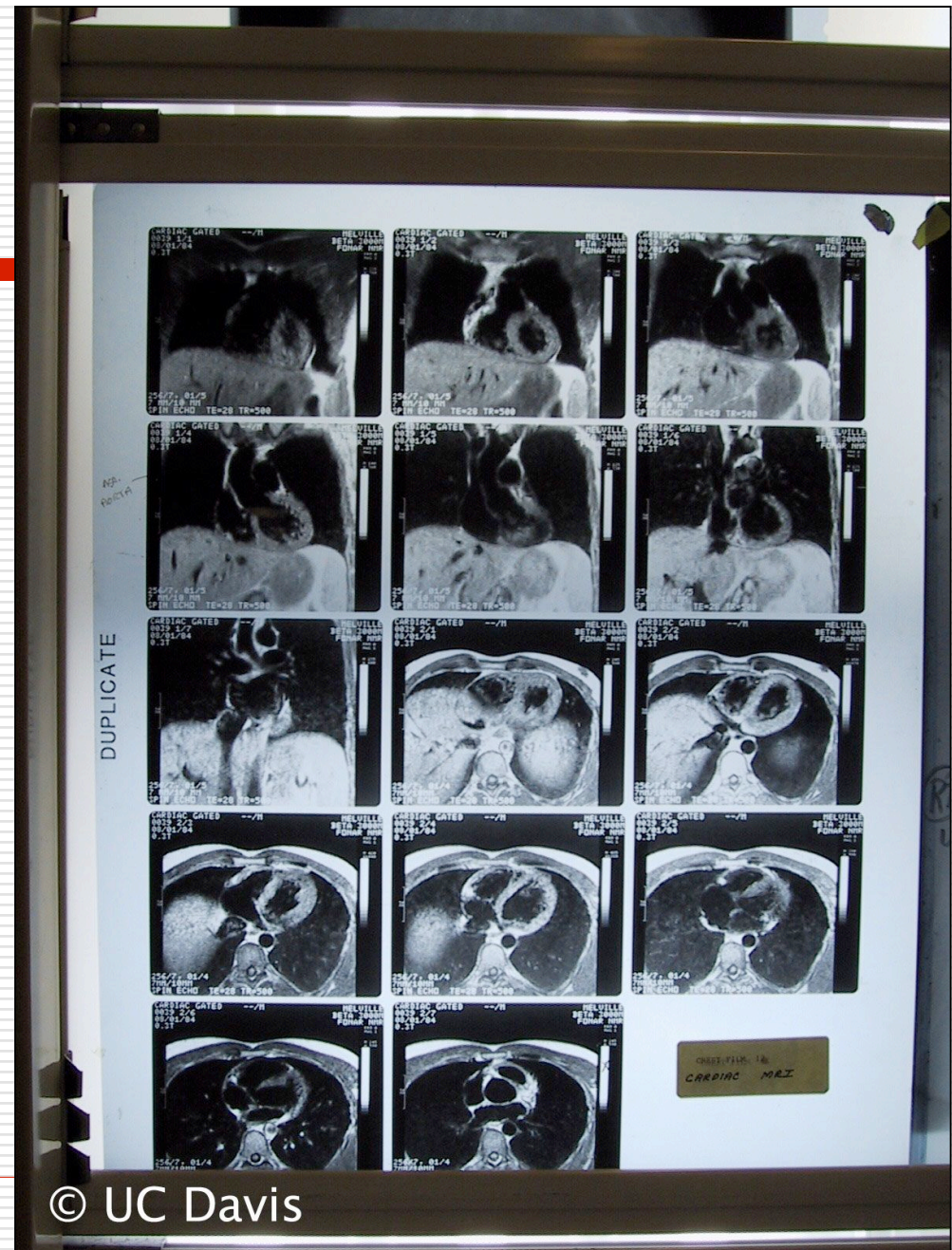
# Diffusion Tensor-Weighted Cardiac MRI





# Cardiac MRI

- Better spatial resolution than echocardiography
- Problem: hearts have trouble holding still...
- Computer reconstructs images to show full cycle



# Question 1

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- Which of the following correctly represents the flow of blood through the heart?
    - A) Vena Cava, RV, RA, Lungs, LV, LA, Aorta
    - B) Vena Cava, LV, LA, Lungs, RV, RA, Aorta
    - C) Aorta, RA, RV, Lungs, LA, LV, Vena Cava
    - D) Aorta, LA, LV, Lungs, RA, RV, Vena Cava
    - **E) Vena Cava, RA, RV, Lungs, LA, LV, Aorta**
    - F) Vena Cava, LA, LV, Lungs, RA, RV, Aorta
-

## Question 2

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- Gap Junctions serve which of the following purposes?
    - A) Connect the valves of the heart to ensure proper blood flow
    - B) Connect the chambers of the heart to ensure proper directionality of flow
    - **C) Connect adjacent cardiac myocytes to ensure proper electrical conduction**
    - D) Connect adjacent blood vessels to ensure proper blood flow to cardiac muscle
-

## Question 3

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- Umbilical arteries carry:
    - A) Oxygenated blood from mother to baby
    - B) De-oxygenated blood from mother to baby
    - C) Oxygenated blood from baby to mother
    - **D) De-oxygenated blood from baby to mother**
-

## Question 4

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- Which of the following cannot cross the placenta?
    - A) Oxygen
    - B) Carbon Dioxide
    - C) Nutrients
    - D) Drugs
    - E) Immune System (antibodies & T-cells)
    - **F) Red Blood Cells**
    - G) None of the above
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# Question 5

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- The ductus venosus, foramen ovale, and ductus arteriosus serve what functions, respectively?
    - A) Provide blood to the developing liver (DV, DA) and lungs (FO)
    - B) Shunt blood away from the developing liver (DV, DA) and lungs (FO)
    - C) Provide blood to the developing liver (DV) and lungs (DA, FO)
    - D) Shunt blood away from the developing liver (DV) and lungs (DA, FO)
-

# Question 6

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- A patent (open) foramen ovale can cause which of the following problems in an adult?
    - I) Clots can travel to the lungs
    - II) Clots can travel to the brain and other tissues
    - III) Blood can pass from the left side of the heart to the right side of the heart, bypassing the lungs
    - IV) Blood can pass from the right side of the heart to the left side of the heart, bypassing the lungs
  - A) I & III
  - **B) II & IV**
  - C) I & IV
  - D) II & III
-

# Question 7

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- Which is the correct hierarchy of coolness in science?
    - A) Physics > Chemistry > Biology > Psych
    - B) Physics > Biology > Chemistry > Psych
    - C) Physics > Psych > Chemistry > Biology
    - D) Physics > Biology > Psych > Chemistry
    - **E) Any of these is acceptable**
-



## Percentage of Chart Which Resembles Pac-man

