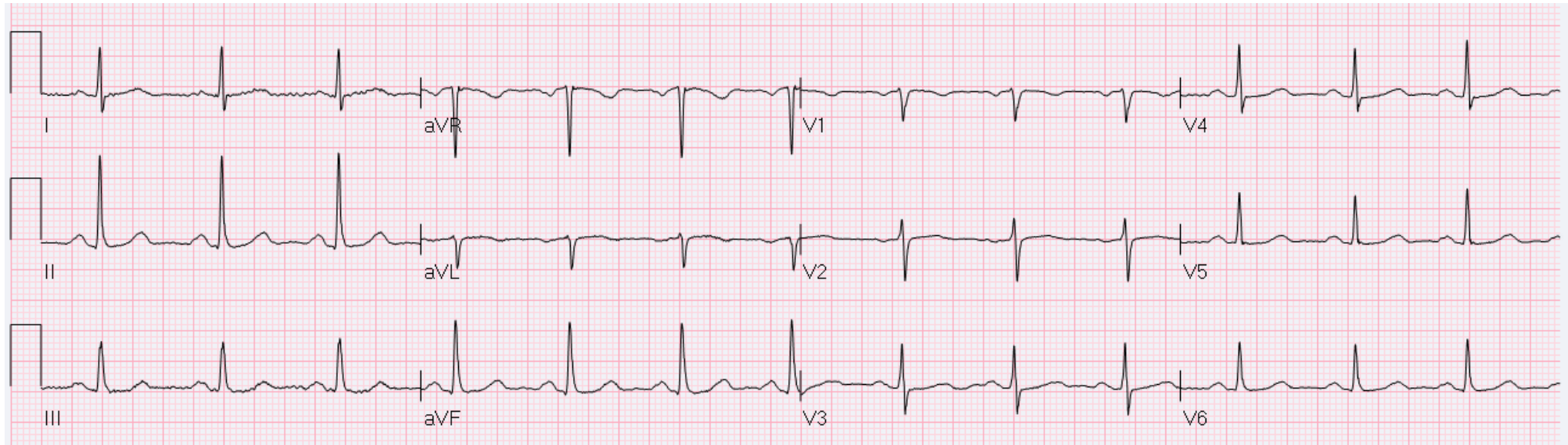
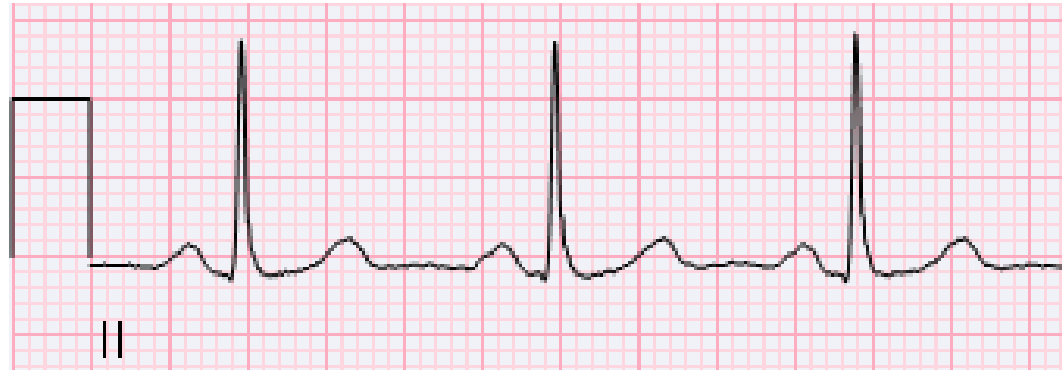


# EKG Interpretation

Jason Ryan, MD, MPH

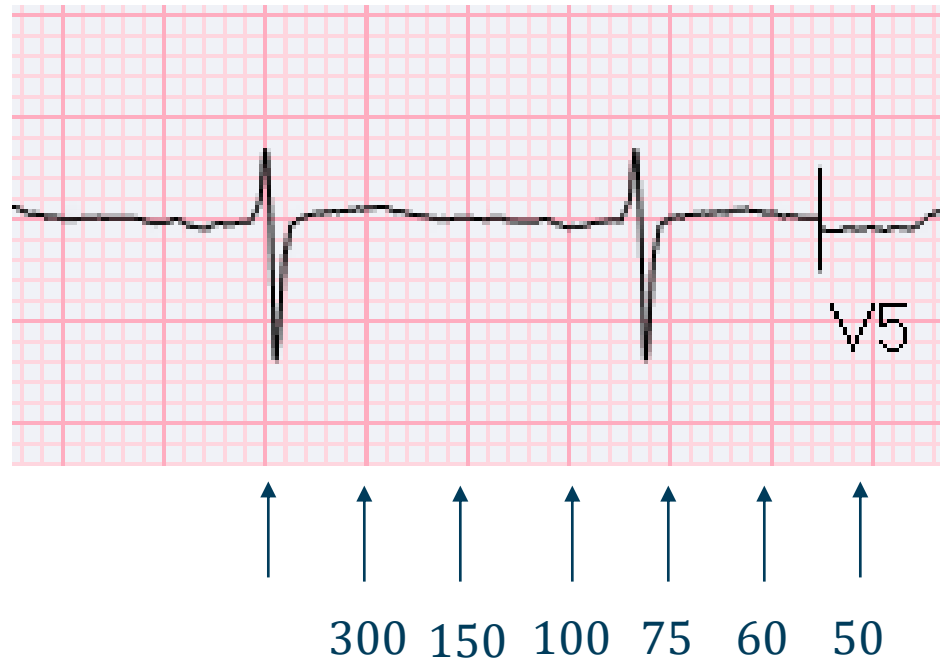


# EKG

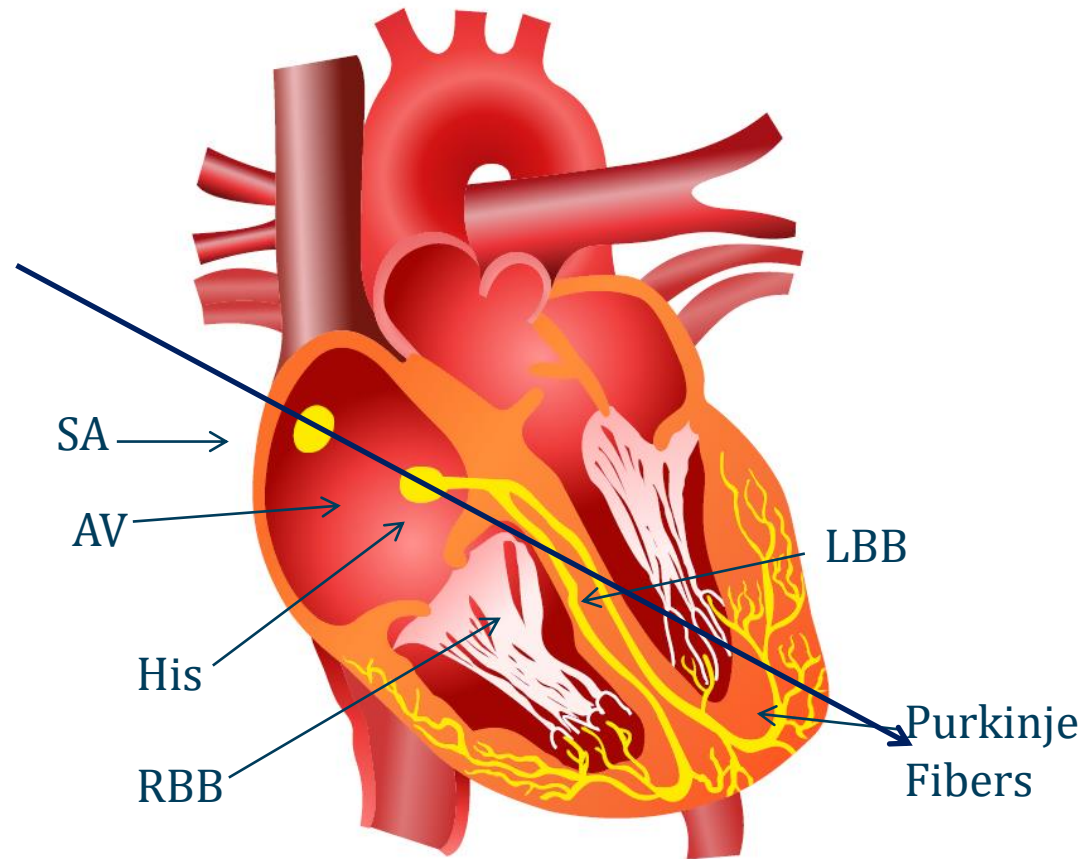


# Determining Heart Rate

- 3 – 5 big boxes between QRS complexes

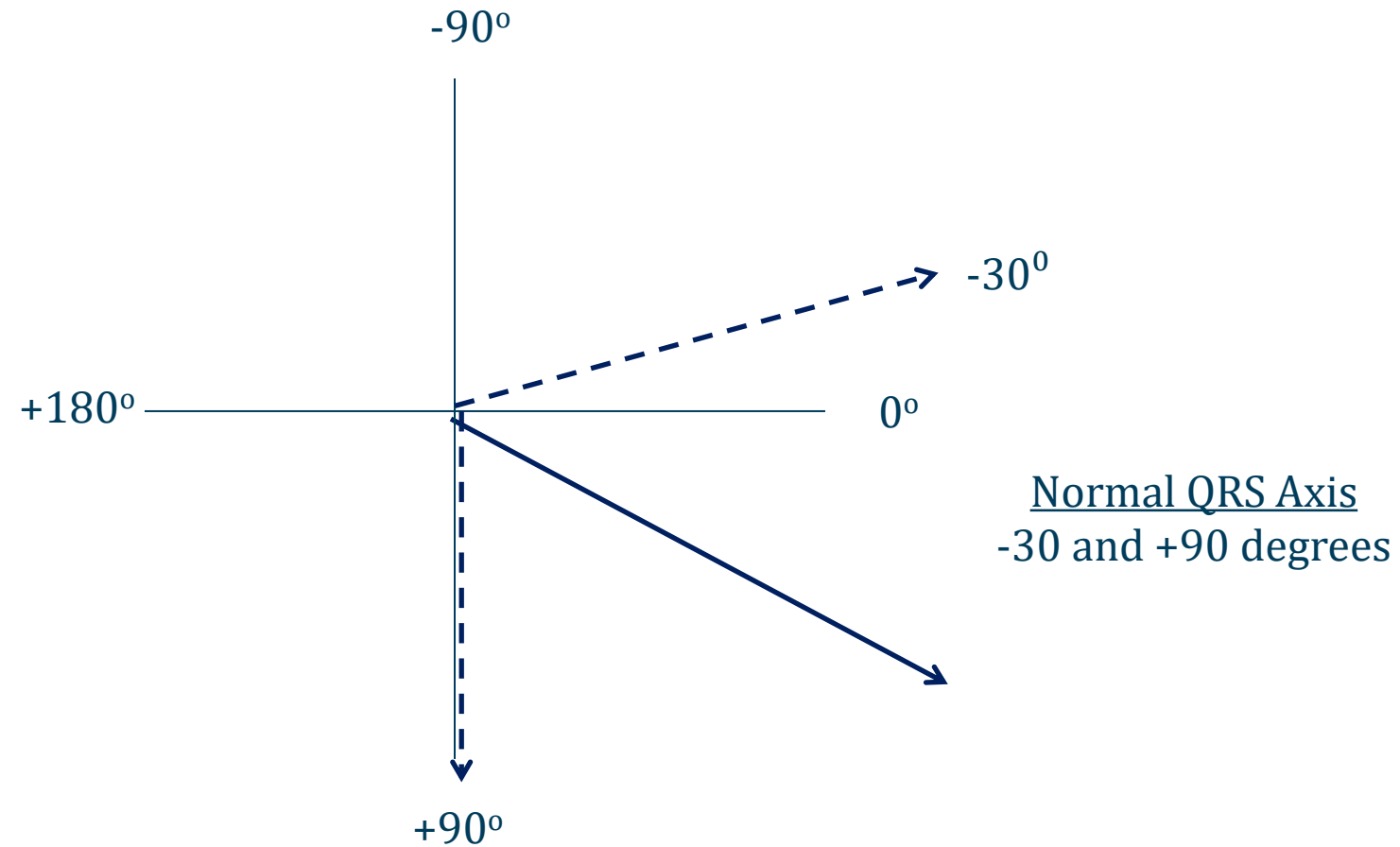


# QRS Axis

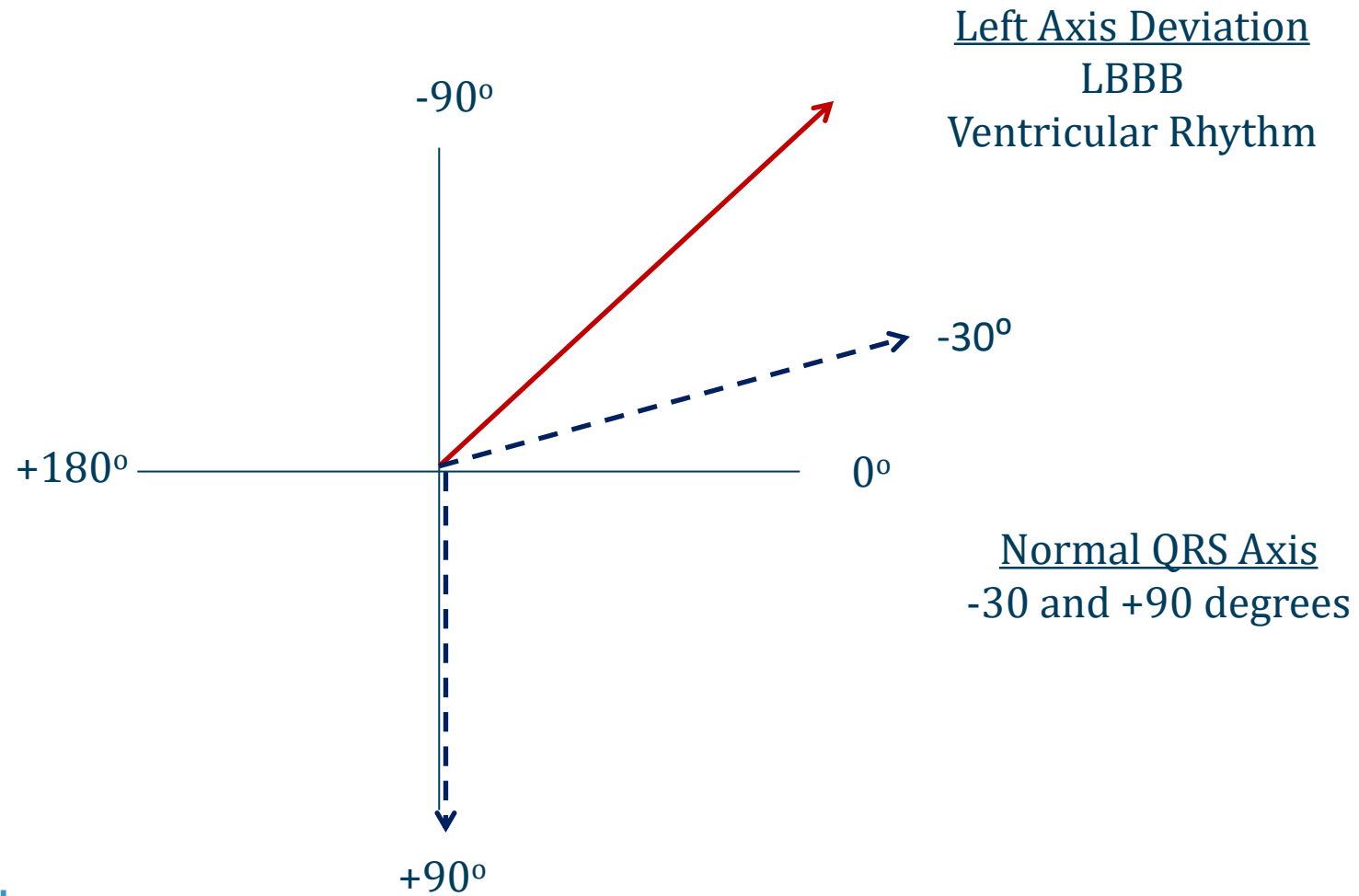




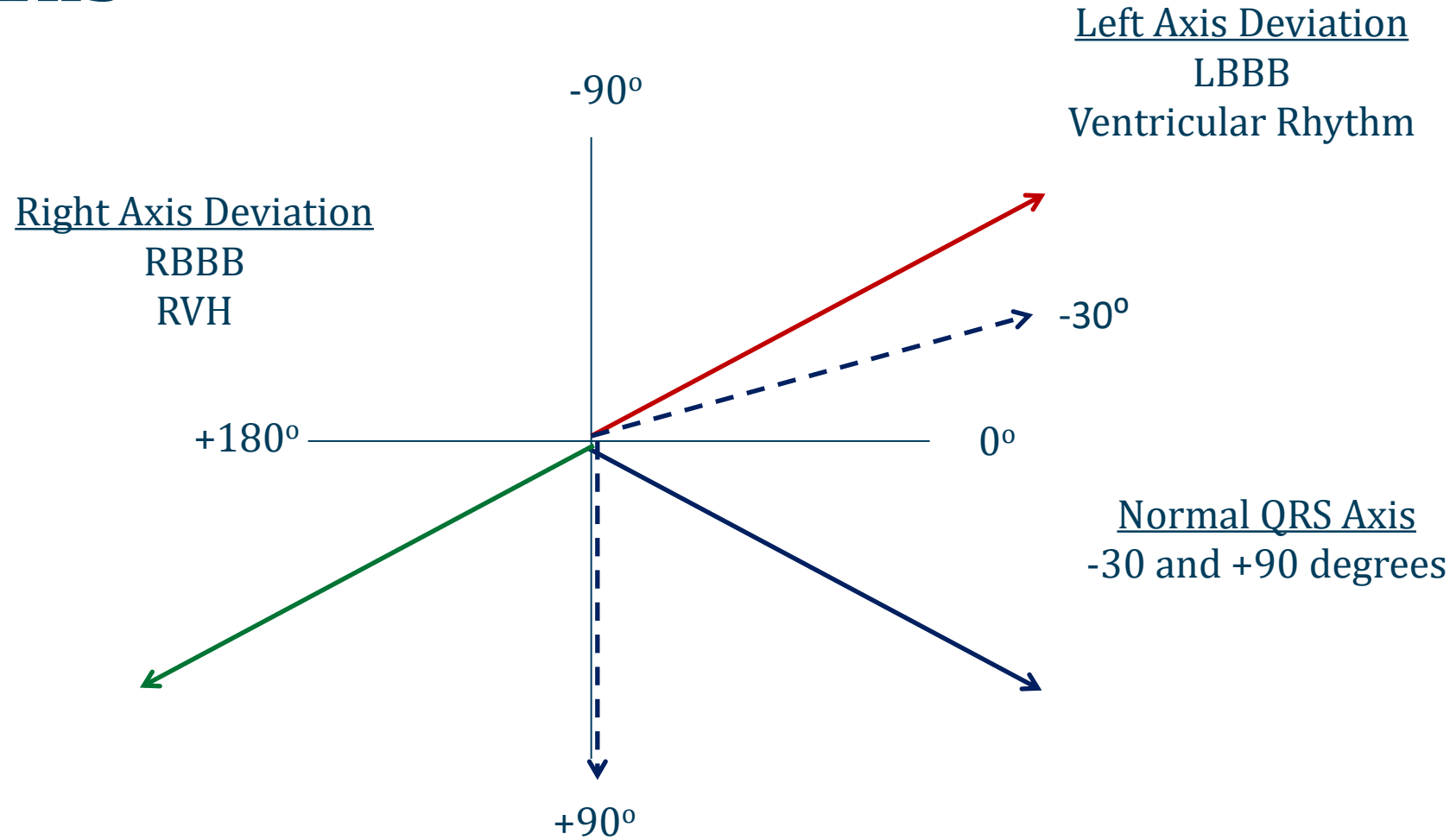
# QRS Axis



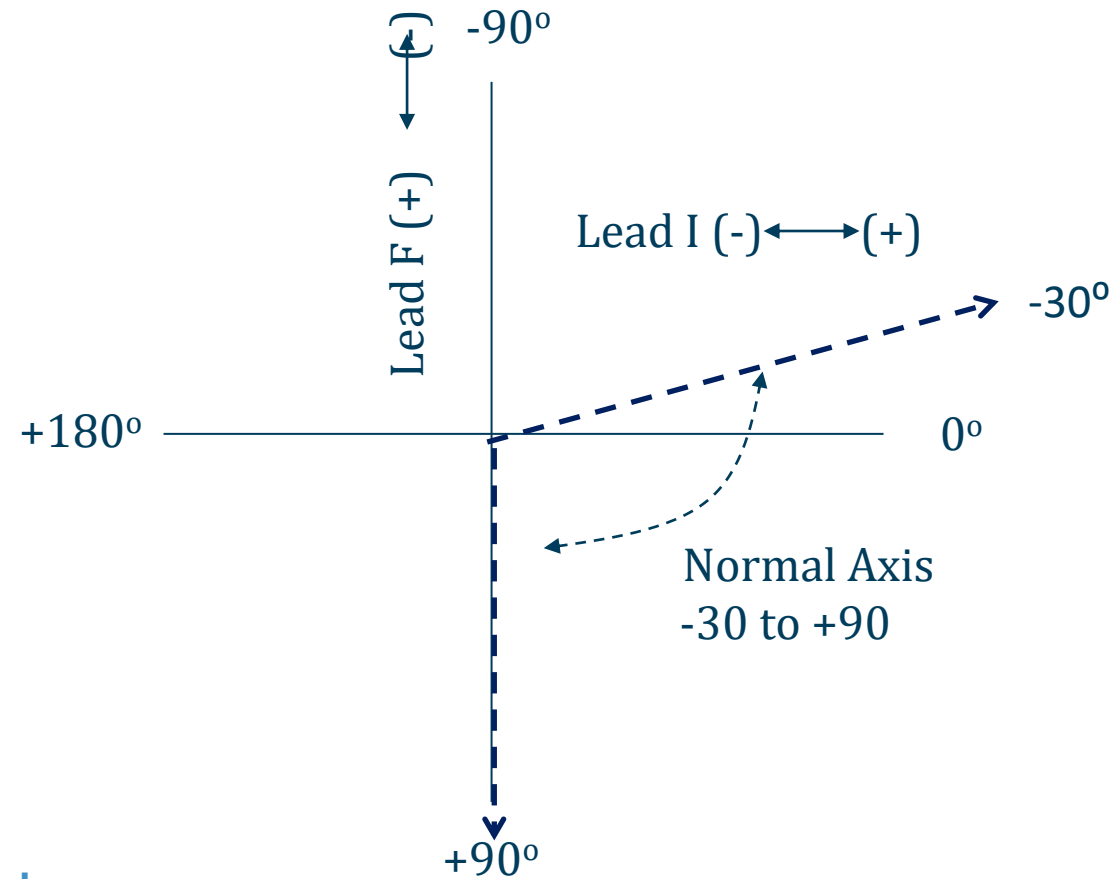
# QRS Axis



# QRS Axis



# Determining Axis



# Axis Quick Method

- First, glance at aVr
- It should be negative
- If upright: limb lead reversal

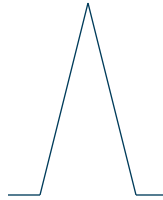


**Normal**

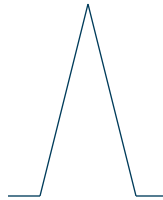
# Axis Quick Method

- If leads I and II are both positive, axis is normal

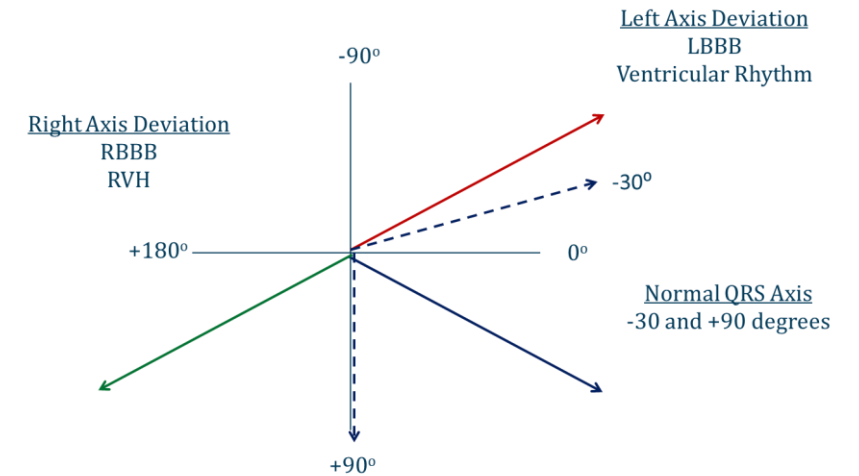
Lead I



Lead II



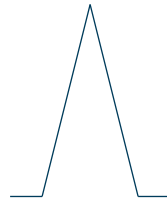
Axis 0 to 90°



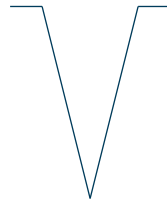
# Axis Quick Method

- For left axis deviation:
  - All you need is lead II

Lead I

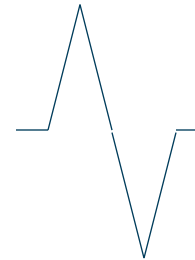


Lead II

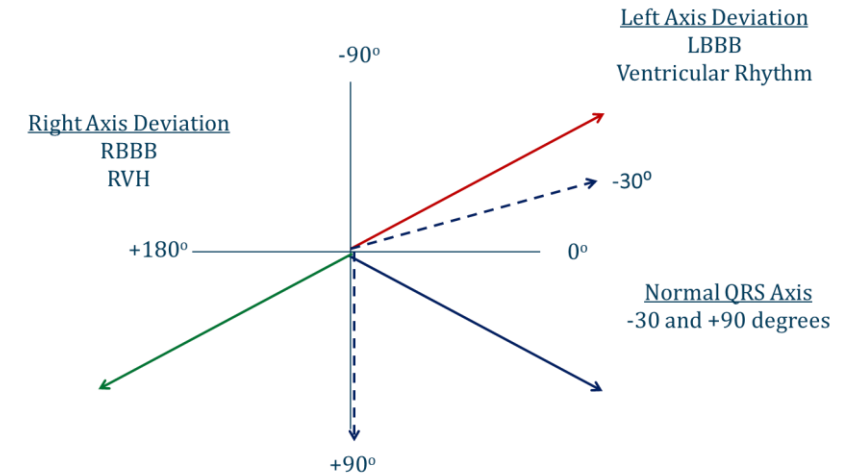


Axis  $-30$  to  $-90^\circ$

Lead II



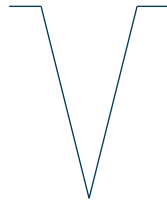
Axis  $0$  to  $-30^\circ$   
Physiologic  
Left Axis



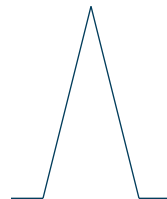
# Axis Quick Method

- For right axis deviation:
  - All you need is lead I
  - Negative = RAD

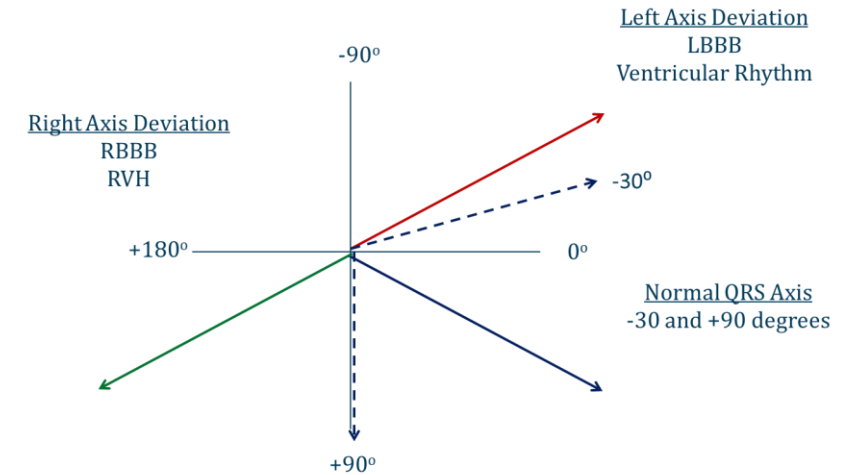
Lead I



Lead II



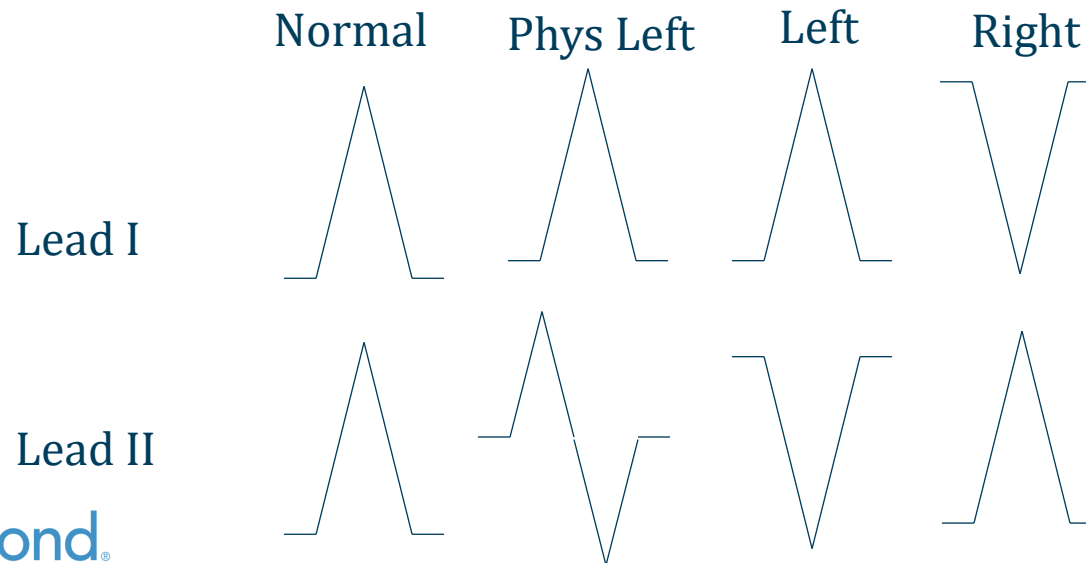
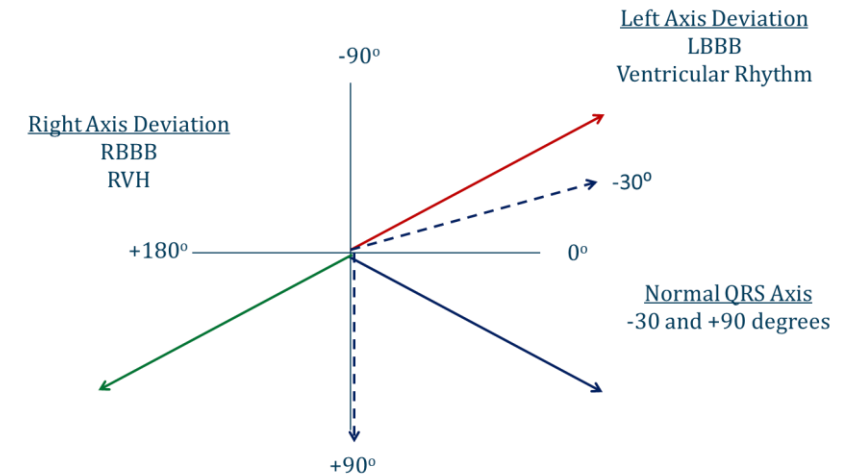
Axis 90 to 180°





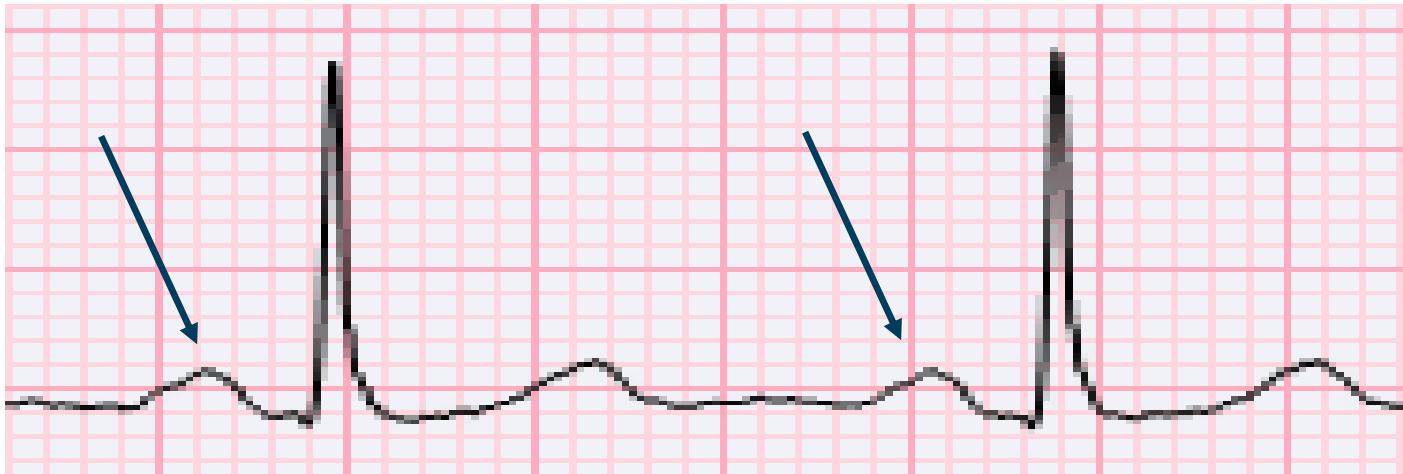
# Axis Quick Method

- Look at aVr: Make sure its negative
- Look at I, II: If both positive, axis is normal
- If II is negative: LAD
- If I is negative: RAD



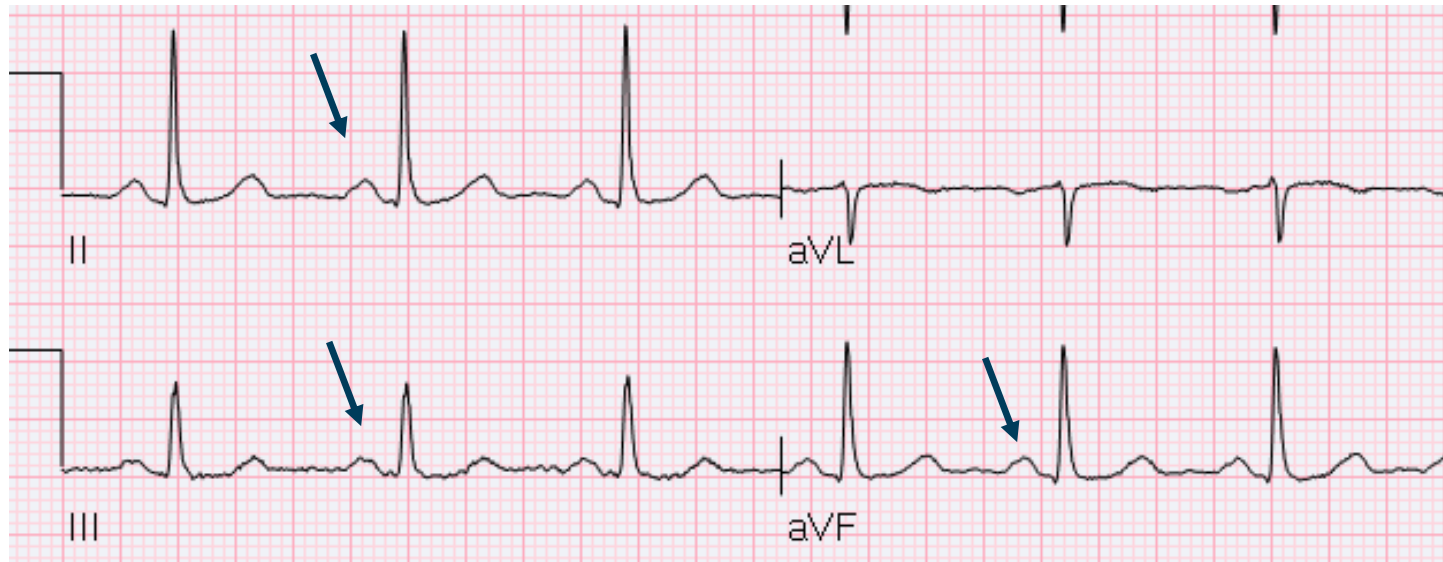
# Step 1: Find the p waves

- Are p waves present?



# Sinus p waves

- Originate in sinus node
- Upright in leads II, III, F



# Step 2: Regular or Irregular

- Distance between QRS complexes (R-R intervals)

Regular



Irregular



# Steps 1 & 2

- P waves present, regular rhythm
  - **Sinus rhythm**
  - Rare: atrial tachycardia, atrial rhythm
- No p waves, irregular rhythm
  - **Atrial fibrillation – irregularly irregular**
  - Atrial flutter with variable block

Sinus Rhythm



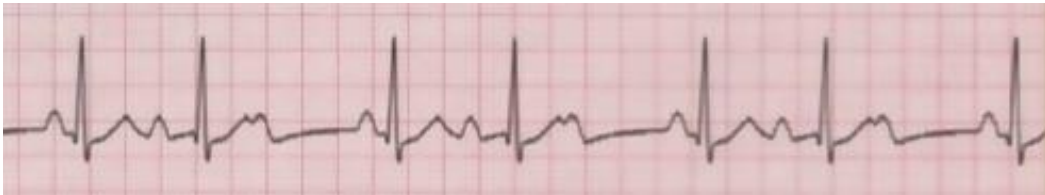
Atrial Fibrillation



# Steps 1 & 2

- P waves present, irregular rhythm
  - Sinus rhythm with PACs
  - Multifocal atrial tachycardia
  - Sinus with AV block

Mobitz I AV Block (Wenckebach)



Sinus rhythm with PAC



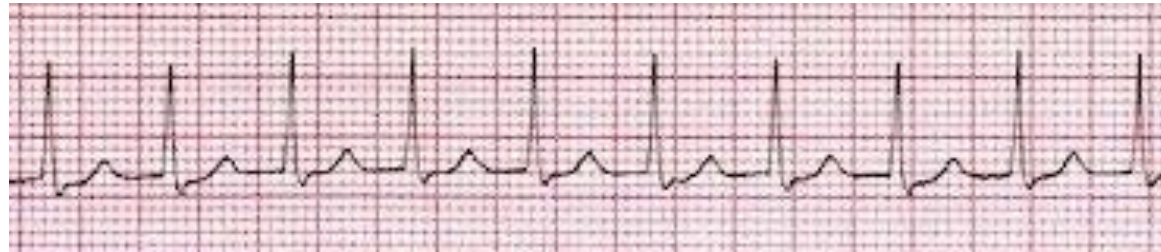
Mutifocal Atrial Tachycardia



# Steps 1 & 2

- No p waves, regular rhythm
  - Hidden p waves: retrograde
  - Supraventricular tachycardias (SVTs)
  - Ventricular tachycardia

AV Nodal Reentrant Tachycardia (AVNRT)



# Step 3: Wide or narrow

- Narrow QRS ( $< 120$  ms; 3 small boxes)
  - His-Purkinje system works
  - No bundle branch blocks present
- Wide QRS
  - Most likely a **bundle branch block**
  - Ventricular rhythm (i.e. tachycardia)





# QRS Interval

Normal QRS

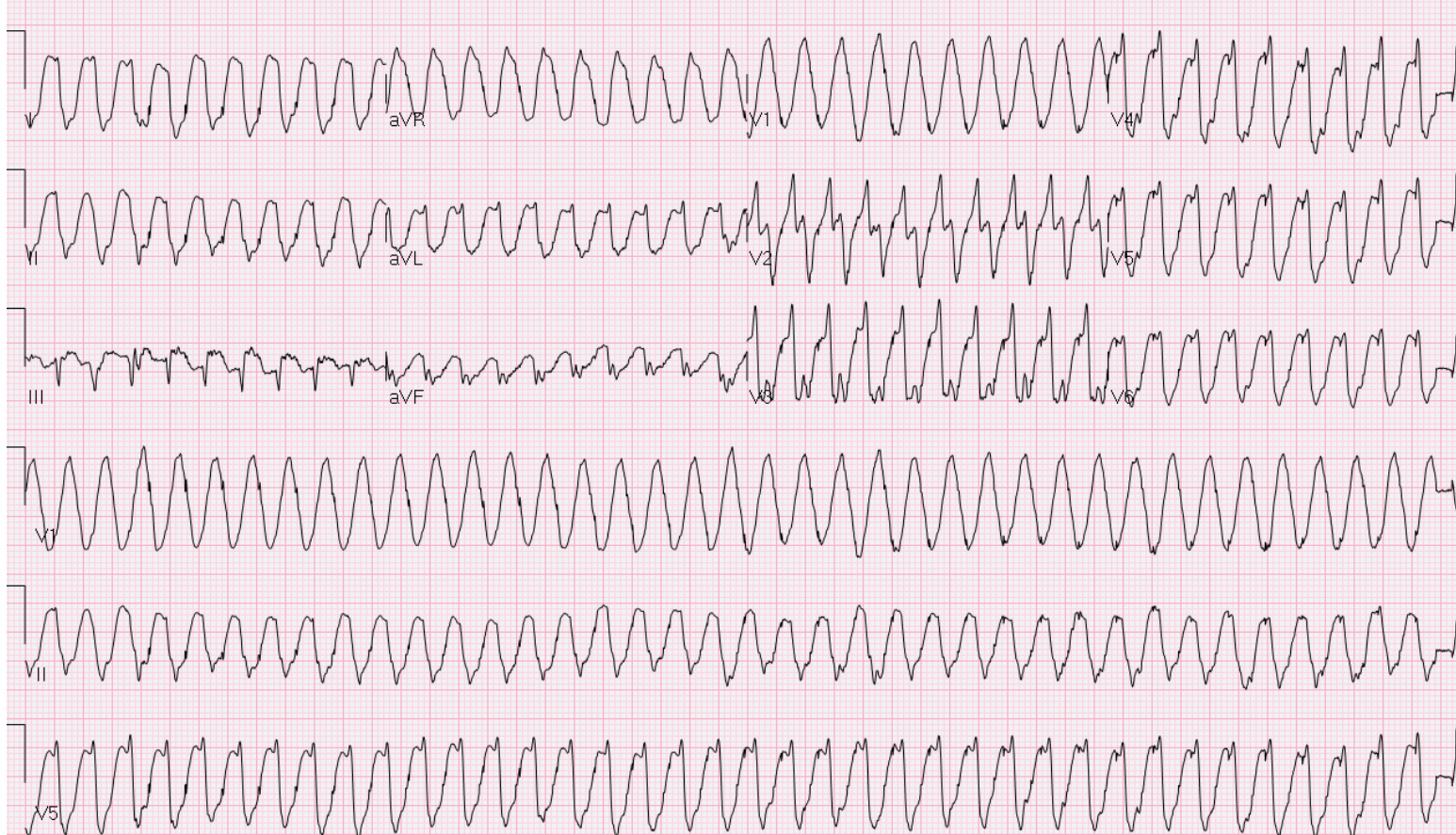


Right Bundle  
Branch Block

Left Bundle  
Branch Block

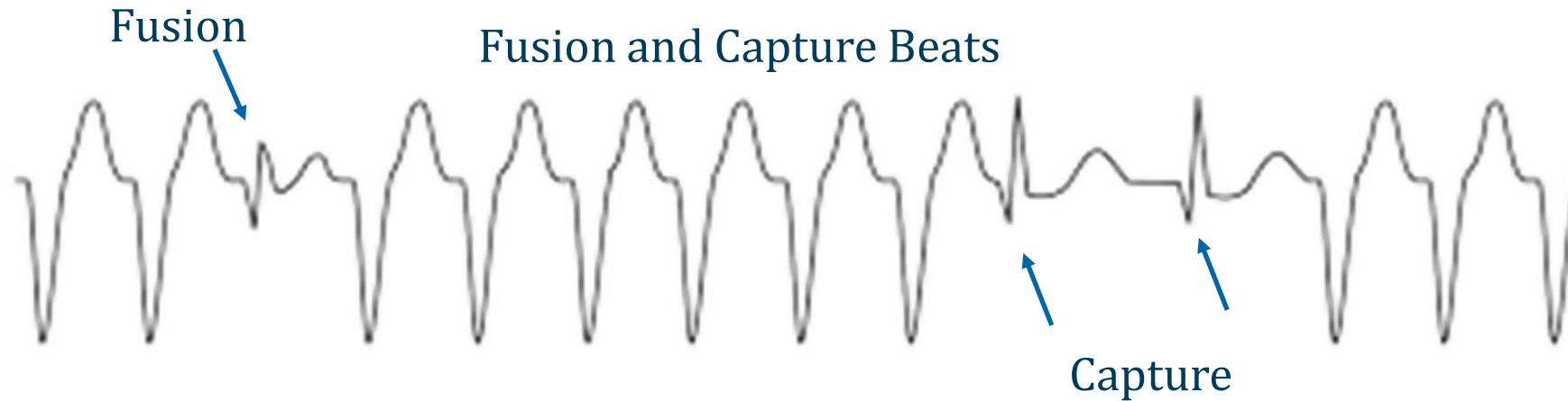
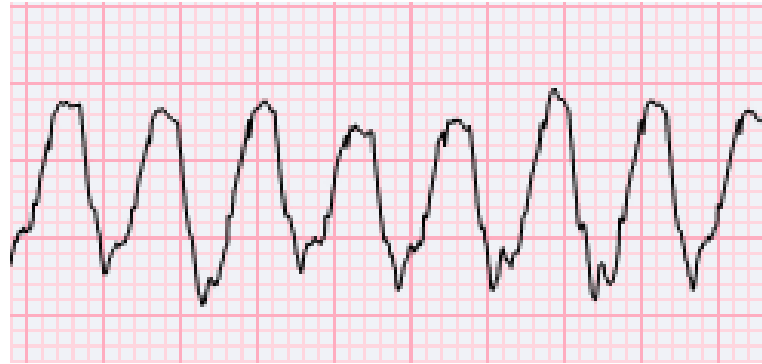


# Ventricular Tachycardia



# Ventricular Tachycardia

AV Dissociation



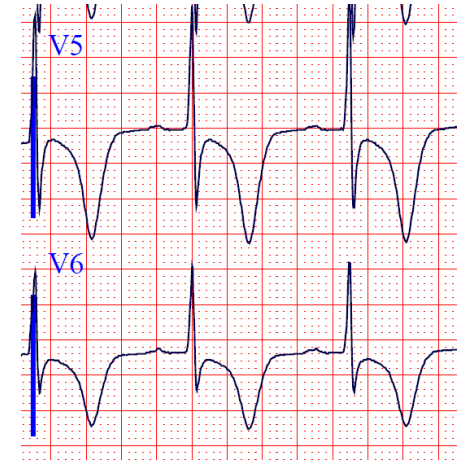
# Step 4: Check the intervals

- PR (normal < 210 ms; ~5 small boxes; ~1 big box)
  - Prolonged in AV block, drugs
- QT (normal < 1/2 R-R interval)
  - Prolonged with ↓ Ca
  - Shortened with ↑ Ca
  - Prolonged by antiarrhythmic drugs, other drugs
  - Can lead to torsades de pointes



# Step 5: ST segments

- T wave abnormalities
  - Inverted: ischemia
  - Peaked: Early ischemia, hyperkalemia ( $\uparrow K$ )
  - Flat/U waves: hypokalemia ( $\downarrow K$ )
- ST depression
  - Subendocardial ischemia
  - Common in UA/NSTEMI
- ST elevation
  - Transmural ischemia
  - STEMI



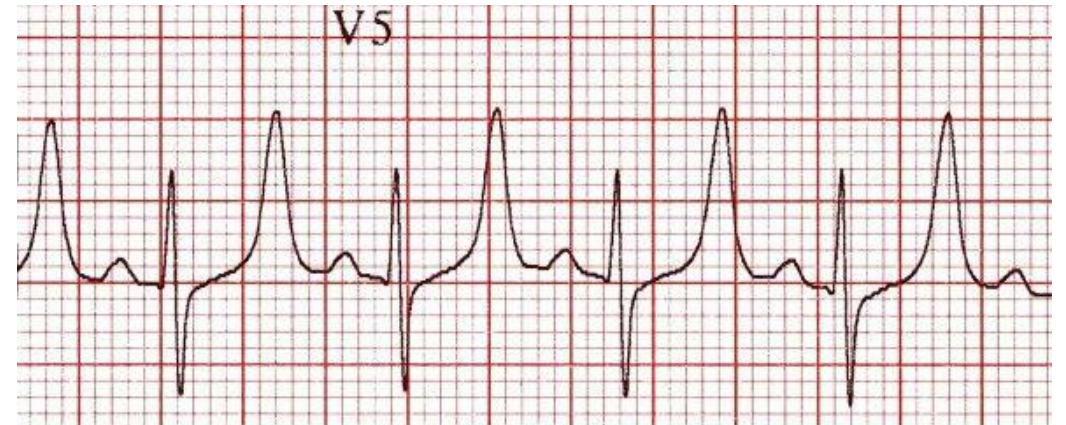
# Peaked T waves

- Hyperkalemia
- Early ischemia: “hyperacute”
  - Precedes ST elevation

Normal T waves

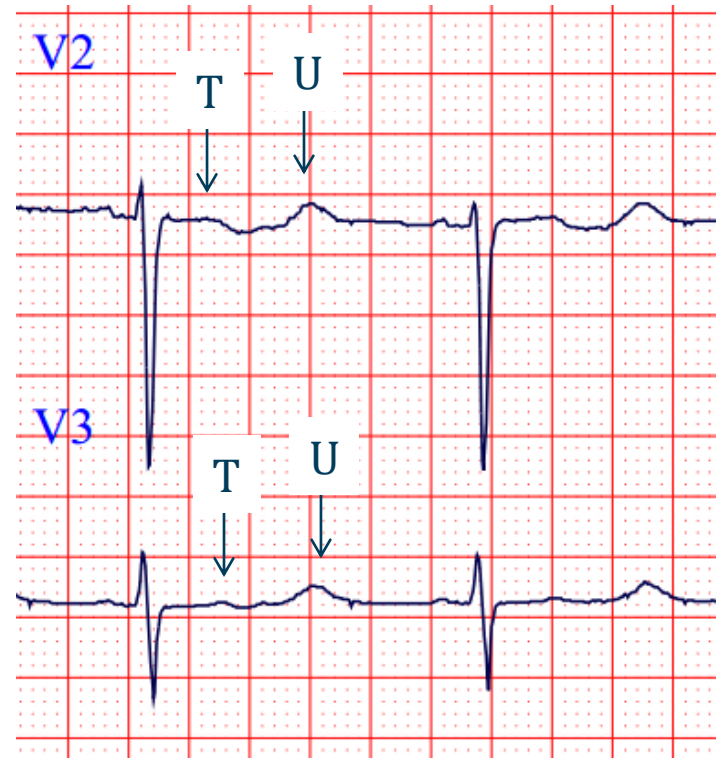


Peaked T waves

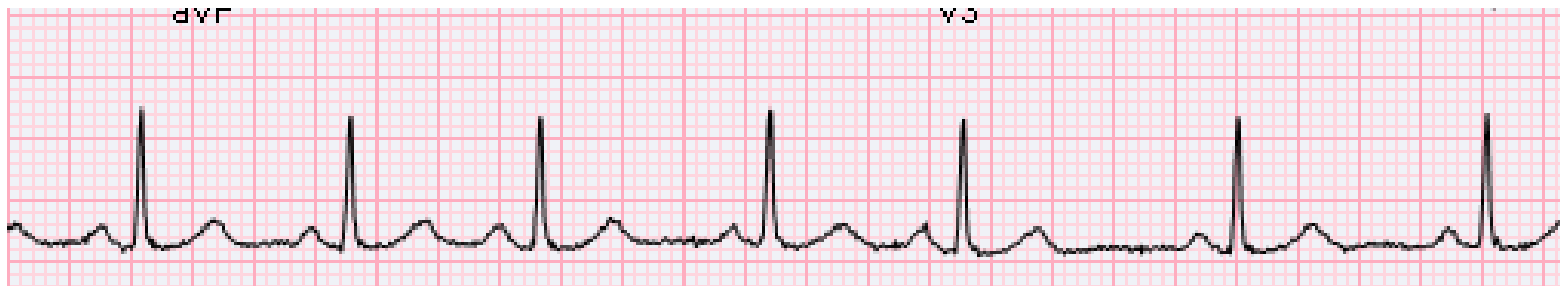
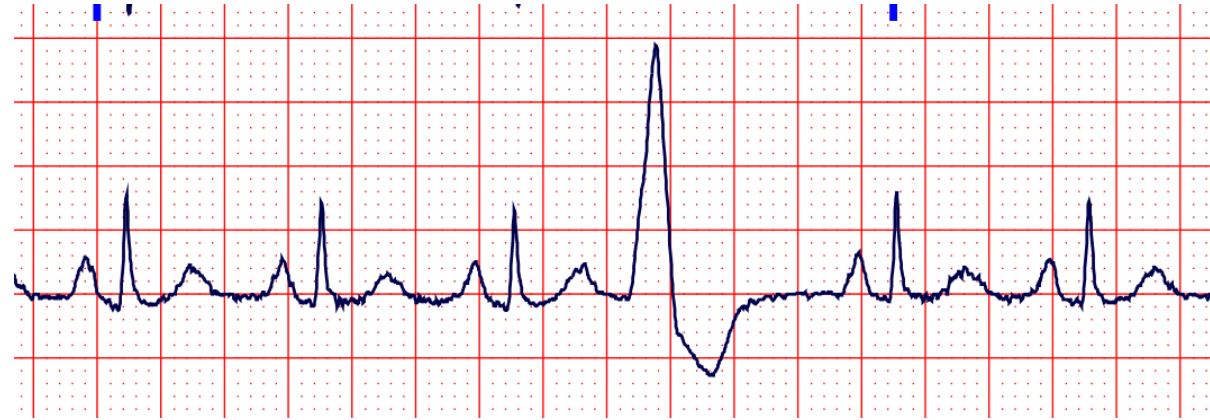


# U waves

- Can be normal
- Also seen in *hypokalemia*



# PAC and PVC





# Coronary Artery Disease

Jason Ryan, MD, MPH

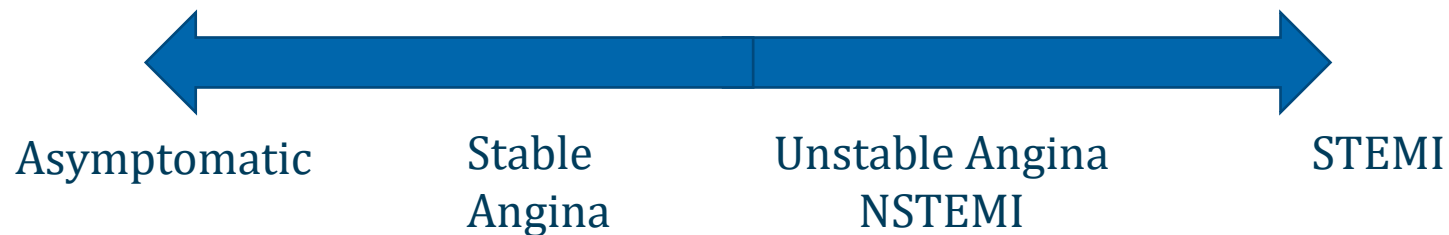


# Coronary Artery Disease

- Narrowing of coronary artery
- Caused by atherosclerosis
- Asymptomatic until ~75% artery lumen occluded
- **Chest pain (angina)**
- May also cause dyspnea, other symptoms



Freestocks.org



# Major Risk Factors

## CAD Equivalents

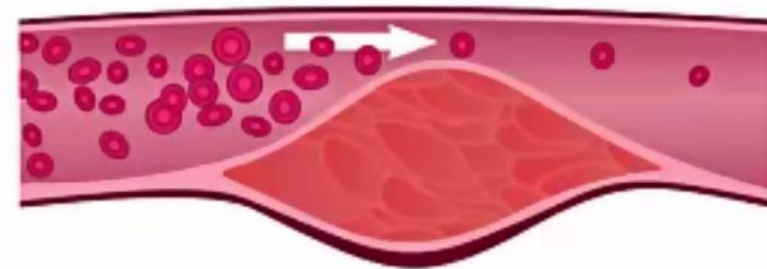
Diabetes

CKD

- Diabetes
- Chronic kidney disease
- Hypertension
- Hyperlipidemia (LDL)
- Age (M > 45, F > 55)
- Family History of premature CAD (1° relative, M < 55, F < 65)
- Smoking (quitting smoking → significantly ↓ risk)
- Obesity, sedentary lifestyle

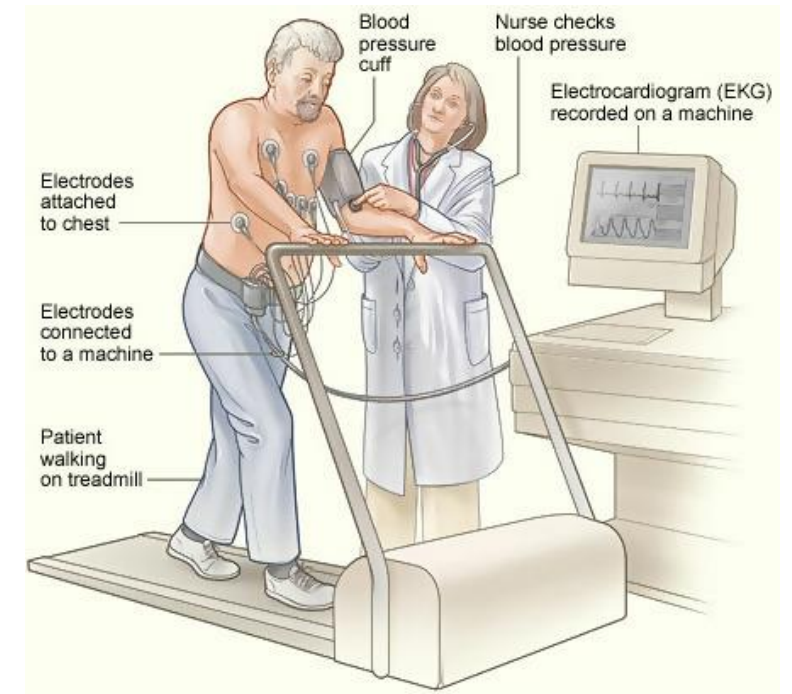
# Stable Angina

- Plaque occluding ~75% or more of coronary artery
- Causes “typical” chest pain
  - Pressure-like chest pain
  - Occur with exertion
  - Relieved by rest or nitroglycerine
- EKG at rest: normal
- Symptoms at rest: absent
- Diagnosis: symptoms or stress testing
  - Stress testing key when diagnosis uncertain

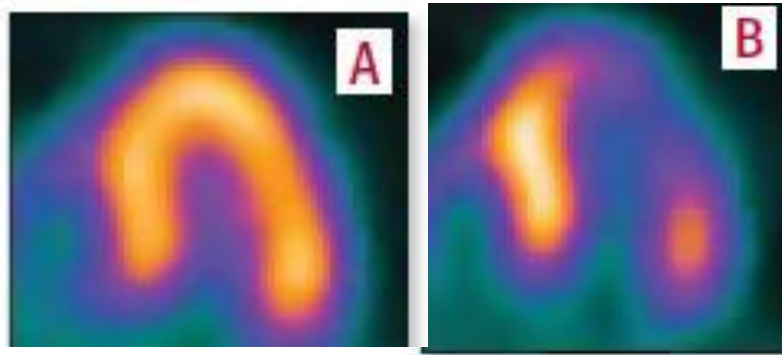


# Stress Testing

- Patient must be asymptomatic
- Goal: provoke ischemia and detect ischemia
- Provocation: exercise always preferred
- Detection:
  - EKG changes (ST-depressions)
  - Nuclear imaging (usually Technetium)
  - Echocardiography



Wikipedia/Public Domain



# Pharmacologic Stress Testing

- Pharmacologic nuclear (induce **coronary steal**)
  - Regadenoson
  - Dipyrimadole
  - Adenosine
  - Persantine
  - Contraindication: reactive airway disease/wheezing
- Dobutamine stress echocardiography
  - Risk of arrhythmias

# Stress Testing

- Identifies ischemia due to **“flow-limiting” stenosis** (usually >75%)
- Non-flow-limiting lesions not detected
- Acute MI may occur despite negative stress test

# Angiography





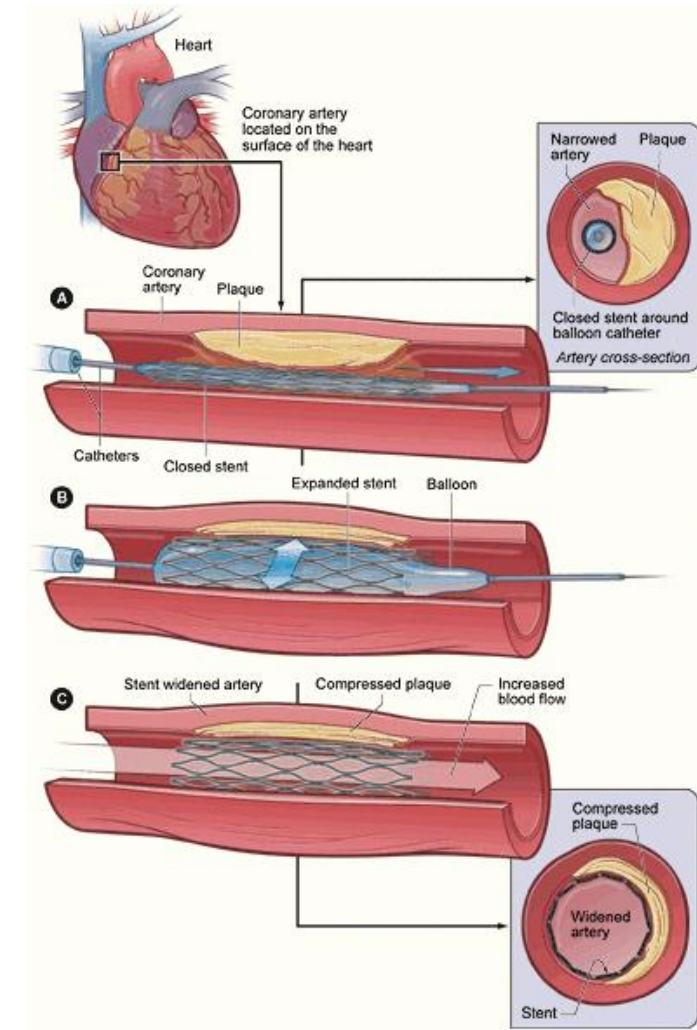
# Stable Angina

## Management

- **Preventative therapy** (↓ risk of mortality and myocardial infarction)
  - Aspirin
  - Statin
- Anti-angina therapy (goal: ↓ O<sub>2</sub> demand)
  - Beta-blockers or calcium-channel blockers (↓ heart rate/contractility)
  - Nitroglycerine (↓ preload)
- Coronary stent implantation
- Coronary artery bypass grafting (CABG) surgery
- COURAGE Trial: medical therapy has similar outcomes to stent implantation

# Coronary Stents

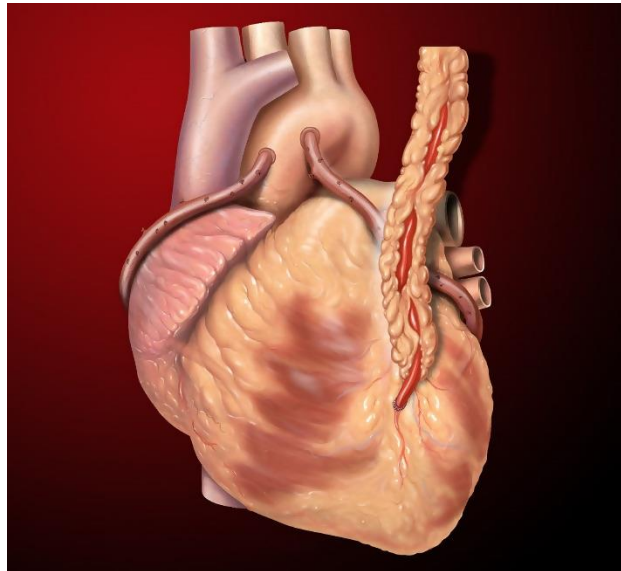
- Percutaneous Coronary Intervention (PCI)
- About 600,000 stents/year implanted US



# CABG

## Coronary Artery Bypass Grafting

- “Bypass Surgery”
- Left Internal Mammary Artery (LIMA) Graft
- Saphenous (leg) Vein Grafts
- Radial (arm) Artery Grafts



Patrick J. Lynch/Wikipedia

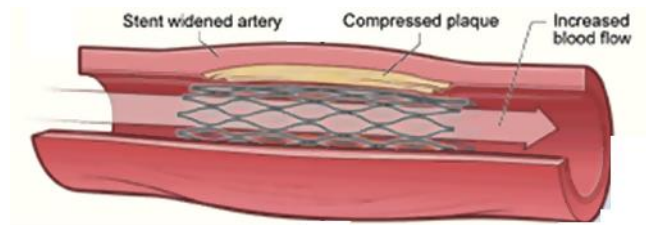
# Stable Angina: Typical Case

- 65-year-old man with chest pain while walking
- Relieved with rest
- Presents to ED:
  - EKG normal
  - Biomarkers normal
- Stress test
  - Walks on treadmill → chest pain, EKG changes
- Cardiac catheterization performed
- 90% LAD artery blockage
- Stent placed → angina resolved

# Stent Complications

## Restenosis

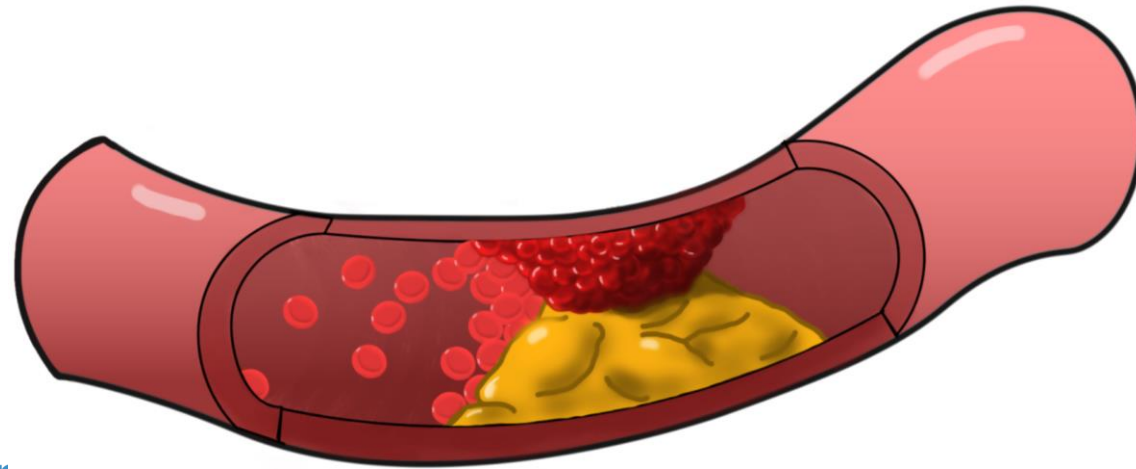
- Slow, steady growth of scar tissue over stent
- “Neo-intimal hyperplasia”
- Re-occlusion of vessel
- Rarely life-threatening
- Slow, steady return of angina
- Most stents coated “drug-eluting stents”
  - Metal stent covered with polymer
  - Polymer impregnated with drug to prevent tissue growth
  - Sirolimus



# Stent Complications

## Thrombosis

- Acute closure of stent
- Same as STEMI: life-threatening event
- Dual anti-platelet therapy for prevention
- Associated with **missed medication doses**



# Stent Thrombosis Prevention

- “Dual antiplatelet therapy”
- Typically one year of:
  - Aspirin
  - Clopidogrel, prasugrel or ticagrelor (P2Y12 receptor antagonists)
- After one year, stent metal no longer exposed to blood
  - Scar tissue and endothelial growth
  - Risk of thrombosis is lower (but not zero)
  - Most patients take aspirin only

# Variant (Prinzmetal) Angina

- Episodic vasoconstriction of coronary vessels
- Episodes usually at rest
- Midnight to **early morning**
- Sometimes symptoms improve with exertion
- Associated with smoking
- Diagnosis: usually based on history



# Variant (Prinzmetal) Angina

## Treatment

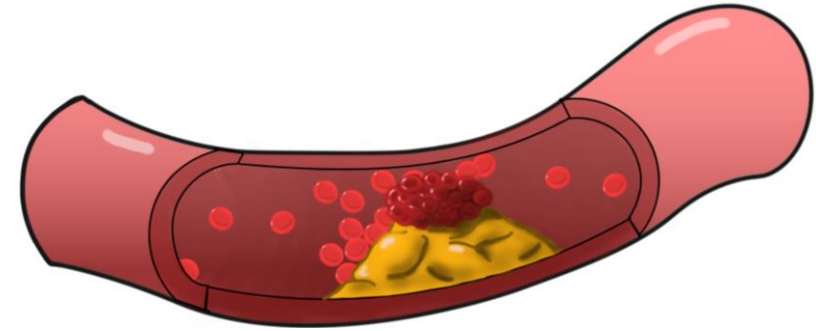
- Quit smoking
- **Calcium channel blockers, nitrates**
  - Dihydropyridine CCB: amlodipine
  - Vasodilators
  - Dilate coronary arteries, oppose spasm
- Avoid propranolol
  - Nonselective beta blocker
  - Can cause unopposed alpha stimulation
  - Symptoms may worsen



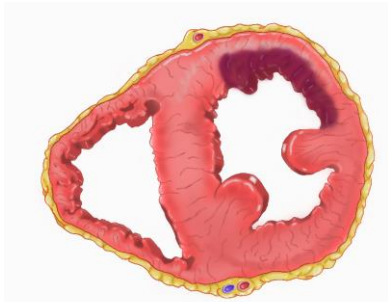
Pixabay/Public Domain

# Acute Coronary Syndromes

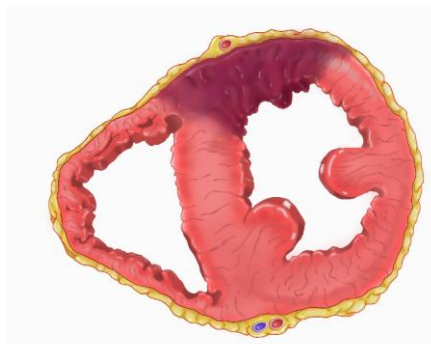
- Plaque rupture → thrombus formation
- Subtotal occlusion
  - Unstable angina
  - Non-ST elevation myocardial infarction
- Total occlusion (100%)
  - ST-elevation myocardial infarction (STEMI)



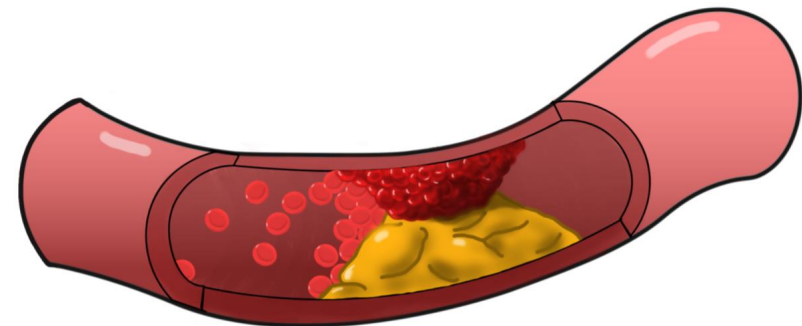
Subtotal Occlusion



Subendocardial Ischemia



Transmural Ischemia



Total Occlusion

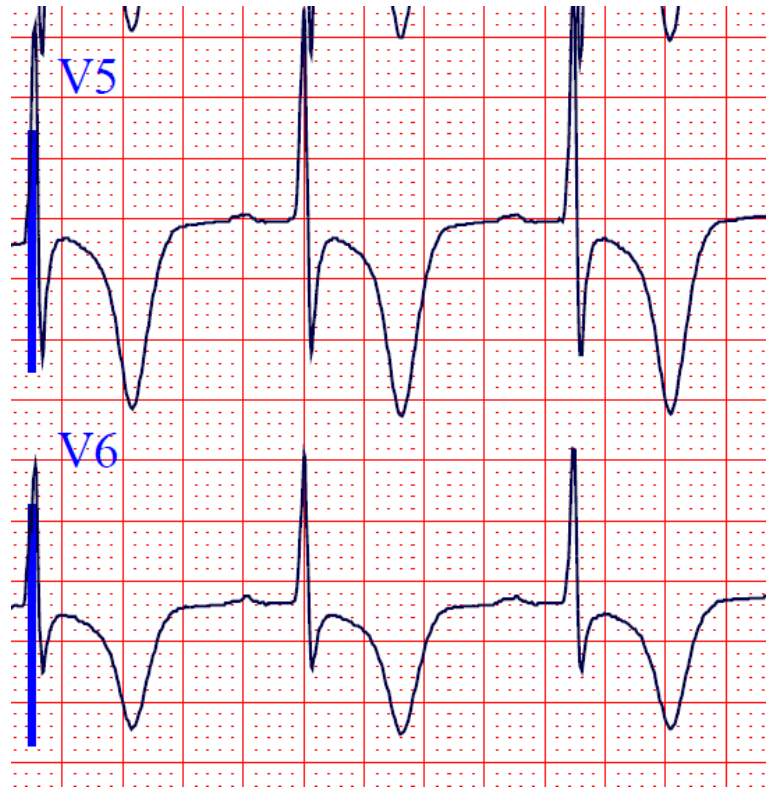
# Unstable Angina and NSTEMI

- Unstable angina
  - Ischemic symptoms occurring with increasing frequency or at rest
  - Negative biomarkers
- NSTEMI
  - Positive biomarkers
- Ischemic EKG changes (other than ST-elevation) may occur in both

# UA/NSTEMI

## ECG Changes

- ST depressions
- T-wave inversions



# UA/NSTEMI

## Cardiac Biomarkers

- Biomarkers spill into blood with cardiac injury
- Most common marker used: **Troponin I or T**
  - Increase 2-4 hours after MI
  - Stay elevated for weeks
- **CK-MB also used**
  - Increase 4-6 hours after MI
  - Normalize within 2-3 days
  - Very good for re-infarction

# Treatment of UA/NSTEMI

- Thrombotic and ischemic syndrome (like STEMI)
- No “ticking clock” (unlike STEMI)
  - Subtotal occlusion
  - Some blood flow to distal myocardium
  - No emergency angioplasty
  - No benefit to thrombolysis
- Aspirin
- Beta-blocker
- Heparin
- Angioplasty (non-emergent)

# Typical UA/NSTEMI Course

- Presents to ER with chest pain
- Biomarkers elevated
- Absence of ST-segment elevations ← Obtain EKG in all chest pain patients
- Medical Therapy
  - Aspirin ← Give aspirin to chest pain patients with possible NSTEMI
  - Metoprolol
  - Heparin drip
- Admitted to cardiac floor
- Hospital day 2 → angiography
- 90% blockage of LAD → Stent

# UA/NSTEMI Treatment

## Long-term therapy

- Goal: ↓ **mortality and recurrent infarction**
  - Aspirin
  - Statin
- Beta-blocker for prevention of recurrent disease
  - Strong indication in STEMI
  - Weak indication NSTEMI/UA
  - Used for prevention in NSTEMI only



# STEMI

Jason Ryan, MD, MPH



# STEMI

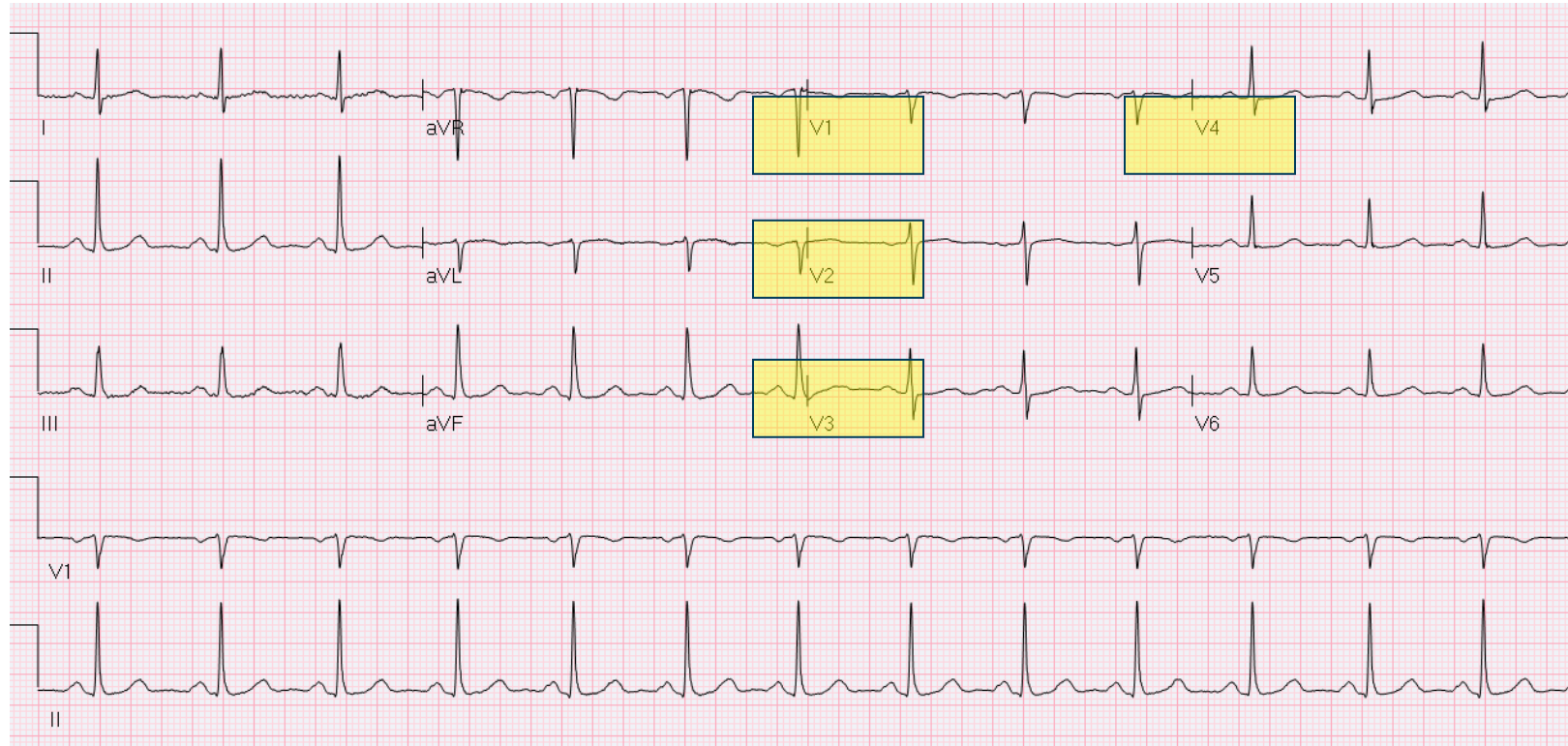
## ST-Elevation Myocardial Infarction

- Angina at rest with ST-segment elevation
- Biomarkers elevated after 4-6 hours



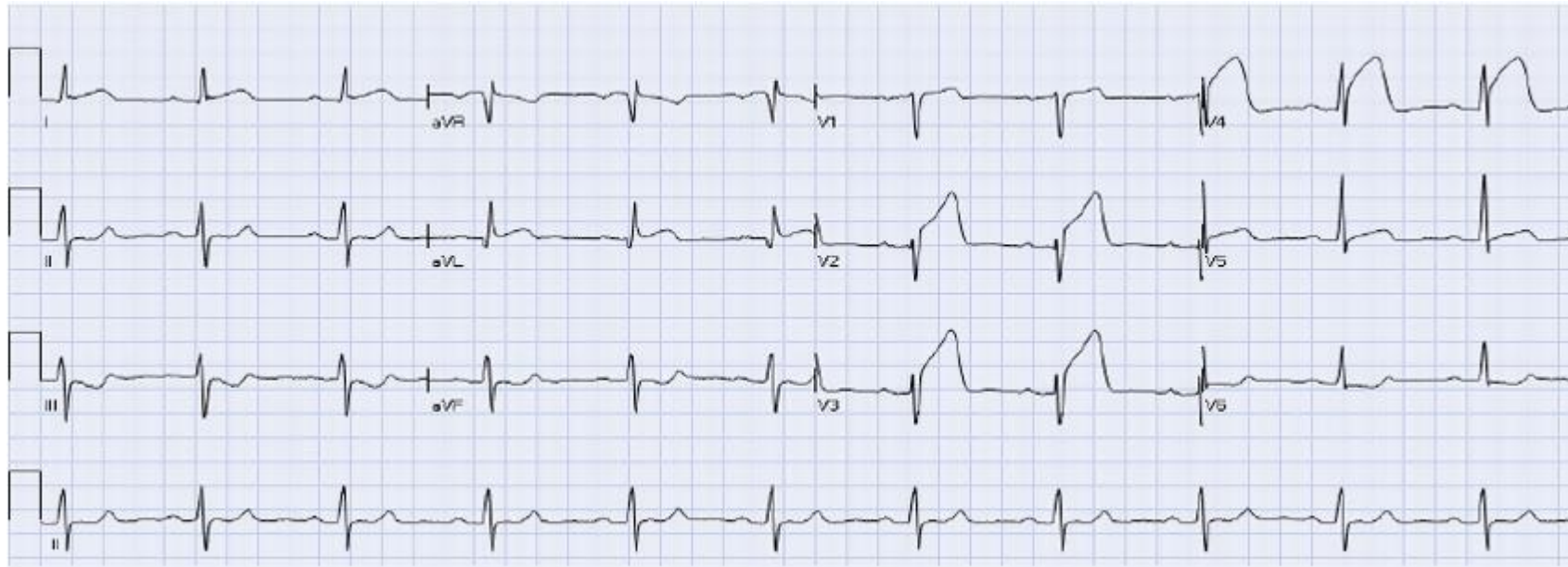
# Leads go together

ST Elevations - Anterior



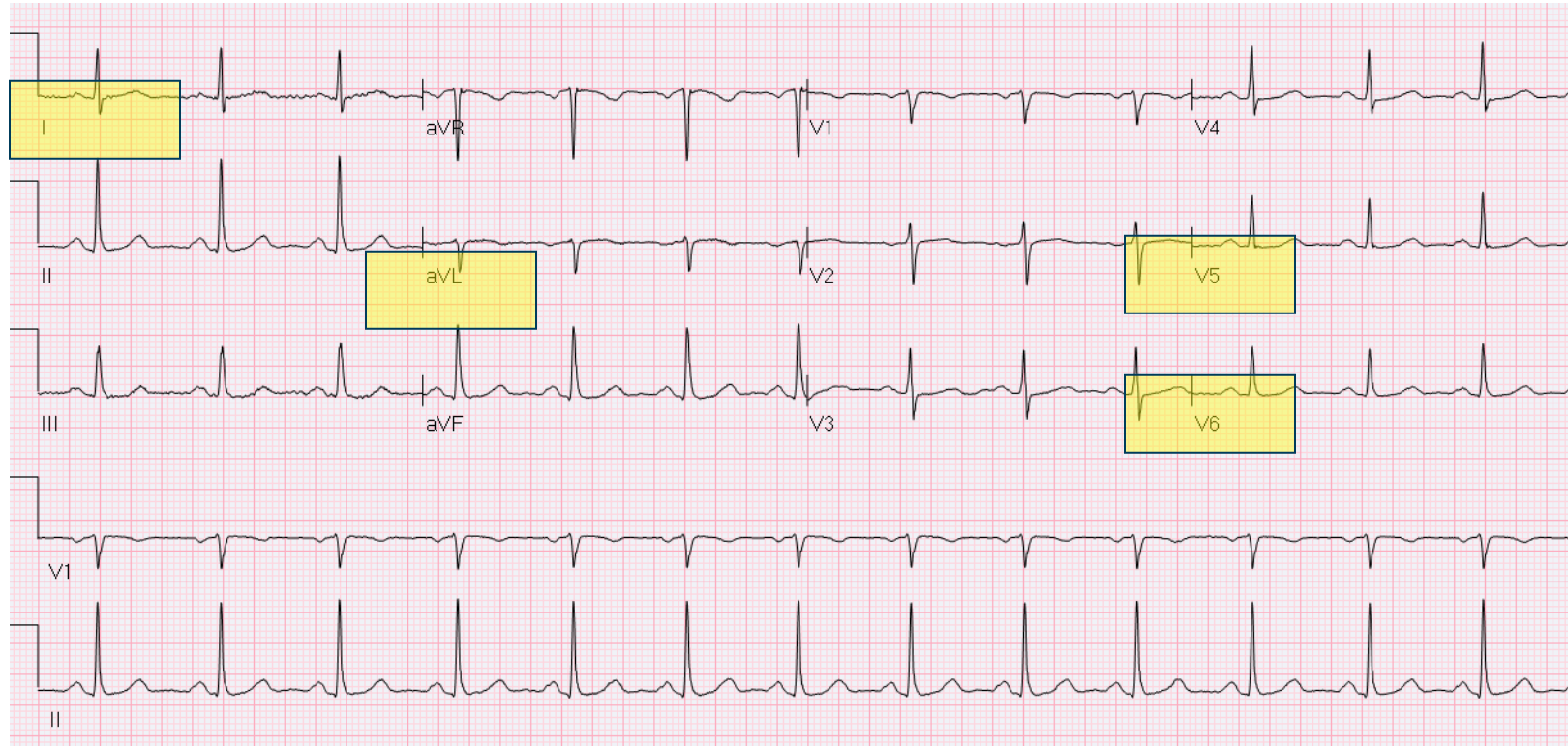
# Leads go together

ST Elevations - Anterior



# Leads go together

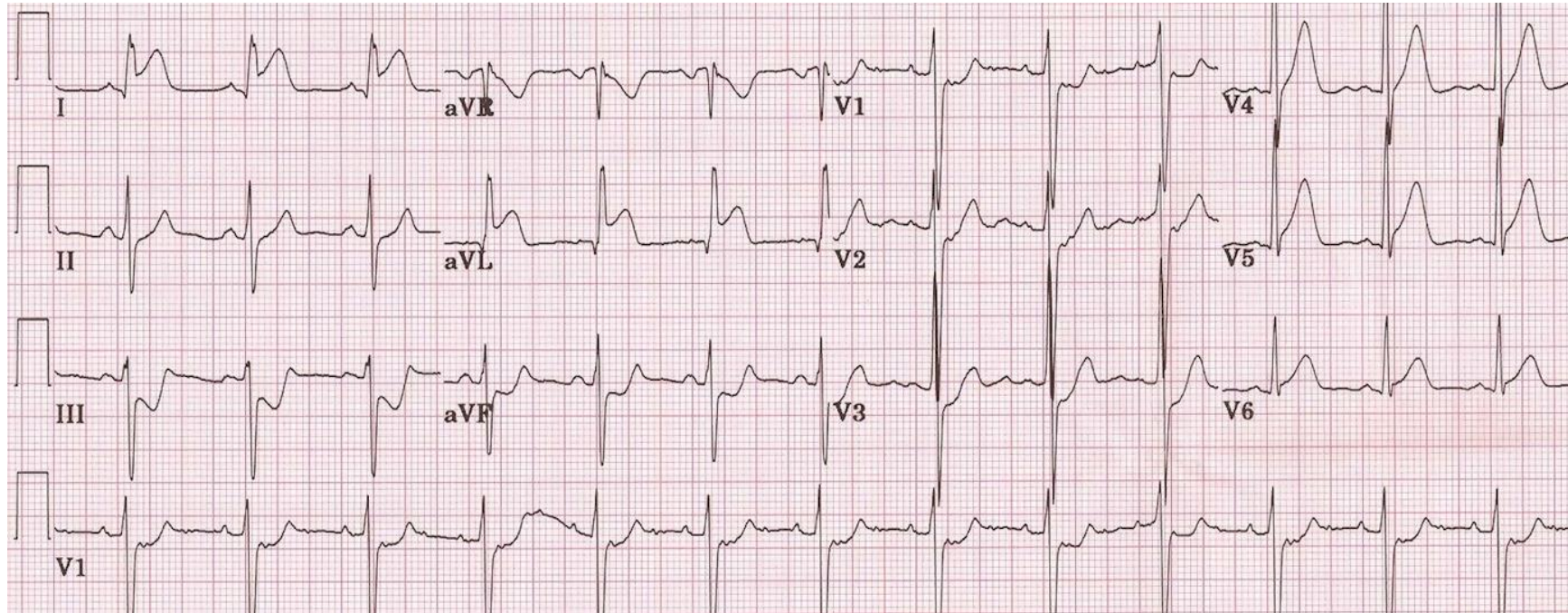
ST Elevations - Lateral





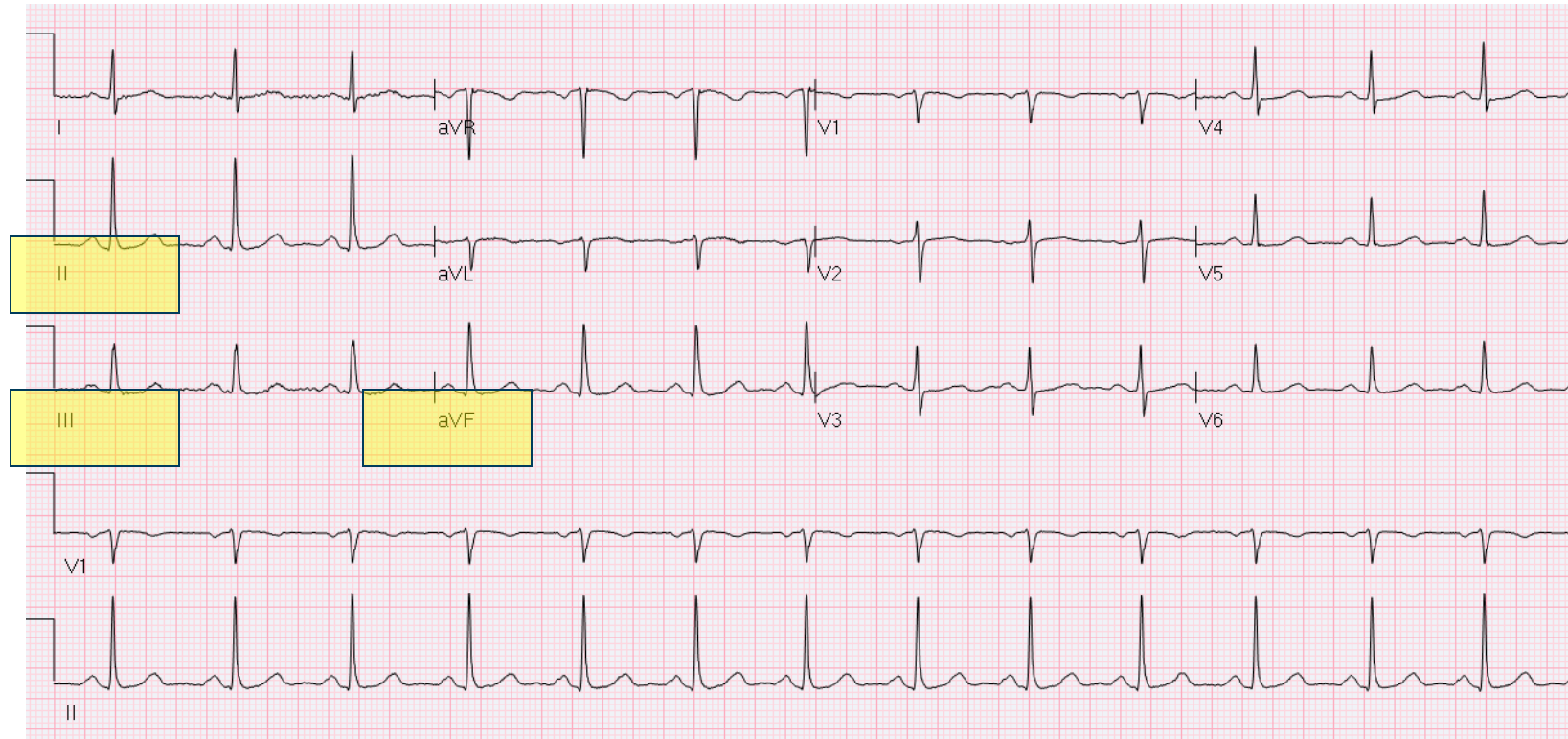
# Leads go together

ST Elevations - Lateral



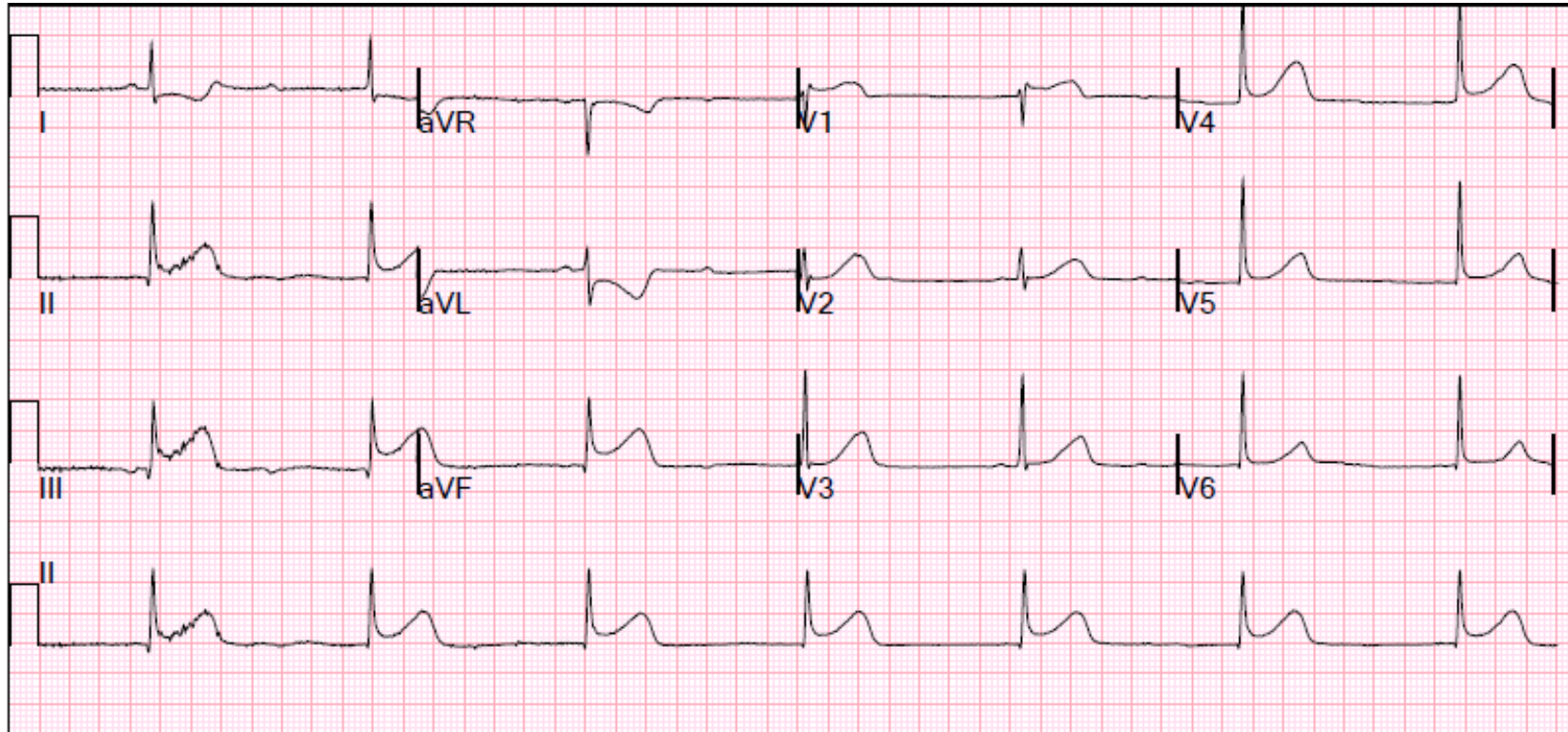
# Leads go together

ST Elevations - Inferior



# Leads go together

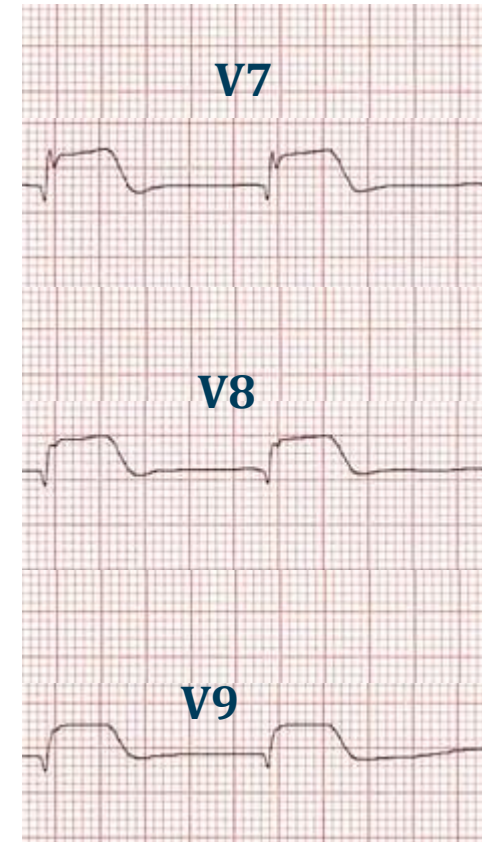
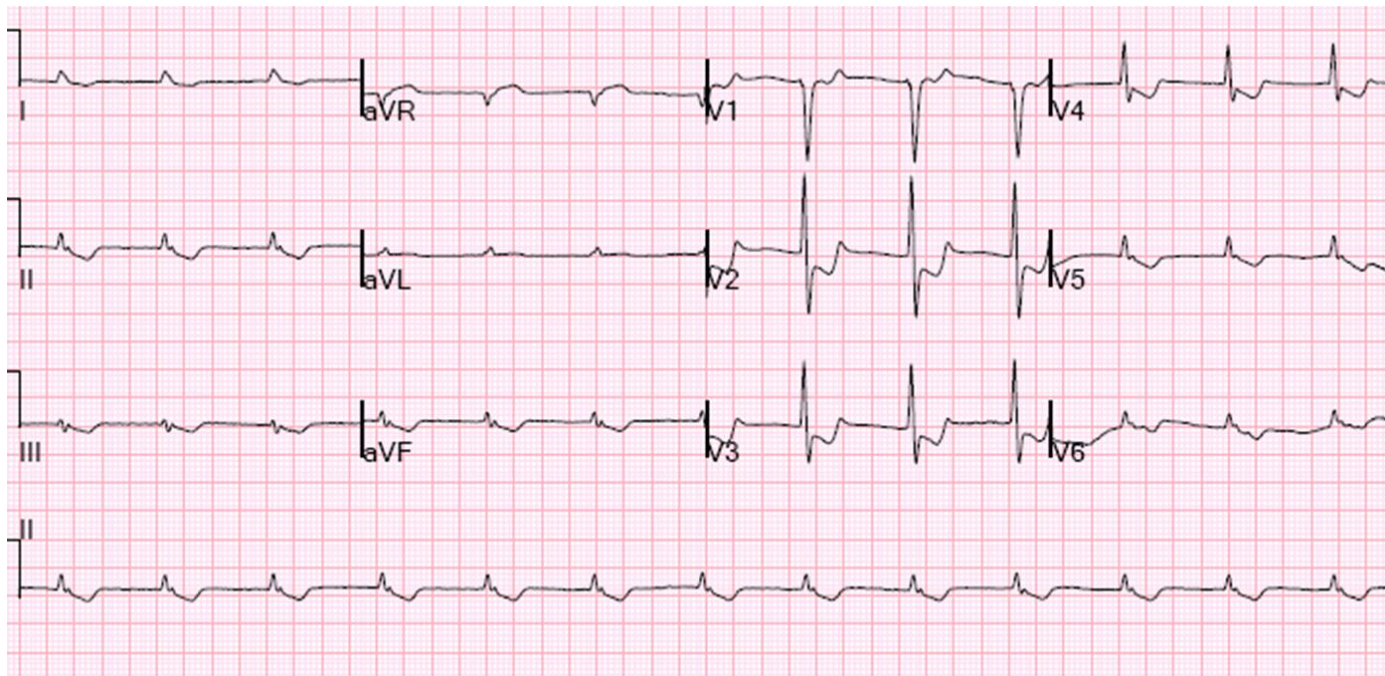
ST Elevations - Inferior



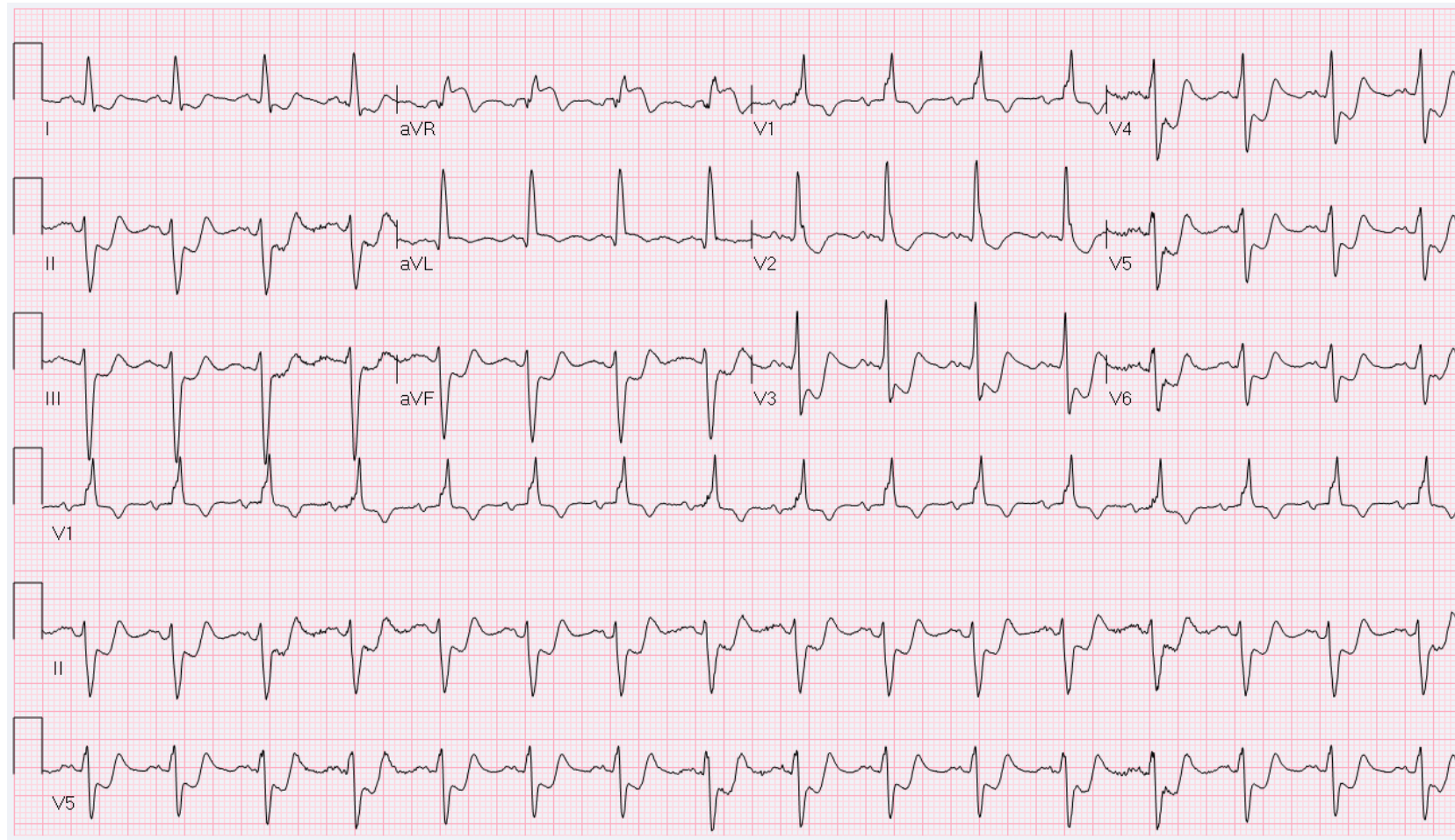


# Posterior STEMI

- Anterior ST depressions with standard leads
- ST-elevation in **posterior leads (V7-V9)**



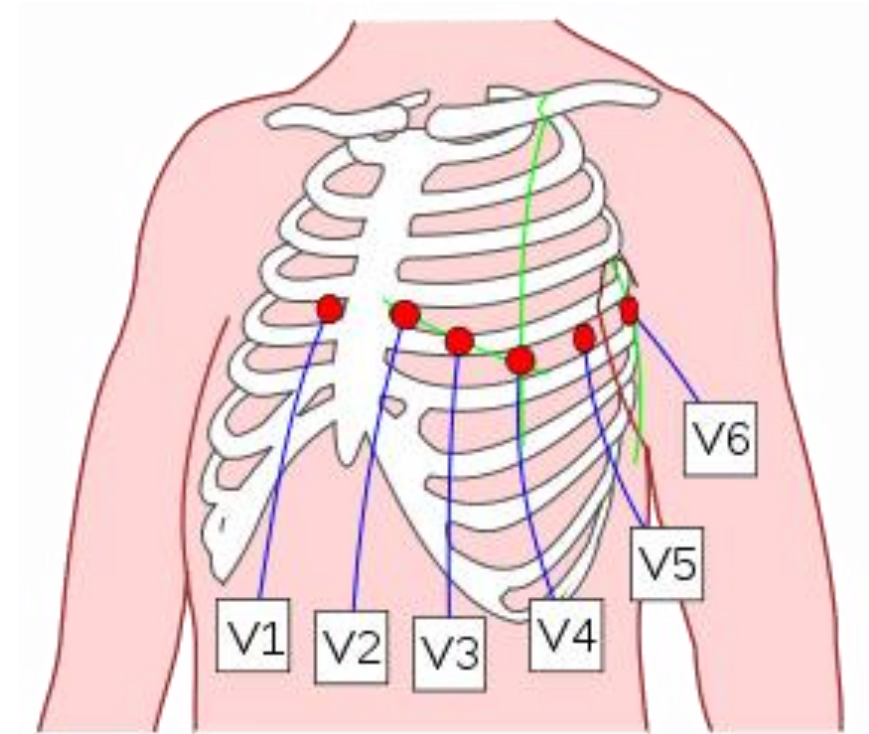
# Left Main Occlusion



# Special Complications

## Inferior MI

- Right ventricular infarction
  - Occurs in inferior STEMI (II, III, aVF)
  - Loss of right ventricular contractility
  - **Elevated jugular venous pressure**
  - Decreased preload to left ventricle → **hypotension**
  - Diagnosis: right-sided chest leads
  - Avoid nitroglycerine
  - Treatment: IV fluids (↑ preload)



# Special Complications

## Inferior MI

- Sinus bradycardia and heart block
  - Inferior wall ischemia
  - RCA: SA node 60%, AV node 90%



# Special Complications

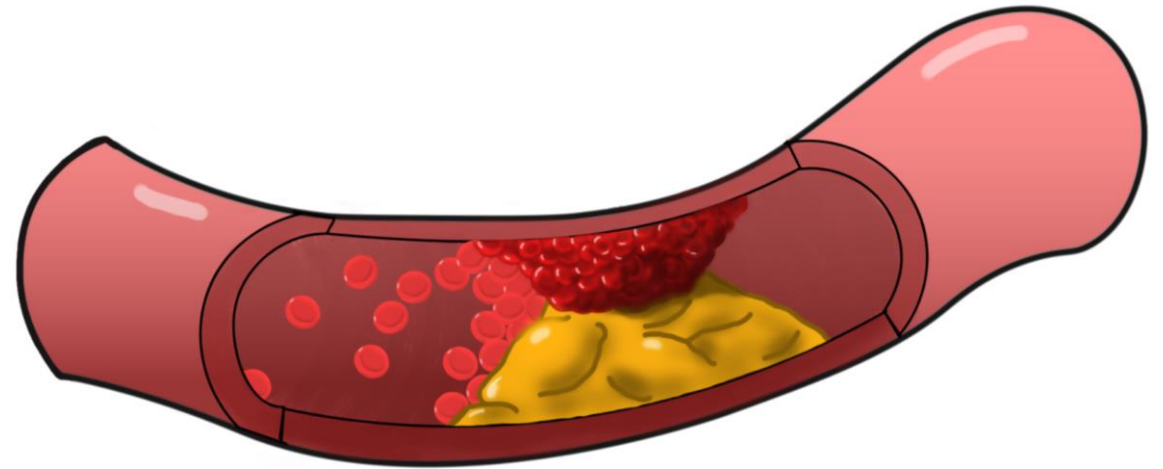
## Anterior MI

- **Cardiogenic shock**
  - Usually occurs with large anterior STEMIs
- Hypotension
- Tachycardia
- Pulmonary edema
- Respiratory distress



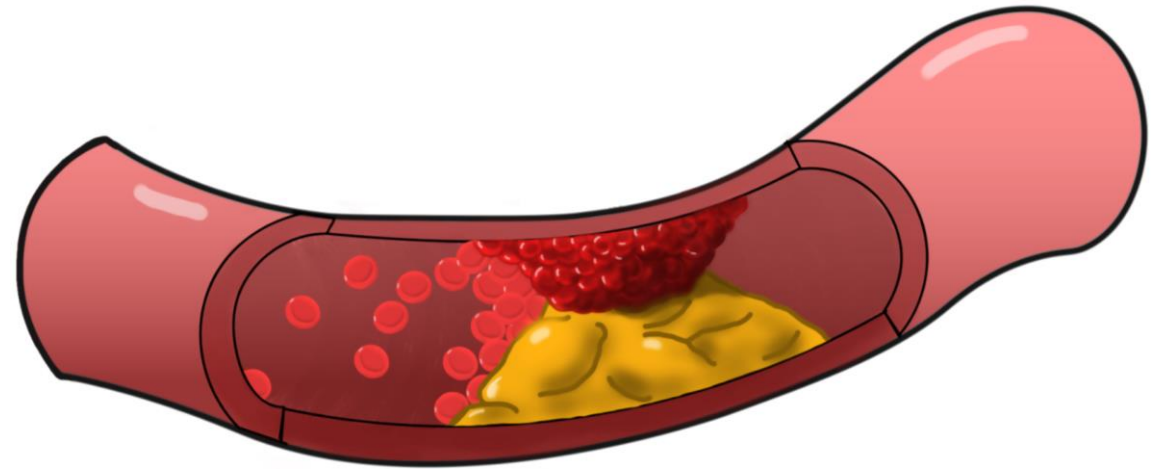
# Treatment of STEMI

- “Time is muscle”
- Coronary artery occluded by thrombus
- Longer occlusion → more muscle dies
  - More likely the patient may die
  - More heart failure symptoms
  - More future hospitalization for heart disease
- **Medical emergency**



# Treatment of STEMI

- Main objective is to open the artery
  - “Revascularization”
- Option 1: Emergency angioplasty
  - Mechanical opening of artery
  - Stent placement
  - Should be done < 90min
- Option 2: Thrombolysis
  - Alteplase, TPA
  - Should be done < 30min
- “Door to balloon” or “door to needle”



# Treatment of STEMI

- Time matters
  - Medical therapy is supportive
  - Given while working to open artery
- This is a **thrombotic** problem
  - Aspirin to inhibit platelet aggregation
  - Heparin to inhibit clot formation
- This is also an **ischemic** problem
  - Beta-blockers to reduce O2 demand
  - Nitrates to reduce O2 demand



# Cautions

- Beta-blockers
  - Inferior MI
  - **Bradycardia and AV block** can develop
- Nitrates
  - Occlusion of RCA can cause **RV infarct**
  - RV infarction → ↓ preload
  - Nitrates ↓ preload → **hypotension**

# Other STEMI Treatments

- Clopidogrel
  - ADP receptor blocker
  - Inhibits platelets
- Eptifibatide
  - IIB/IIIA receptor blocker
  - Inhibits platelets
- Bivalirudin
  - Direct thrombin inhibitor
  - Inhibits clot formation

# Typical STEMI Course

- Arrival in ER with chest pain 5:42 pm
- EKG done 5:50 pm
  - STEMI identified
- Cardiac cath lab activated for emergent angioplasty
- Meds given in ER
  - Aspirin
  - Metoprolol
  - Nitro drip
  - Heparin bolus
  - Transport to cath lab 6:15 pm
- Artery opened with balloon 6:42 pm
  - DTB time 60 minutes (ideal < 90min)

# Typical STEMI Course

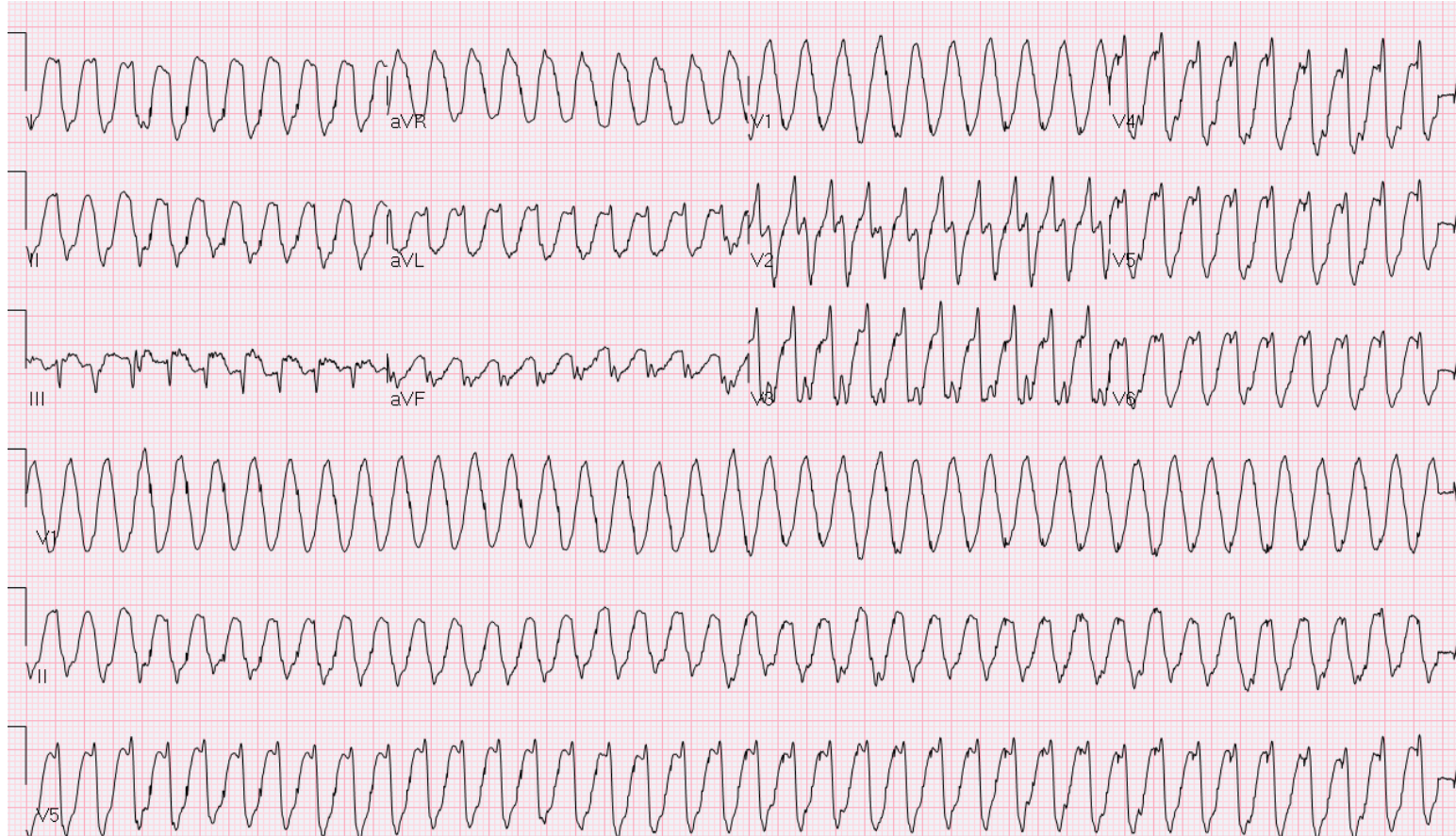
- Arrival in ER with chest pain 5:42 pm
- EKG done 5:54 pm
  - STEMI identified
- Meds given in ER
  - Aspirin
  - Metoprolol
  - Nitro drip
  - Heparin bolus
- tPA given based on weight 6:07 pm
  - IV push
  - Door to needle time 25 min (ideal < 30)

# Complications of Ischemia

- First 4 days
  - Arrhythmia
- 5 – 10 days
  - Free wall rupture
  - Tamponade
  - Papillary muscle rupture
  - VSD (septal rupture)
- Weeks later
  - Dressler's syndrome
  - Aneurysm
  - LV Thrombus/CVA

# Cause of Death

0 – 4 days after MI



# Sudden Cardiac Death

- Most common cause among older patients: **myocardial infarction**
- Ventricular tachycardia → ventricular fibrillation → cardiac arrest

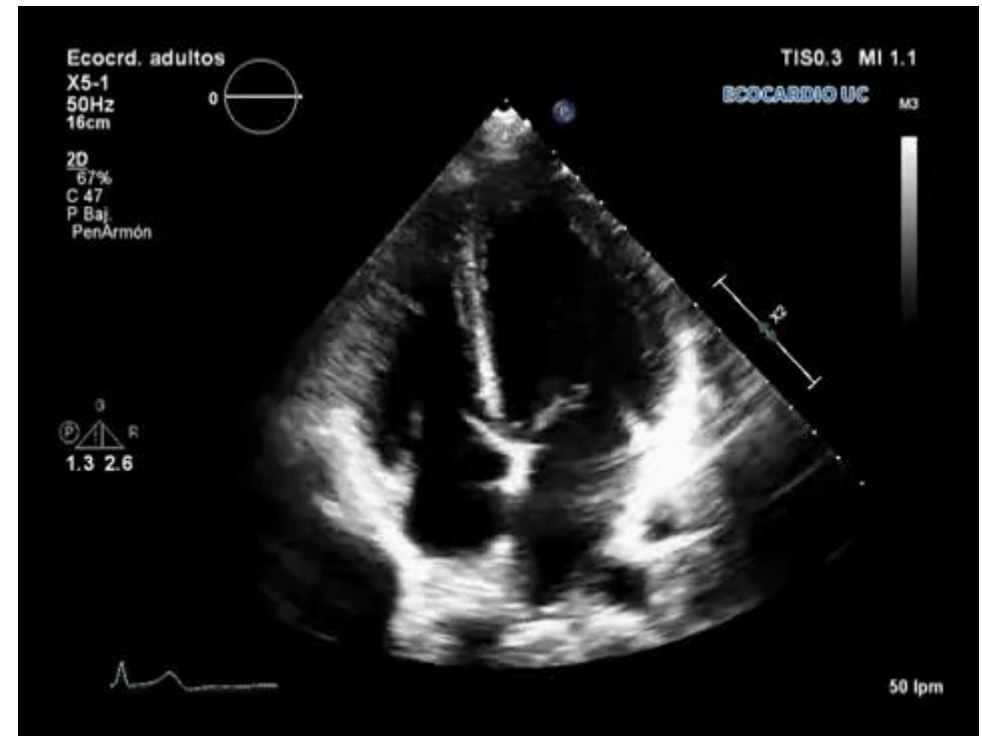


# Cause of Death

5-10 days after MI

- **Free wall rupture**
  - Usually fatal – sudden death
  - May lead to tamponade
- **Papillary muscle rupture**
  - Acute mitral regurgitation (holosystolic murmur)
  - Heart failure, respiratory distress
  - More common inferior MIs
- **Septal rupture – VSD**
  - Loud, holosystolic murmur (thrill)
  - Hypotension, right heart failure (↑ JVP, edema)

Best Test:  
**Transthoracic Echocardiogram**

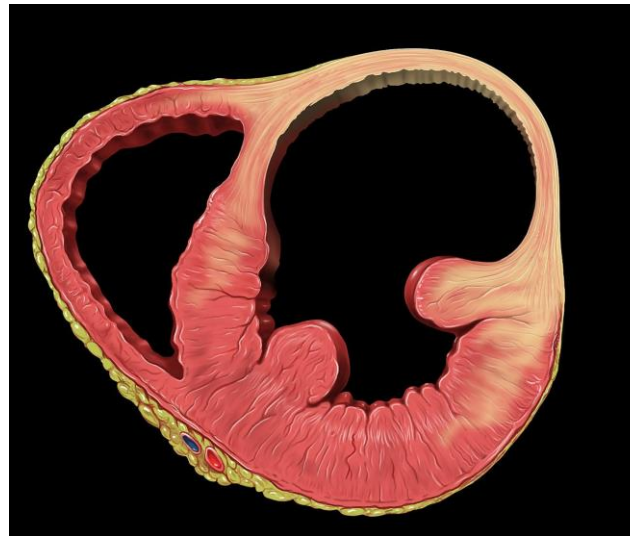




# Ventricular Aneurysm

Weeks to months after MI

- More common **anterior infarction**
- Risk of thrombus → stroke, peripheral embolism
- Causes persistent ST elevations

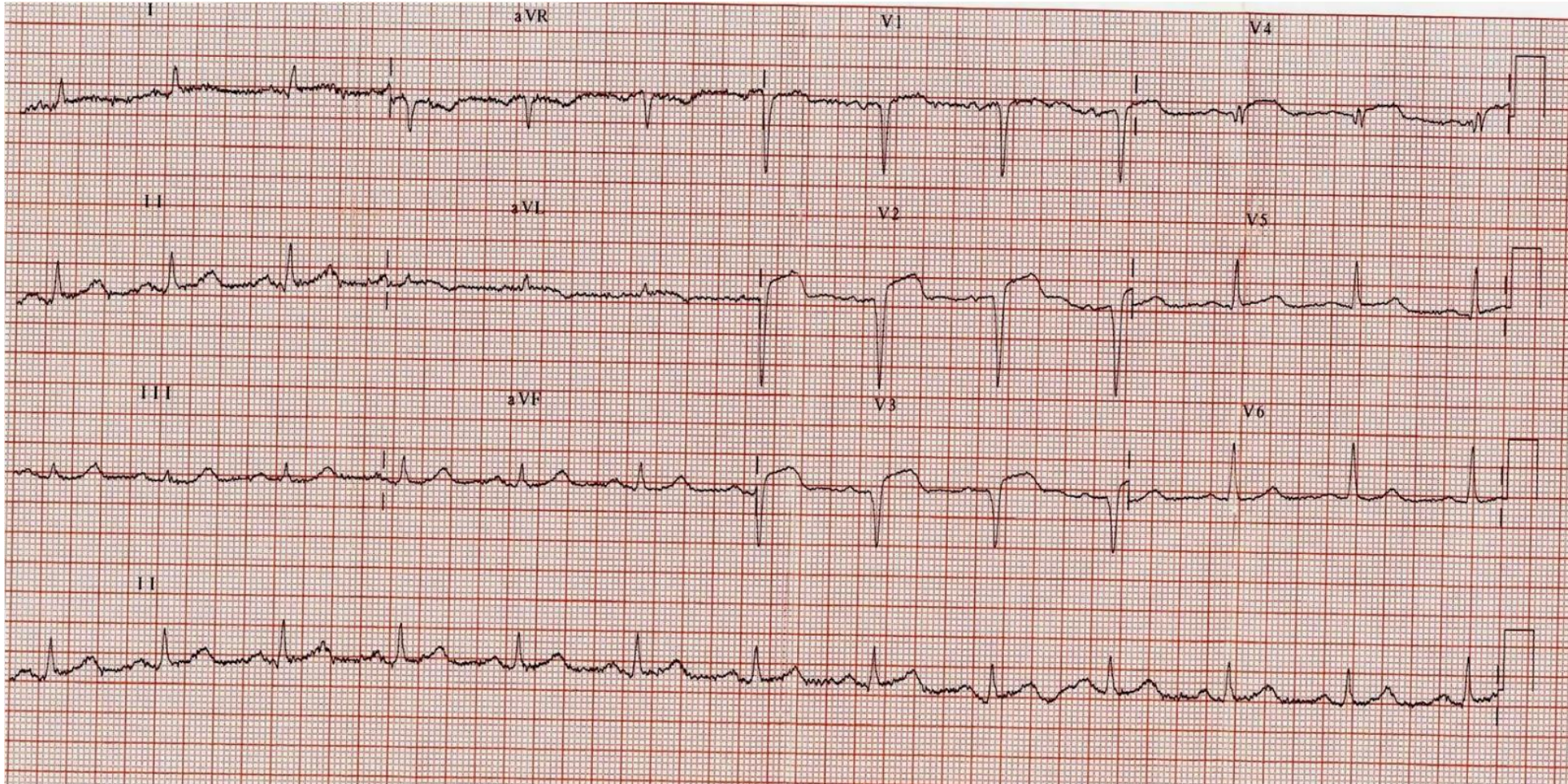


Patrick J. Lynch, medical illustrator/Wikipedia



# Ventricular Aneurysm

Weeks to months after MI





# Ventricular Pseudoaneurysm

1 to 2 weeks after MI

- **Rupture contained by pericardium/scar tissue**
- Not a true aneurysm
  - No endocardium or myocardium
- May rupture
- Presents as chest pain or dyspnea
- Often seen in the **inferior wall**
- Occurs earlier (< 2 weeks) than true aneurysm

# Dressler's Syndrome

Weeks to months after MI

- Form of pericarditis
  - Chest pain
  - Friction rub
- Immune-mediated (details not known)
- Diagnosis: clinical
- Treatment: NSAIDs or steroids

# Fibrinous Pericarditis

- Occurs *days* after MI
  - Sometimes called “post-MI” pericarditis
  - Not autoimmune
  - Extension of myocardial inflammation
- Dressler’s occurs *weeks* after MI
  - Sometimes called “post cardiac injury” pericarditis
- Rarely life-threatening
- Diagnosis: clinical

# Evaluation of Chest Pain

- Must consider: STEMI, aortic dissection and pulmonary embolism
- Best first test: **EKG** to evaluate for STEMI
- Additional testing considerations:
  - CT scan (PE or dissection)
  - Cardiac biomarkers (NSTEMI)
  - D-dimer



Public Domain

# Heart Failure I

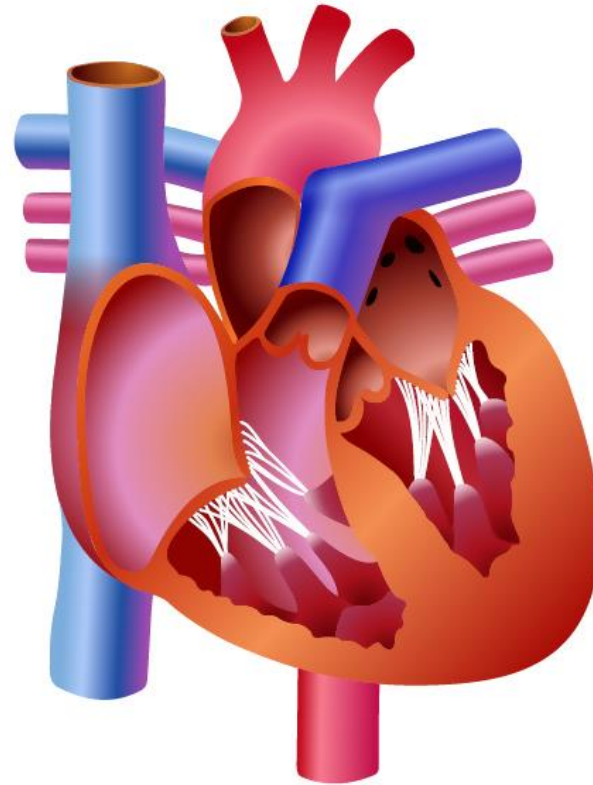
Jason Ryan, MD, MPH



# Heart Failure

## Definition

- Clinical syndrome
- Impaired ability of **left ventricle** to **fill or eject blood**

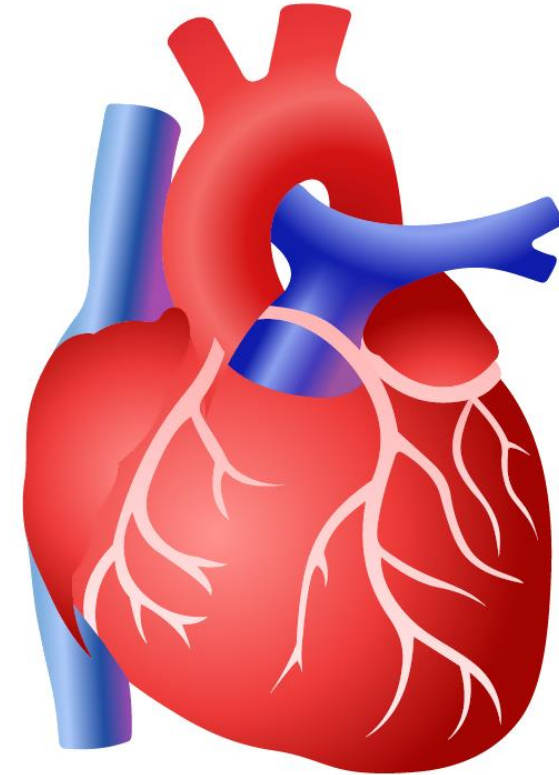




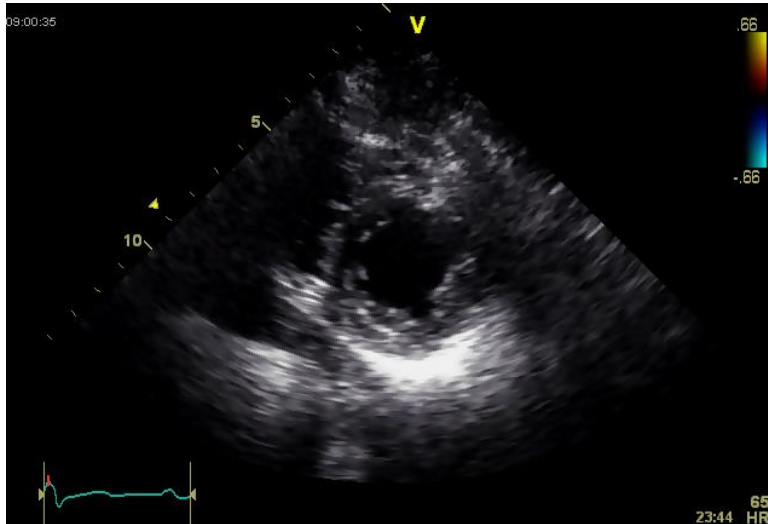
# Heart Failure

## Types

- Heart failure with reduced ejection fraction
  - HFrEF
  - Systolic heart failure
  - Problem ejecting blood from left ventricle
  - Usually caused by a **dilated cardiomyopathy**
- Heart failure with preserved ejection fraction
  - HFpEF
  - Diastolic heart failure
  - Problem filling left ventricle with blood

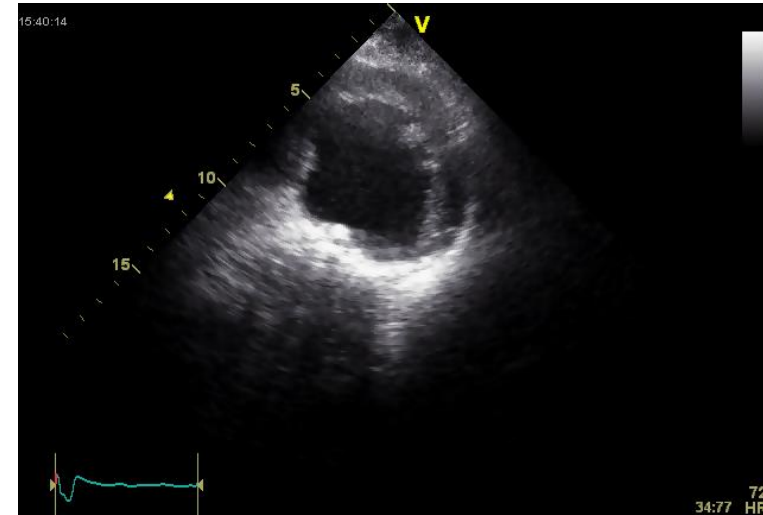


## Diastolic Heart Failure



EF is normal (55-65%)

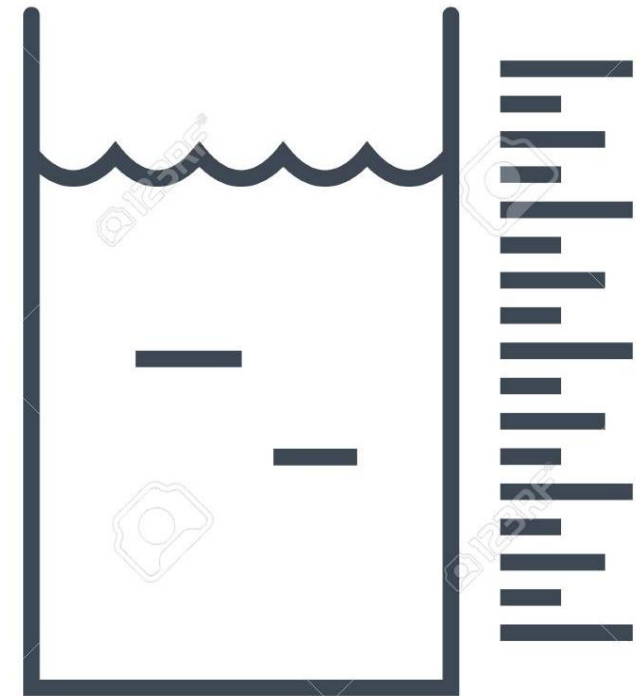
## Systolic Heart Failure



Ejection fraction is reduced

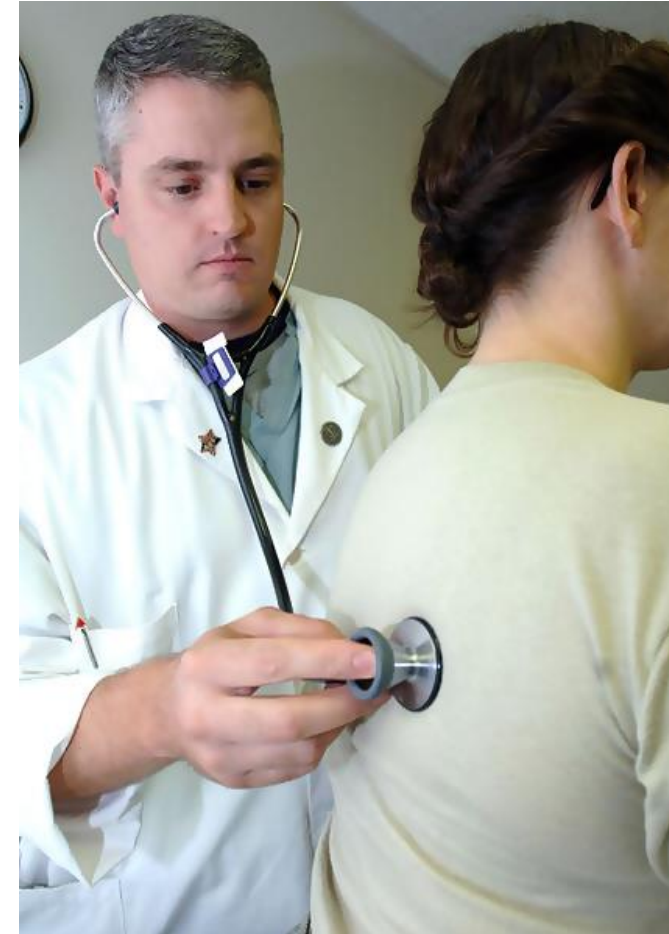
# Volume Status

- Euvolemic
- Hypervolemic
  - Volume overloaded
  - Wet
- Hypovolemic
  - Volume depleted
  - Dry
- Most heart failure symptoms from **volume overload**



# Volume Status

- Assessed by **physical exam**
  - Rales, edema, jugular venous pressure
- **Unrelated to ejection fraction**
  - LVEF of 20% can be dry
  - LVEF of 70% can be wet



Wikipedia/Public Domain

# Heart Failure

## Volume Overload Symptoms

- Dyspnea
  - Orthopnea
  - Paroxysmal nocturnal dyspnea
- Classic finding is **rales**
  - Fluid filled alveoli “pop” open on inspiration
- Chest X-ray shows congestion

Normal

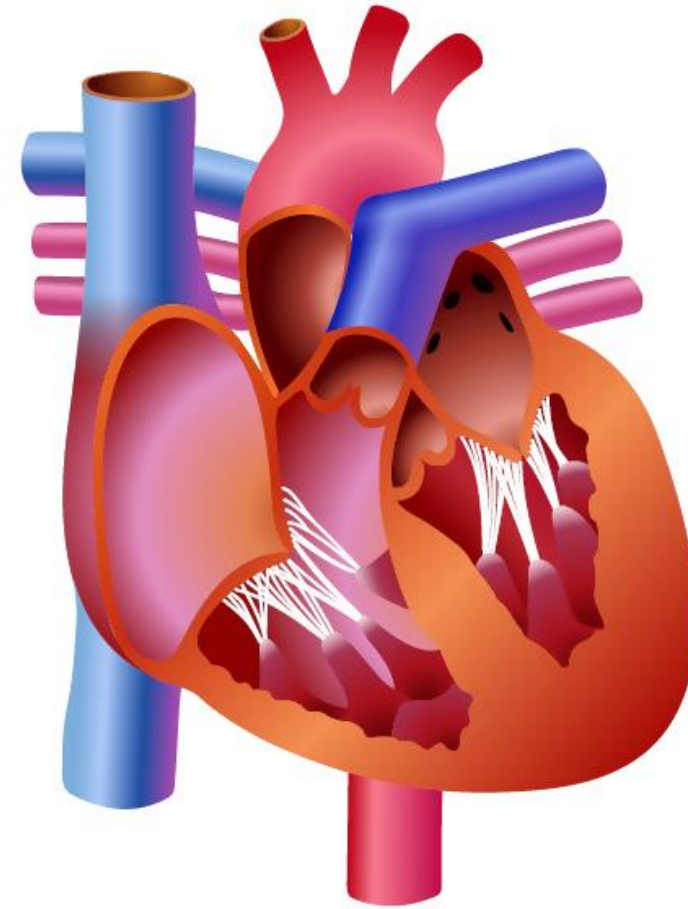


Pulmonary Edema



# Increased Pressures

- Increased left atrial pressure
- Pulmonary capillary wedge pressure
- Increased pulmonary artery pressure
- Increased right atrial pressure



# NYHA Classification

Class	Symptoms
I	Asymptomatic
II	Symptoms with moderate exertion
III	Symptoms with activities of daily living
IV	Symptoms at rest

# S3 Gallop

## Signs/Symptoms

- Classic finding associated with **increased LA pressure**
- Indicates volume overload state
- Normal finding in children, pregnant women

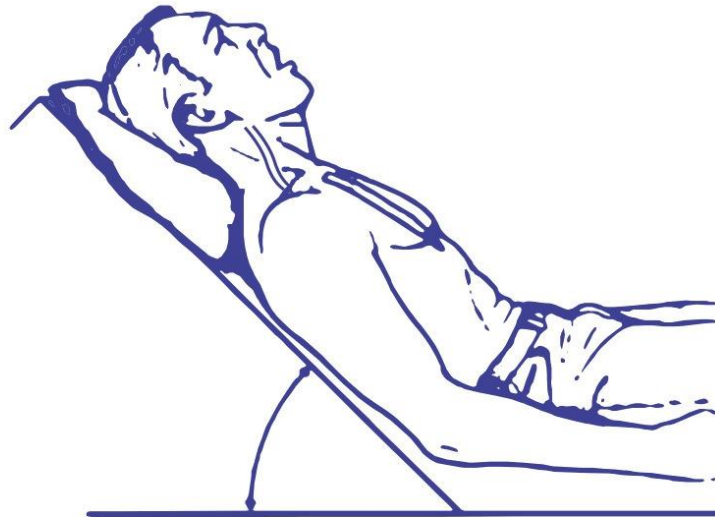




# Heart Failure

## Signs/Symptoms

- Elevated **jugular venous pressure** (normal 6-8cmH<sub>2</sub>O)
- Look for height of double bounce
- **Hepatojugular reflux**



# Heart Failure

## Signs/Symptoms

- **Lower extremity pitting edema**
- Increased capillary hydrostatic pressure
- Fluid leak from capillaries → tissues
- Gravity pulls fluid to lower extremities



James Heilman, MD/Wikipedia

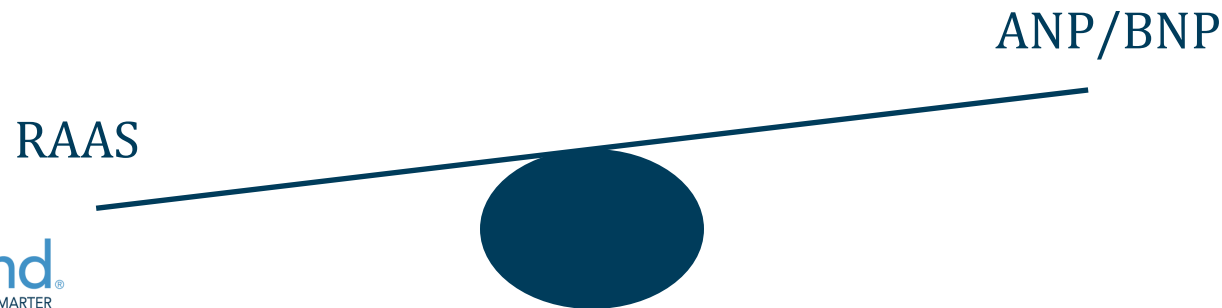
# EKG and Echocardiogram

- EKG
  - Exclude ischemia as precipitating cause
  - Q waves suggest prior infarction
  - Evaluate for arrhythmia (atrial fibrillation)
- Transthoracic echocardiogram
  - Used to distinguish HFpEF from HFrEF
  - Critical to determine therapy

# Brain Natriuretic Peptide

BNP

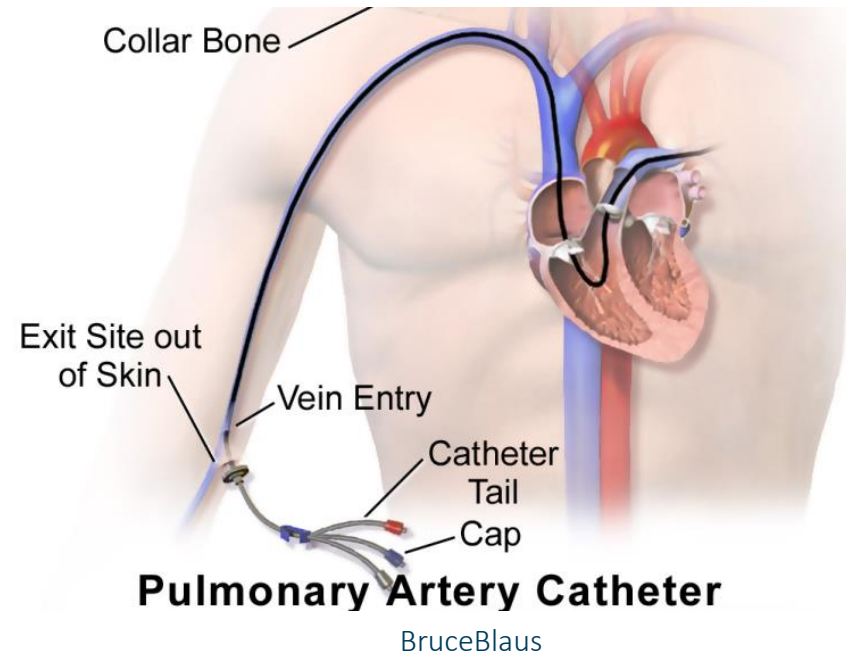
- ANP (atrial natriuretic peptide) released by atrial myocytes
- **BNP (brain natriuretic peptide)** released by ventricles
- Serum levels rise with volume/pressure overload
- Both counter effects of RAAS system
- BNP sometimes used for diagnosis in dyspnea
  - **Highly sensitive** for diagnosis of heart failure
  - High levels seen in most cases of heart failure but also many other disorders
  - Low levels strongly suggest other causes of dyspnea



# Right heart catheterization

## Pulmonary Artery Catheterization

- Increased PCWP = left heart congestion/failure
  - PCWP = pulmonary capillary wedge pressure
- Increased RA, RVEDP = right heart congestion/failure



# Heart Failure

## Diagnosis

- History
- Physical examination
- Chest X-ray
- Transthoracic echocardiogram
- EKG
- BNP level
- Right heart catheterization

# Cor Pulmonale

- Isolated **right heart failure**
  - Hypertrophy
  - Dilation
  - Decreased contractility
- Caused by long standing pulmonary hypertension
  - Lung disease (e.g., COPD)
  - Primary pulmonary hypertension



# Cor Pulmonale

- Dyspnea with **right heart failure**
  - Elevated jugular venous pressure
  - Lower extremity edema
  - Hepatomegaly
  - Absence of rales
- Treatment:
  - Usually aimed at underlying disease (COPD, etc.)





# High Output Heart Failure

- Exact mechanism unclear
  - Decreased LV filling time
- Defining characteristic: **HIGH cardiac output**
  - Heart failure symptoms in absence of low output
  - ↑JVP, pulmonary edema
- Heart in overdrive
  - Severe anemia
  - Thyroid disease
  - Thiamine (B1) vitamin deficiency (beriberi)
  - A-V fistulas



John Liu/Flickr

# Heart Failure II

Jason Ryan, MD, MPH



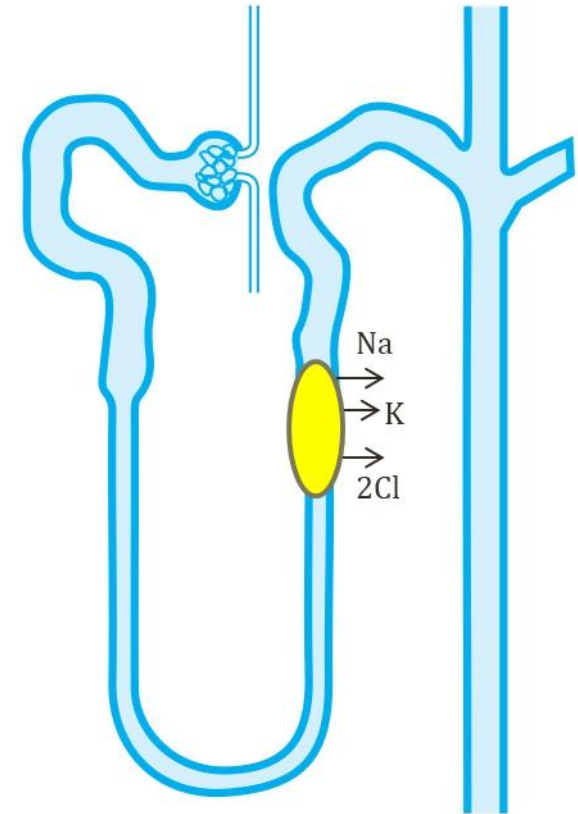
# Heart Failure

## Treatment

- Acute heart failure
  - Volume overloaded
  - Goal: **improve symptoms** of dyspnea, pulmonary congestion
- Chronic heart failure
  - Euvolemic
  - Goal: **prevention** of hospitalizations, mortality

# Acute Heart Failure

- Goal: **reduce left atrial pressure and remove fluid**
  - Improves pulmonary edema
- Most commonly used drug class: **loop diuretics**
  - Furosemide, torsemide
  - Increased urine output
  - Reduce intracardiac pressures
  - Improve pulmonary edema and lower extremity edema
  - Main adverse effect: **hypokalemia**
  - Other adverse effects: acute renal failure, hypotension
- Also cause some venous dilation: ↓ left atrial pressure



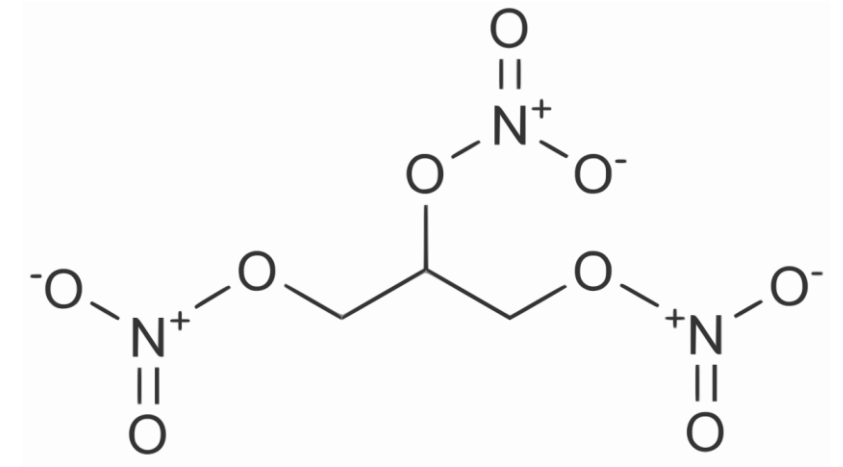
# Acute Heart Failure

- **Nitroglycerine**

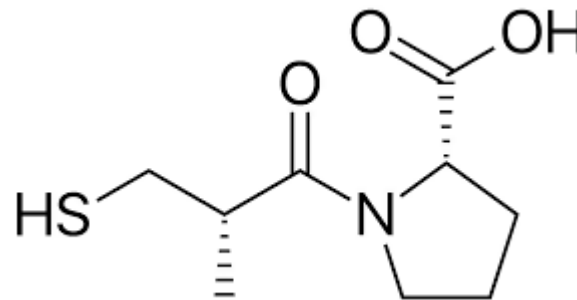
- Venous dilation → pool volume in venous system
- Reduces left atrial pressure
- Improves dyspnea

- **Afterload reducers**

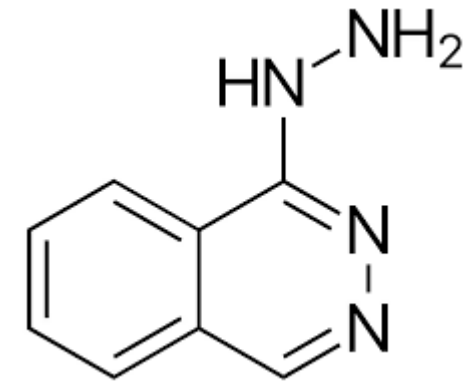
- Hydralazine, ACE-inhibitors
- Increased cardiac output → improve renal perfusion → diuresis



Nitroglycerine



Captopril



Hydralazine

# Chronic Heart Failure

- **HFpEF**
  - No specific therapies
  - Control blood pressure, blood sugar
  - Chronic diuretics often used (furosemide)
- **HFrEF**
  - Many specific therapies shown to reduce hospitalizations and mortality
  - Treatments aimed at prevention of **cardiomyopathy progression**

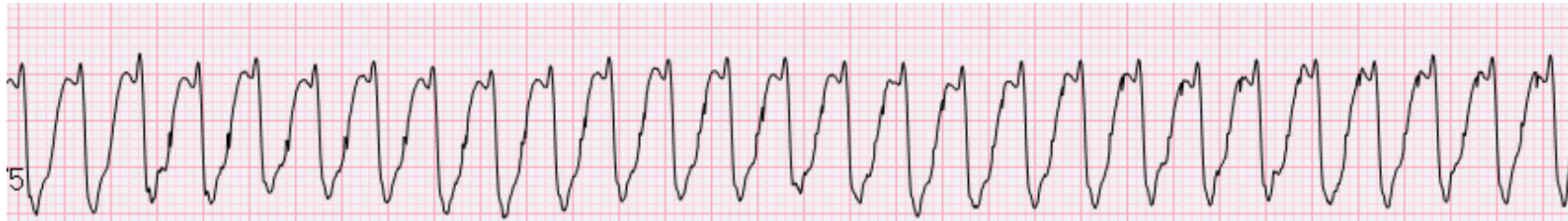
# Chronic Systolic Heart Failure

- Goal: reduce **hospitalizations and mortality**
- **Guideline directed medical treatment (GDMT)**
  - **Beta-blockers** (metoprolol, carvedilol, bisoprolol)
  - **ACE-inhibitors** (captopril, lisinopril)
  - **Aldosterone antagonists** (spironolactone, eplerenone)
  - **Neprilysin inhibitors** (sacubitril → increases ANP)
  - **Ivabradine** (inhibits SA node → ↓ heart rate)
  - **Nitrates/hydralazine** (combination therapy)
- Most drugs disrupt chronic activation of SNS and RAAS
- Prevent cardiac remodeling (progression of LV dysfunction)

# ICD

## Implantable Cardiac Defibrillator

- Annual risk SCD > 20% some studies
- Most due to ventricular tachycardia





# ICD

## Implantable Cardiac Defibrillator

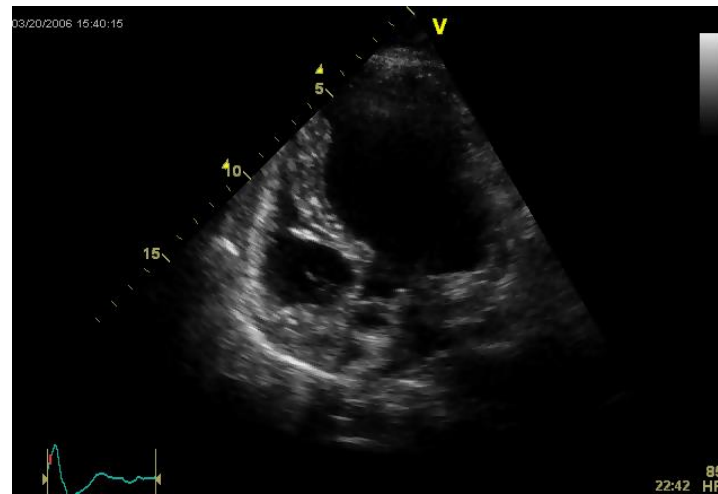
- Improve **mortality** in appropriate patients
- Indications:
  - Aborted sudden cardiac death
  - LVEF < 35%



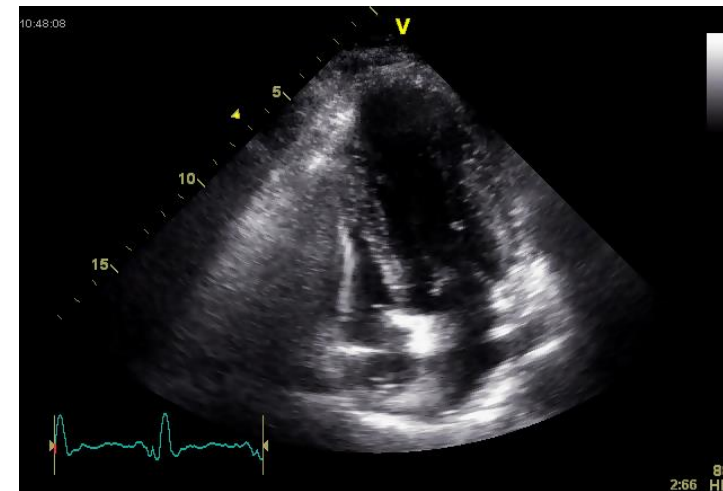
# Biventricular Pacemakers

Cardiac Resynchronization Therapy (CRT)

## Out of Synchrony



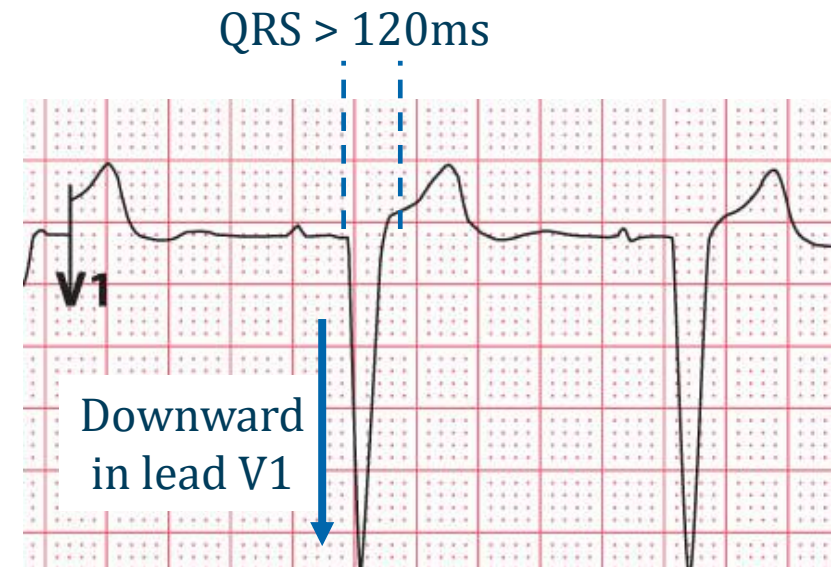
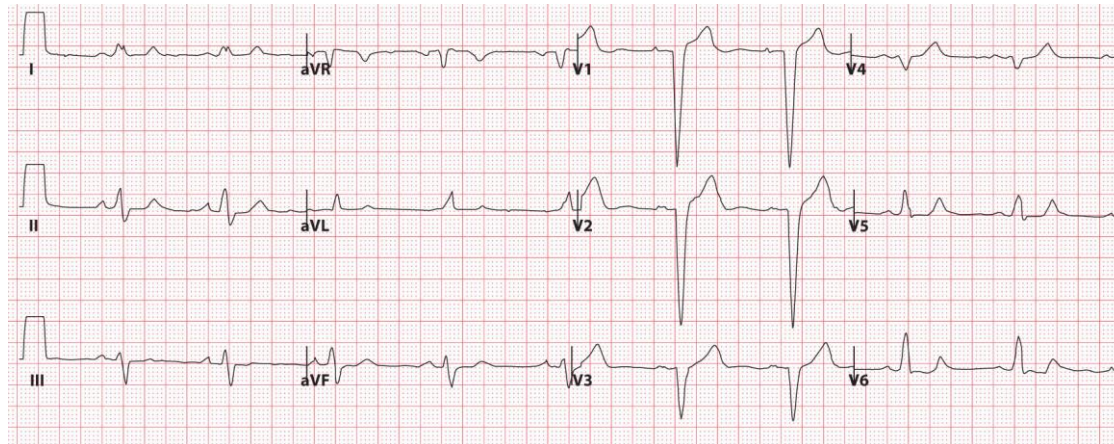
## After Pacemaker



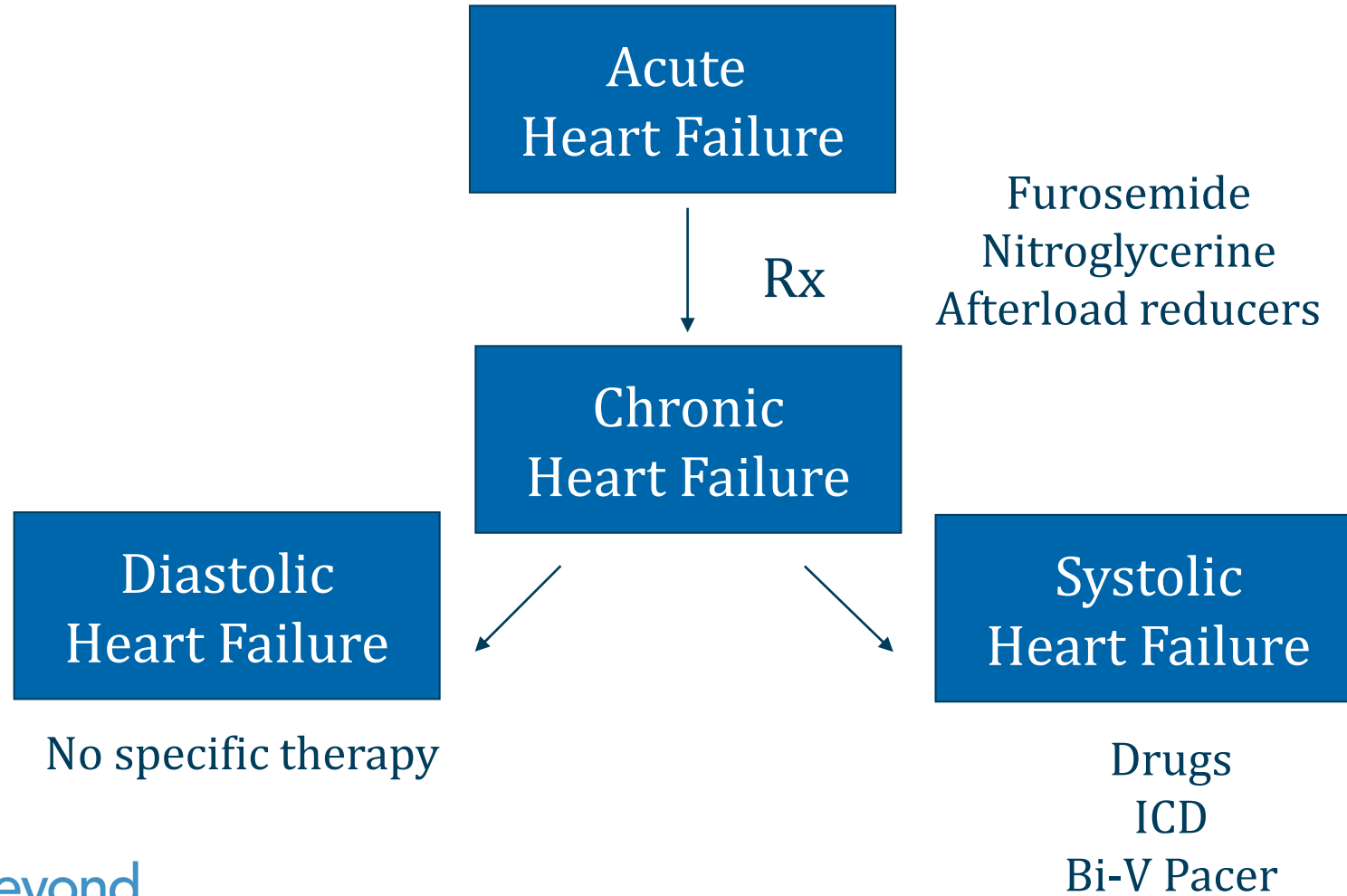
# Biventricular Pacemakers

## Cardiac Resynchronization Therapy (CRT)

- Improve **mortality** in appropriate patients
- Indications:
  - Left bundle branch block (wide QRS;  $> 120\text{ms}$ )
  - LVEF  $< 35\%$



# Heart Failure Treatment Pathway



# Advanced Heart Failure

- Severe form of HFrEF
- Severely reduced cardiac output
  - Fatigue
  - Hypotension
  - Cool extremities
  - Confusion
  - Decreased appetite (cardiac cachexia)

# Advanced Heart Failure

## Treatments

- **Inotropes (associated with ↑ mortality)**
  - Dobutamine
  - Milrinone
  - Digoxin (oral)
- Left ventricular assist devices (LVADs)
- Heart transplantation

# Acute Exacerbations

## Causes

- #1: Dietary indiscretion
  - High salt intake
- #2: Poor medication compliance



# Acute Exacerbations

## Causes

- Infection/trauma/surgery
  - Activation of sympathetic nervous system
- Ischemia (rare)
  - Decreased cardiac output
- Arrhythmias (A fib)
- NSAIDs
  - Inhibit cyclooxygenase (COX) → ↓ prostaglandins
  - Prostaglandins maintain renal perfusion
  - Result: Less renal perfusion → salt/water retention



# Typical Acute Heart Failure Course

- ER presentation:
  - Dyspnea, edema, sleeping in chair
- Admitted to hospital
  - Nitro drip to relieve dyspnea
  - IV Furosemide to remove fluid
- Hospital Day 2
  - Weight down 4 kg, feels better
  - Nitro drip stopped
  - Changed to oral furosemide
- Hospital Day 3: Discharge

# More Complex Heart Failure Course

- ER presentation:
  - Dyspnea, edema, sleeping in chair
  - Known LVEF 10%
- Admitted to hospital
  - Nitro drip to relieve dyspnea
  - IV Furosemide to remove fluid
- Hospital Day 2
  - Poor urine output, Cool extremities, Cr rises 1.1→1.4
  - Dobutamine drip started

# More Complex Heart Failure Course

- Hospital Day 3-5
  - Good urine output
  - Weight loss 4 kg
  - Breathing improves
- Hospital Day 6
  - Dobutamine stopped
  - Furosemide drip stopped
- Hospital Day 7
  - Oral furosemide given
- Hospital Day 8: Discharge

# Noninvasive Ventilation

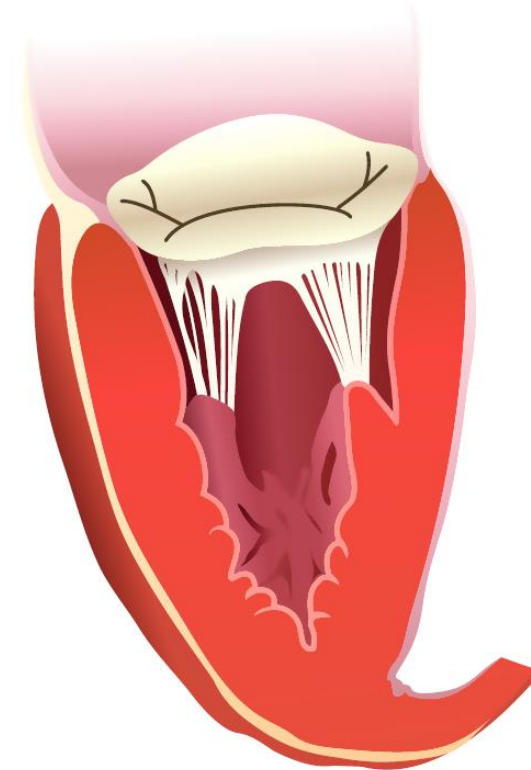
- Positive pressure ventilation
- Administered through mask not ETT
- Used in acute respiratory failure
- Often effective for pulmonary edema
- Often avoids intubation
- Patient must be awake, alert, cooperative
- Classic case
  - HF patient in respiratory distress
  - Tachypnea, hypoxemia
  - NIV → improved respiratory status



Wikipedia/Public Domain


# Functional Mitral Regurgitation

- Caused by left ventricular dilatation
- Mitral valve leaflets pulled apart
- Can cause holosystolic murmur at cardiac apex
- May resolve with diuresis



# Hyponatremia

- Occurs in severe heart failure
  - RAAS activation → ADH release → water retention
  - Poor renal perfusion → decreased water excretion
- **Poor prognostic indicator**



1 H			
3 Li	4 Be		
11 Na	12 Mg		
19 K	20 Ca	21 Sc	22 Ti
37 Rb	38 Sr	39 Y	40 Zr

# Venous Stasis Edema

- Common in the elderly
- Caused by poor venous drainage
- Unrelated to heart
  - No dyspnea
  - Normal lung exam
  - Normal jugular venous pressure
- Treatments:
  - Leg elevation
  - Compression stockings
  - Diuretics rarely work
- May lead to skin ulcers/infection



# Drugs to Avoid in Heart Failure

- Metformin
  - May cause lactic acidosis
- Thiazolidinediones (glitazones)
  - Pioglitazone, rosiglitazone
  - Cause fluid retention
- Calcium channel blockers
  - Negative inotropes
- NSAIDs
  - Cause fluid retention



Public Domain



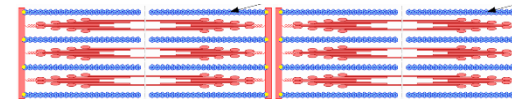
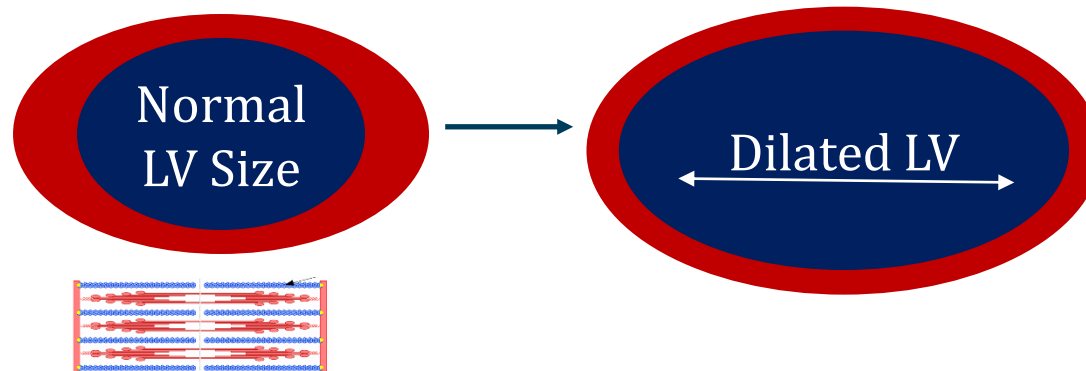
# Cardiomyopathy

Jason Ryan, MD, MPH



# Dilated Cardiomyopathy

- Systolic heart failure with LV cavity dilation
- **“Eccentric” hypertrophy**
  - Volume overload (chronic retention of fluid in cavity)
  - Longer myocytes
  - Sarcomeres added in series

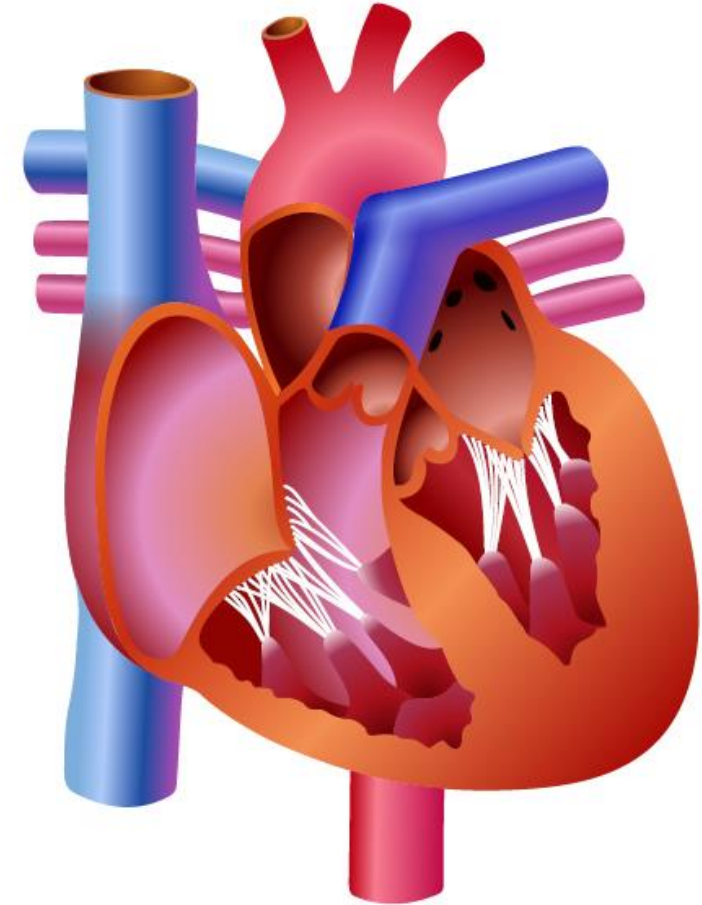


Increased myocyte size  
Sarcomeres in series  
Normal wall thickness

# Dilated Cardiomyopathy

## Symptoms

- **Depend on volume status**
- Volume overload → acute systolic heart failure
  - Dyspnea
  - Pitting edema
- Severely reduced LVEF
  - Fatigue
  - Cachexia
  - Confusion



# Dilated Cardiomyopathy

- Diagnosis: **Transthoracic echocardiography**
- Treatment: **Guideline directed medical treatment (GDMT)**
  - Beta-blockers
  - ACE inhibitors
  - Aldosterone antagonists
  - Neprilysin inhibitors
- Defibrillators
- Bi-ventricular pacemakers



Ejection fraction is reduced

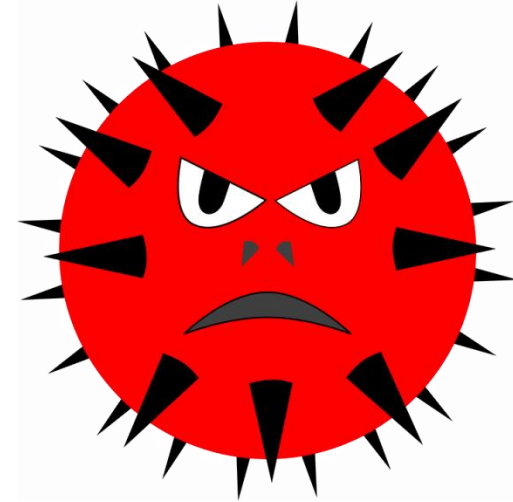
# Dilated Cardiomyopathy

- Most common cause: **myocardial infarction**
  - Ischemic cardiomyopathy
  - Myocytes replaced by scar tissue
  - Focal hypokinesis (e.g., anterior wall)
- Many causes of **“non-ischemic” cardiomyopathy**
  - About 50% idiopathic
  - Many other causes
  - Global hypokinesis

# Nonischemic Cardiomyopathy

## Viral

- May follow upper respiratory infection
- Many associated viruses
  - **Coxsackie**
  - Influenza, adenovirus, others
- No specific therapy for virus



Pixabay/Public Domain

# Nonischemic Cardiomyopathy

## Peripartum

- Late in pregnancy or early post-pregnancy
- Exact cause unknown (likely multifactorial)
- Women often advised to avoid future pregnancy

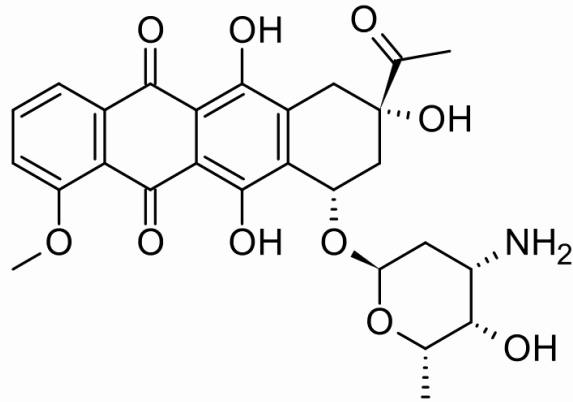


Øyvind Holmstad/Wikipedia

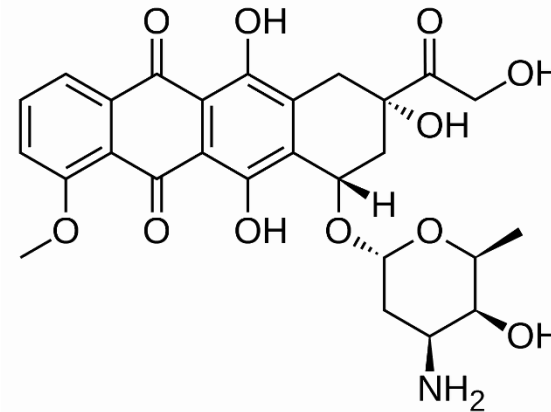
# Nonischemic Cardiomyopathy

## Chemotherapy

- Usually after treatment with anthracyclines
  - Antitumor antibiotics
  - Doxorubicin and daunorubicin



Daunorubicin



Doxorubicin  
(Adriamycin)



# Nonischemic Cardiomyopathy

## Familial

- Mutations
  - Often sarcomere proteins
  - Beta-myosin heavy chain
  - Alpha-myosin heavy chain
  - Troponin
- Many autosomal dominant
- X-linked, autosomal recessive also described



Wikipedia/Public Domain

# Nonischemic Cardiomyopathy

## Tachycardia-mediated

- Constant, rapid heart rate for weeks/months
- Leads to depression of LV systolic function
- **Reversible** with slower heart rate

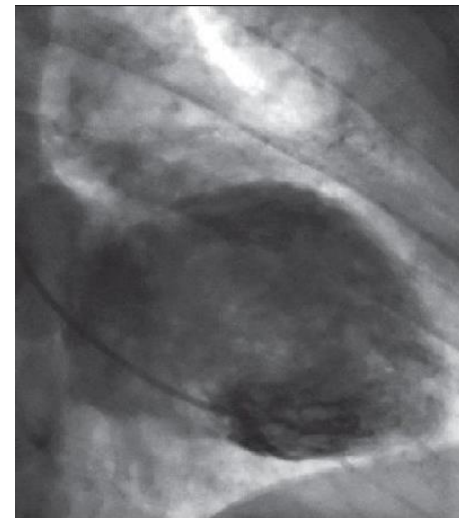


# Nonischemic Cardiomyopathy

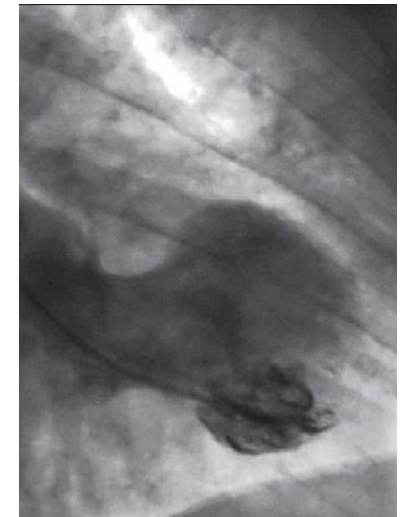
## Takotsubo/Apical ballooning

- **Stress-induced** cardiomyopathy
- Occurs after severe emotional distress and **high catecholamines**
- Markedly reduced LVEF
- Increase CK, MB, Troponin; EKG changes
- Looks like anterior MI (but no coronary disease)
- Usually recovers 4-6 weeks

Diastole



Systole



# Alcohol

- Chronic consumption can cause cardiomyopathy
- Believed to be due to toxic metabolites
- Can recover with cessation of alcohol



Pixabay/Public Domain

# Restrictive Cardiomyopathy

- Something “infiltrates” the myocardium
  - Amyloid protein (Amyloidosis)
- Heart cannot relax and fill
- **SEVERE diastolic dysfunction**
  - Presents as diastolic heart failure
  - Treatment: diuretics
  - Also treat underlying cause

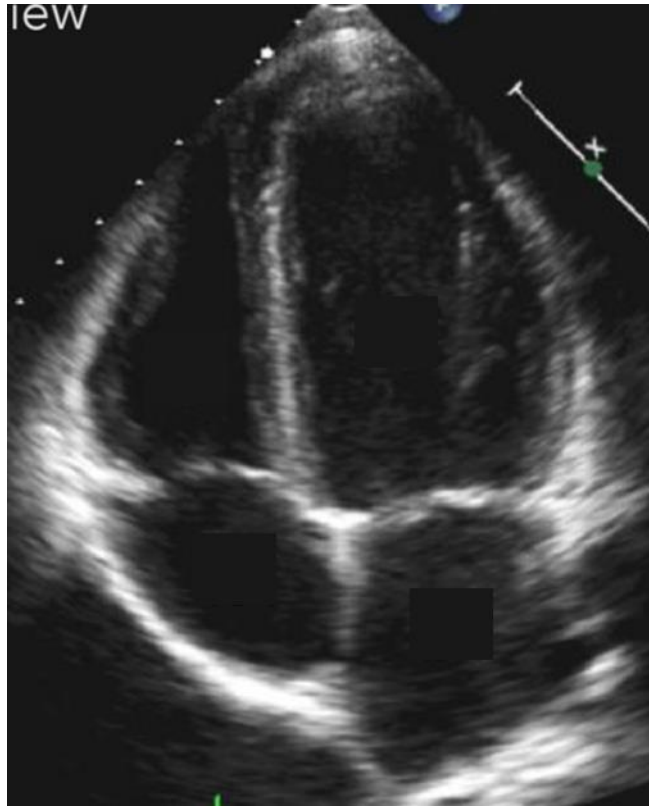


MarkBuckawicki/Wikipedia

# Restrictive Cardiomyopathy

- **LVEF = normal**
- Restricted filling =  $\uparrow$  atrial pressure
- **Dilated left and right atria**
- Classic imaging findings:
  - Normal left ventricular function/size
  - Bi-atrial enlargement

# Restrictive Cardiomyopathy



Normal



Restrictive Cardiomyopathy

# Restrictive Cardiomyopathy

## Clinical Features

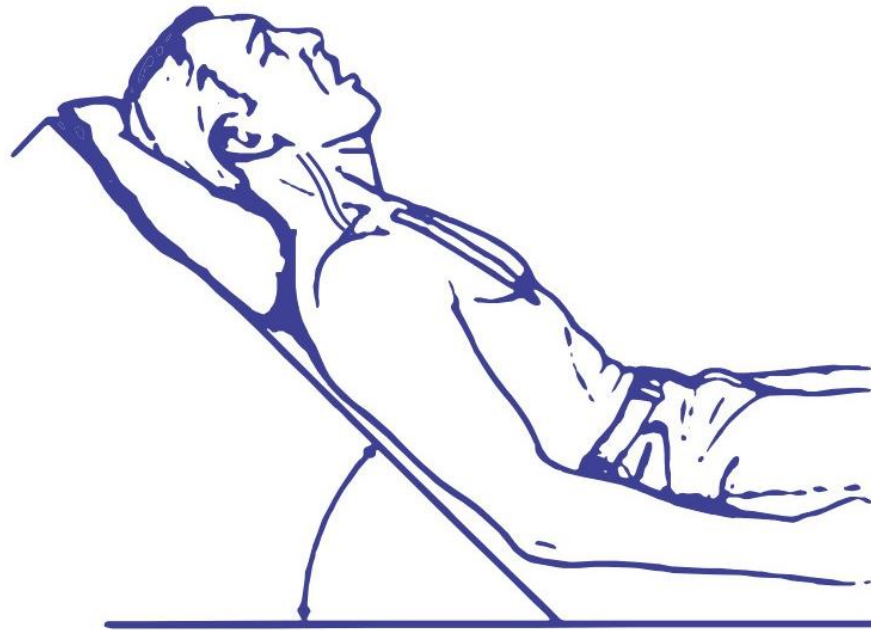
- Dyspnea
- Prominent **right heart failure**
  - Markedly elevated jugular venous pressure
  - Lower extremity edema
  - **Liver congestion**
  - May lead to cirrhosis



# Restrictive Cardiomyopathy

## Classic signs

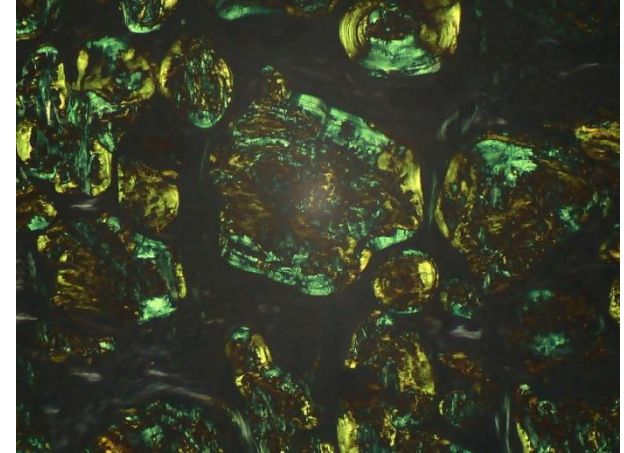
- **Kussmaul's sign**
  - Inspiration causes rise in JVP



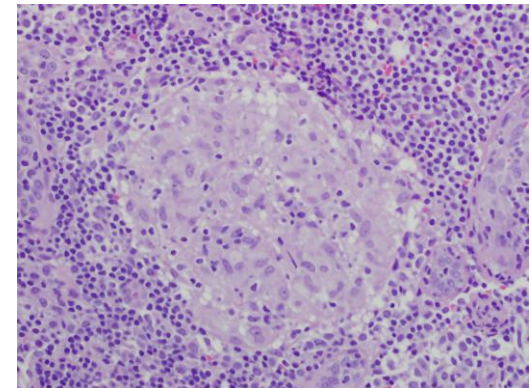
# Restrictive Cardiomyopathy

## Major Causes

- Amyloidosis
- Sarcoidosis
- Fabry disease (lysosomal storage disease)
- Hemochromatosis (rare)
- Post-radiation
- Loeffler's syndrome (hypereosinophilic syndrome)
- Endocardial fibroelastosis (babies)

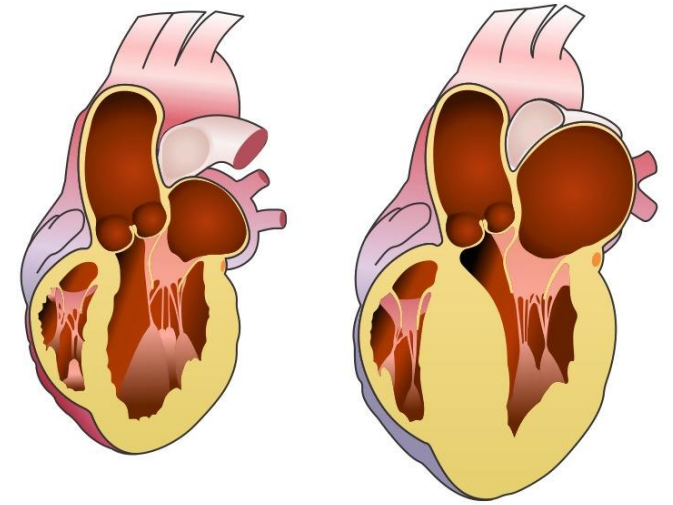


Ed Uthman, MD

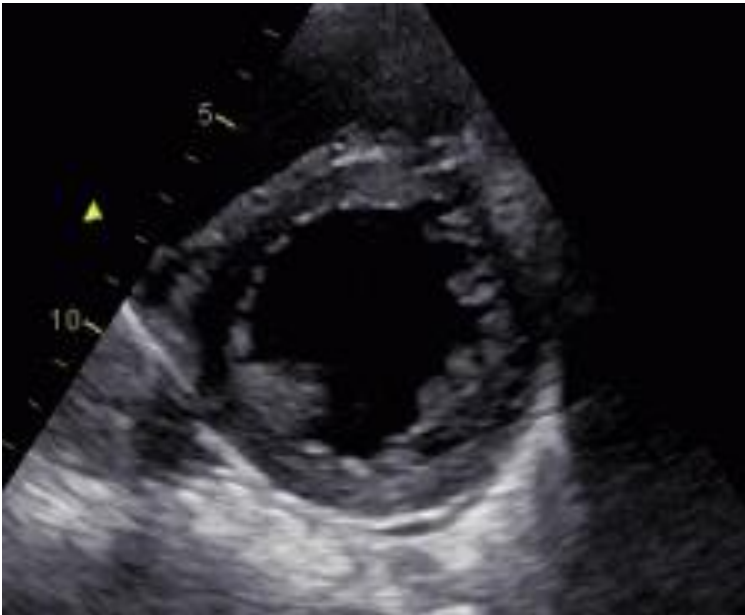


# Hypertrophic Cardiomyopathy

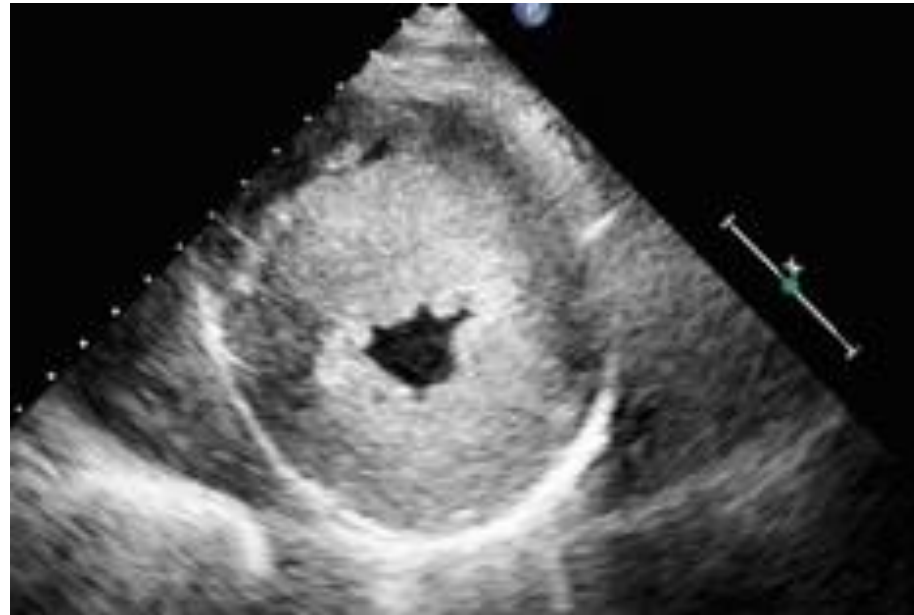
- Cardiomyopathy of **myocyte hypertrophy**
  - Concentric hypertrophy
- Pathologic hypertrophy
  - Not due to stress
  - Absence of HTN or athlete's heart
- Diagnosis:
  - Echocardiography
  - Genetic testing
- LVEF normal with increased wall thickness



# Hypertrophic Cardiomyopathy



Normal



Hypertrophic Cardiomyopathy

# Hypertrophic Cardiomyopathy

- Genetic disorder caused by gene mutations
- About 50% cases familial (50% sporadic)
- **Autosomal dominant**
- Variable expression
  - Significant variation in severity of symptoms
  - Many variations in location/severity of hypertrophy

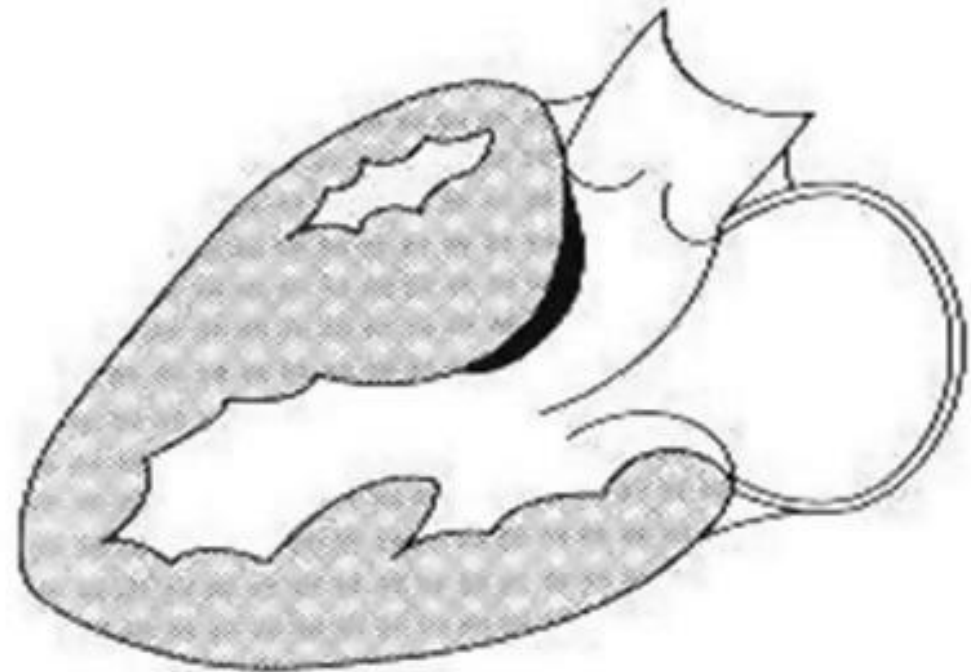


Wikipedia/Public Domain

# Hypertrophic Cardiomyopathy

## Clinical Features

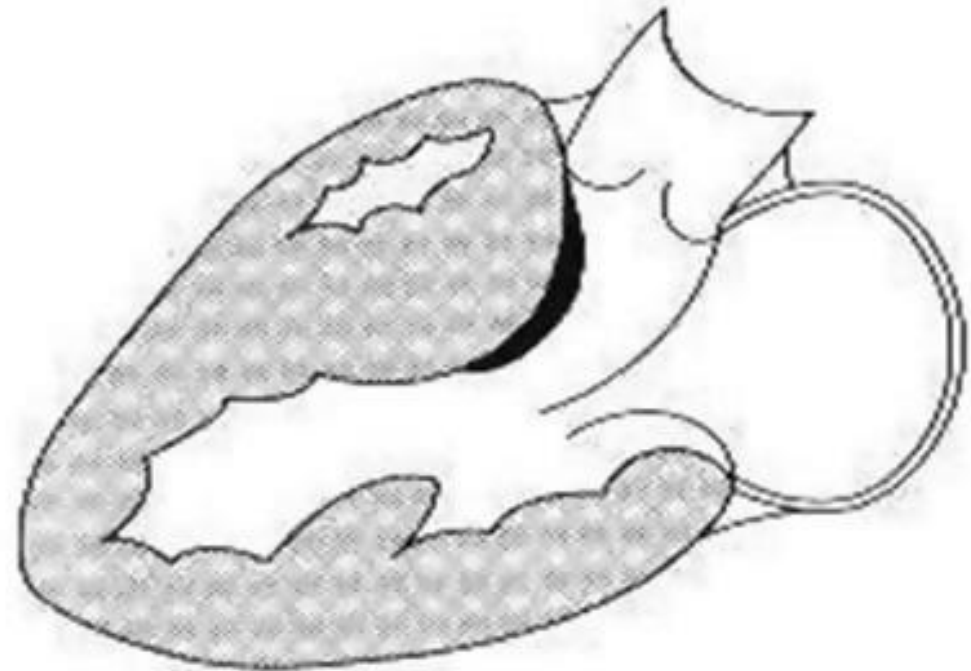
- Many patients asymptomatic
- Many symptoms from **LVOT obstruction**
  - Left ventricular outflow tract



# Hypertrophic Cardiomyopathy

## Clinical Features

- **Heart failure**
  - Diastolic dysfunction
  - LVOT obstruction
- **Chest pain (angina)**
  - Increased O<sub>2</sub> demand

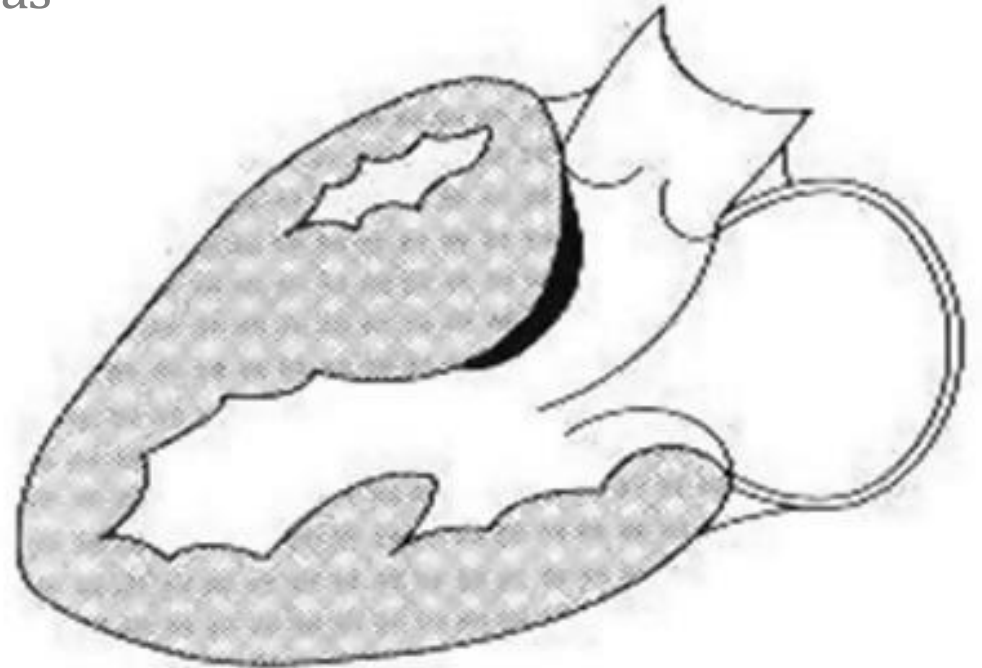




# Hypertrophic Cardiomyopathy

## Clinical Features

- **Sudden cardiac death**
  - Abnormal myocytes → ventricular arrhythmias
  - Most common cause SCD in young patients
- **Syncope**
  - Arrhythmias may lead to syncope
  - LVOT obstruction
- **Mitral regurgitation**
  - Systolic anterior motion (SAM)

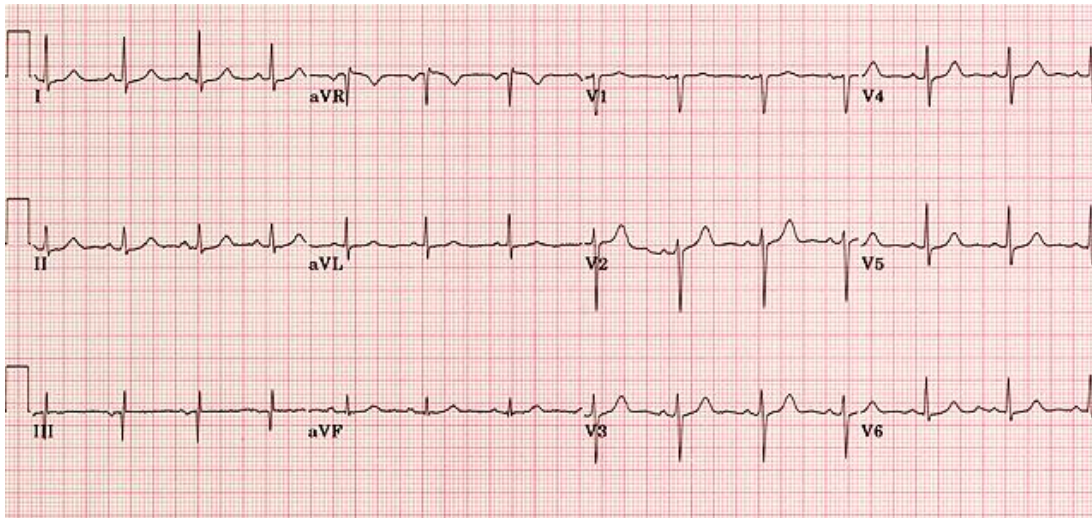




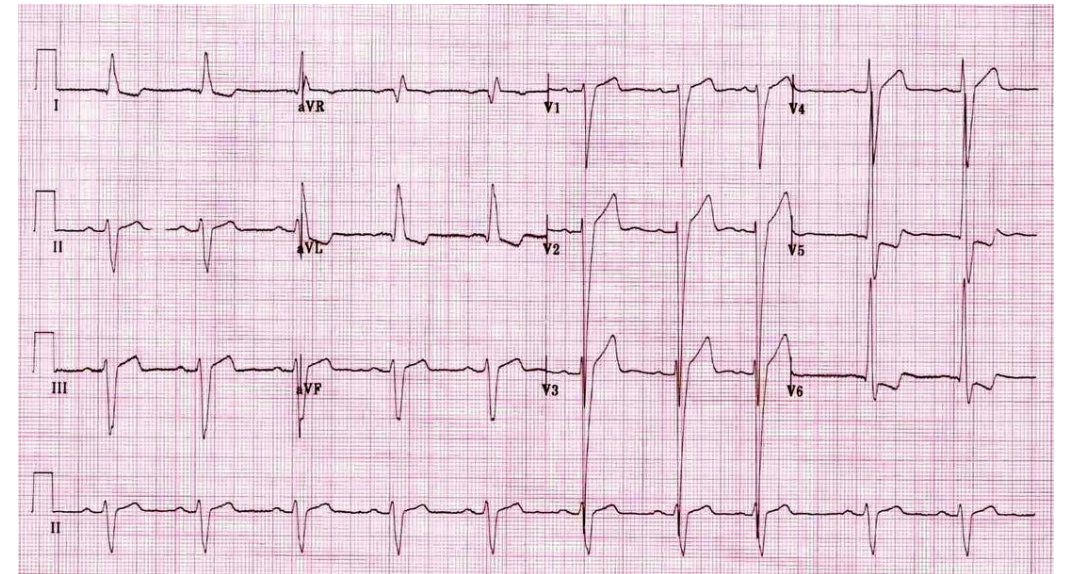
# Hypertrophic Cardiomyopathy

## Clinical Features

- EKG: Left ventricular hypertrophy (LVH)



Normal

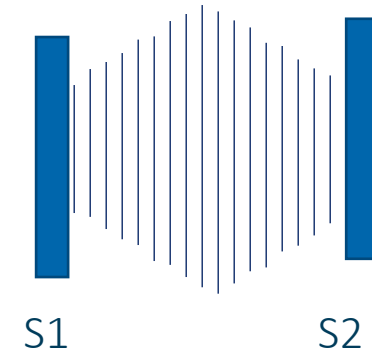
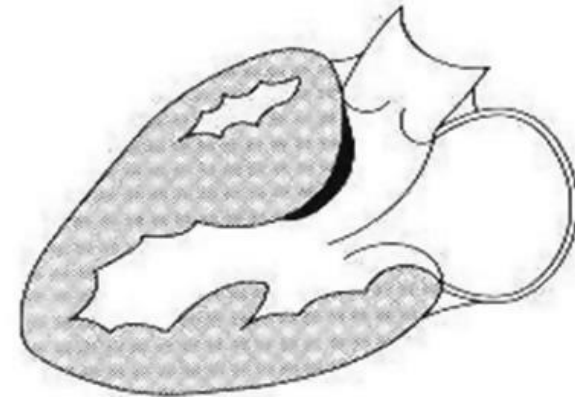


Hypertrophic Cardiomyopathy

# Hypertrophic Cardiomyopathy

## Clinical Features

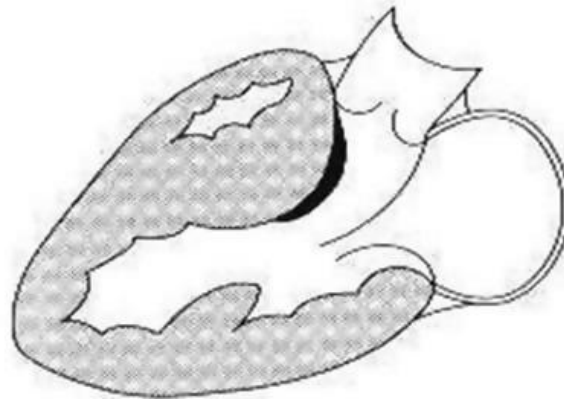
- **Systolic ejection murmur**
- Usually left lower sternal border
- Caused by outflow tract obstruction
- Sounds just like AS unless you do maneuvers
- Other associated abnormal heart sounds
  - S4
  - Holosystolic murmur of MR
  - Paradoxical split S2



# Hypertrophic Cardiomyopathy

## Maneuvers

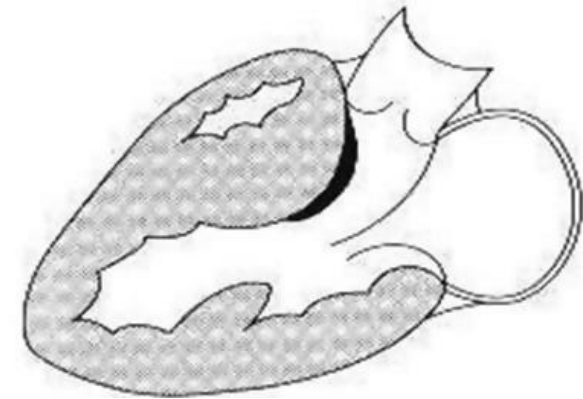
- For any HCM maneuver, think about size of LV
- $\uparrow$  LV size  $\rightarrow$   $\downarrow$  murmur
- $\downarrow$  LV size  $\rightarrow$   $\uparrow$  murmur



# Hypertrophic Cardiomyopathy

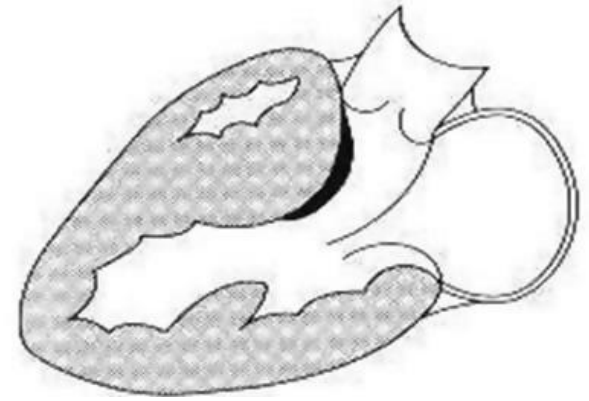
## Maneuvers

- Valsalva
  - Patient bears down as if having a bowel movement
  - Or blows out against closed glottis
  - Increase thoracic pressure  $\rightarrow$  compression of veins  $\rightarrow$   $\downarrow$  VR
  - Less VR  $\rightarrow$  Less preload  $\rightarrow$  Smaller LV cavity
  - Obstructing septum moves further into the outflow tract
  - Murmur **INCREASES** in intensity

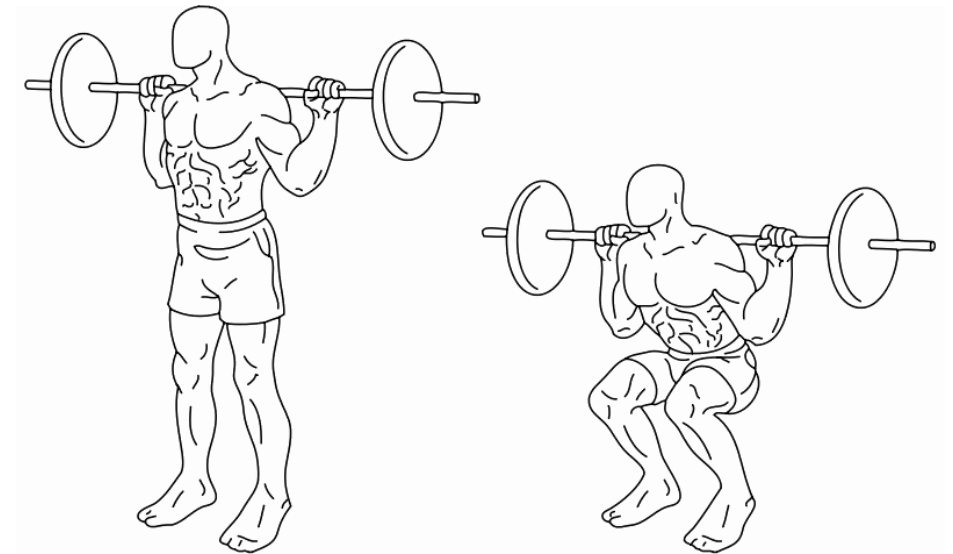


# Hypertrophic Cardiomyopathy

## Maneuvers



- Squatting
  - Forces blood volume stored in legs to return to heart
  - Preload rises → size of LV increases → less obstruction
  - Murmur **DECREASES** in intensity
- Raising the legs
  - Increases venous return
  - Murmur **DECREASES** in intensity
- Standing
  - Opposite mechanism of leg raise
  - Murmur **INCREASES** in intensity



# Aortic Stenosis

- Both HCM and AS cause a systolic ejection murmur
- Opposite effects of maneuvers in aortic stenosis
  - Less preload → less flow → quieter AS murmur



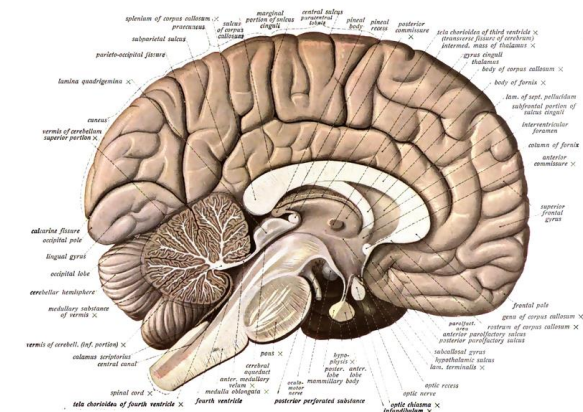
# Hypertrophic Cardiomyopathy

## Associations

- **Maternal diabetes**
  - Infants: transient hypertrophic cardiomyopathy
  - Usually thickening of interventricular septum
  - Resolves by a few months of age
- **Friedreich Ataxia**
  - Autosomal recessive CNS disease
  - Cause of death



Øyvind Holmstad/Wikipedia

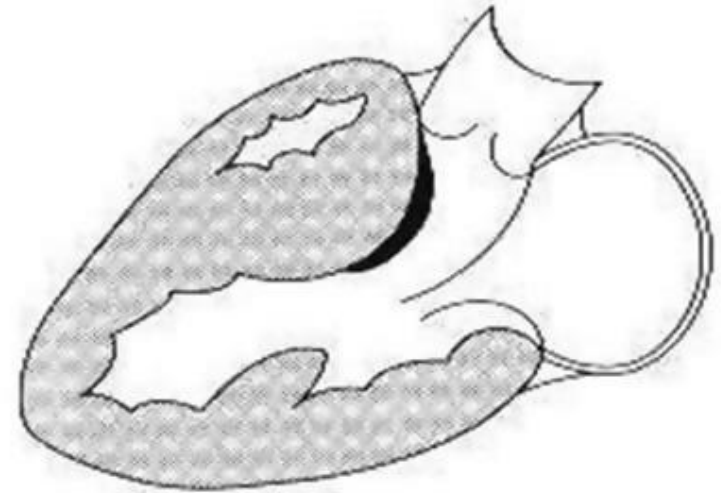


Wikipedia/Public Domain

# Hypertrophic Cardiomyopathy

## Treatment

- **Beta-blockers and calcium channel blockers**
  - ↓ contractility
  - ↓ outflow gradient
- **Surgery**
  - Myomectomy
  - Alcohol septal ablation
  - Eliminates outflow obstruction
- Cautious diuretics for pulmonary edema
  - ↓ preload → hypotension
- Implantable cardiac defibrillators (ICDs)

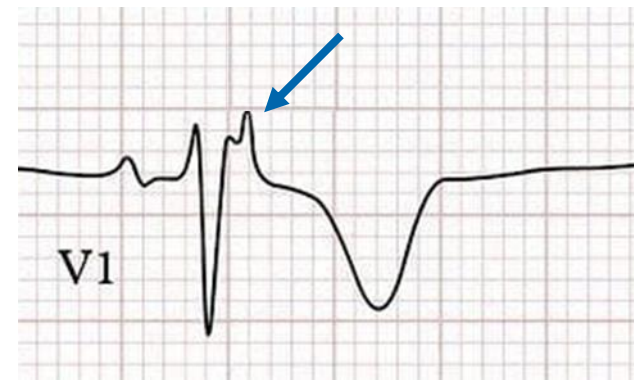
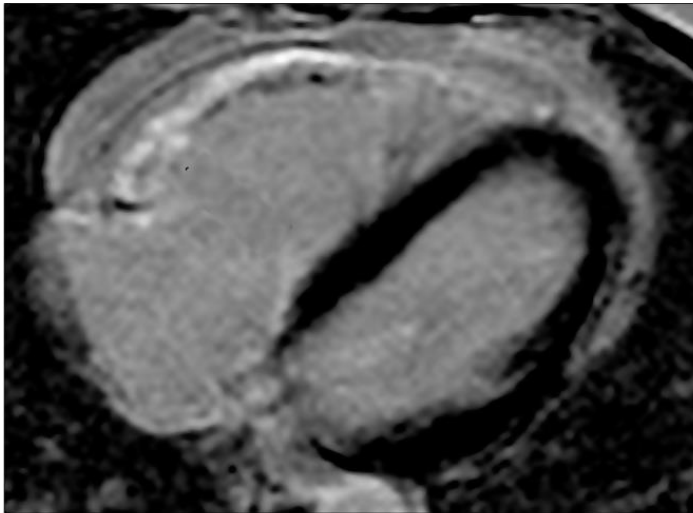




# ARVD

## Arrhythmogenic right ventricular dysplasia

- Genetic disorder
- Cardiomyopathy of right ventricle → arrhythmias
- Associated with **sudden cardiac death** in young adults
- EKG: epsilon wave
- Diagnosis: **cardiac MRI**



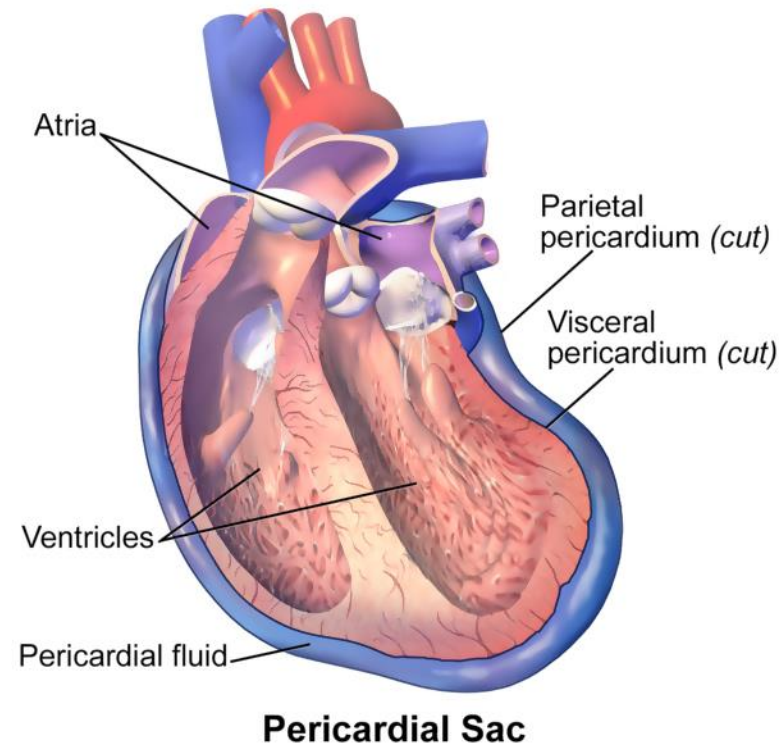
# Pericardial Disease

Jason Ryan, MD, MPH



# Pericardial Diseases

- Pericarditis
- Effusion/Tamponade
- Constrictive pericarditis



Blausen Medical Communications, Inc.

# Acute Pericarditis

- Most common pericardial disorder
- Inflammation of the pericardium
- May recur after treatment

# Pericarditis

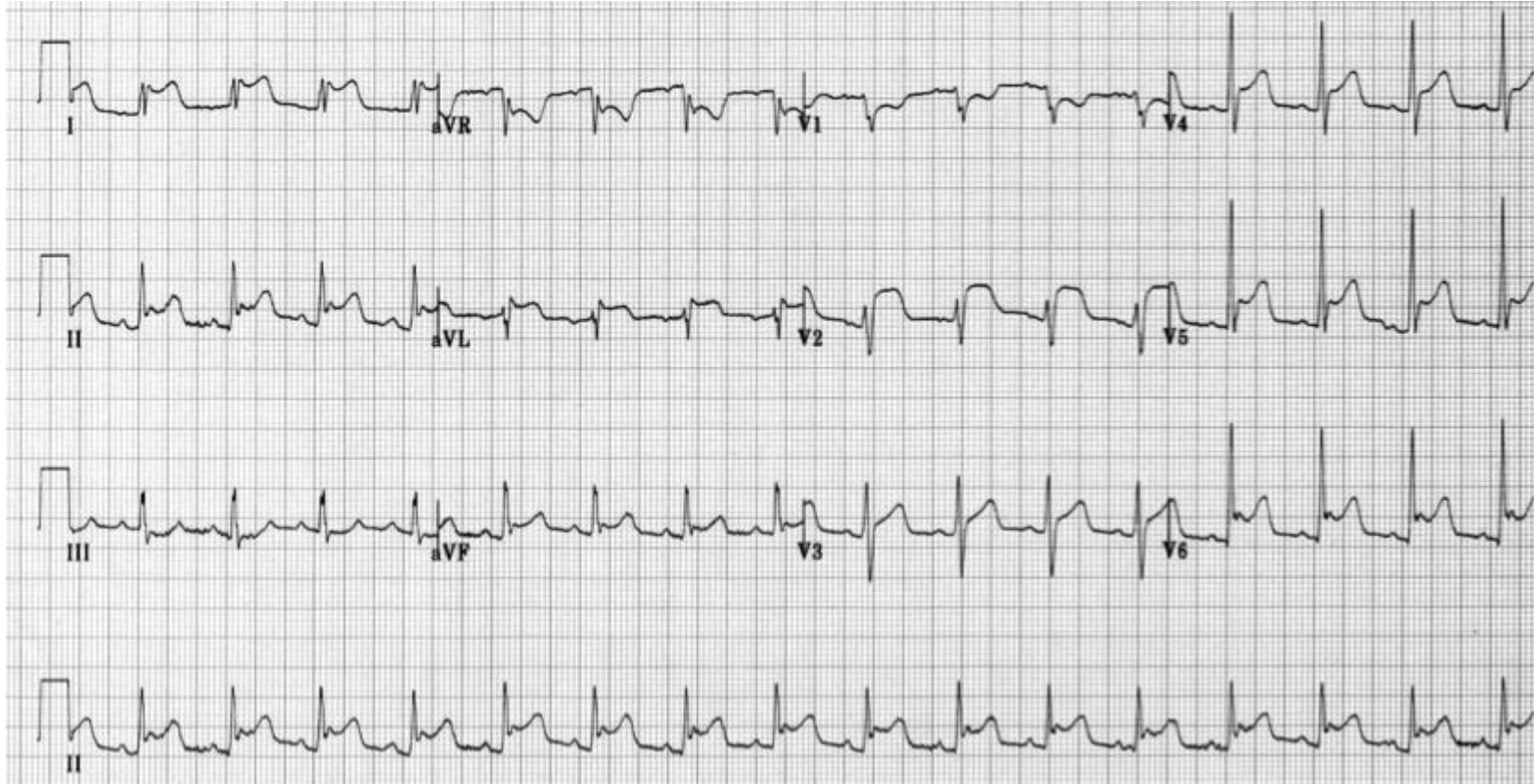
## Clinical Features

- **Chest pain**
  - Sharp
  - Worse with deep breath (pleuritic)
  - Worse lying flat (supine)
  - Better sitting up/leaning forward
- Fever
- Leukocytosis
- Elevated ESR
- About 50% have a pericardial effusion



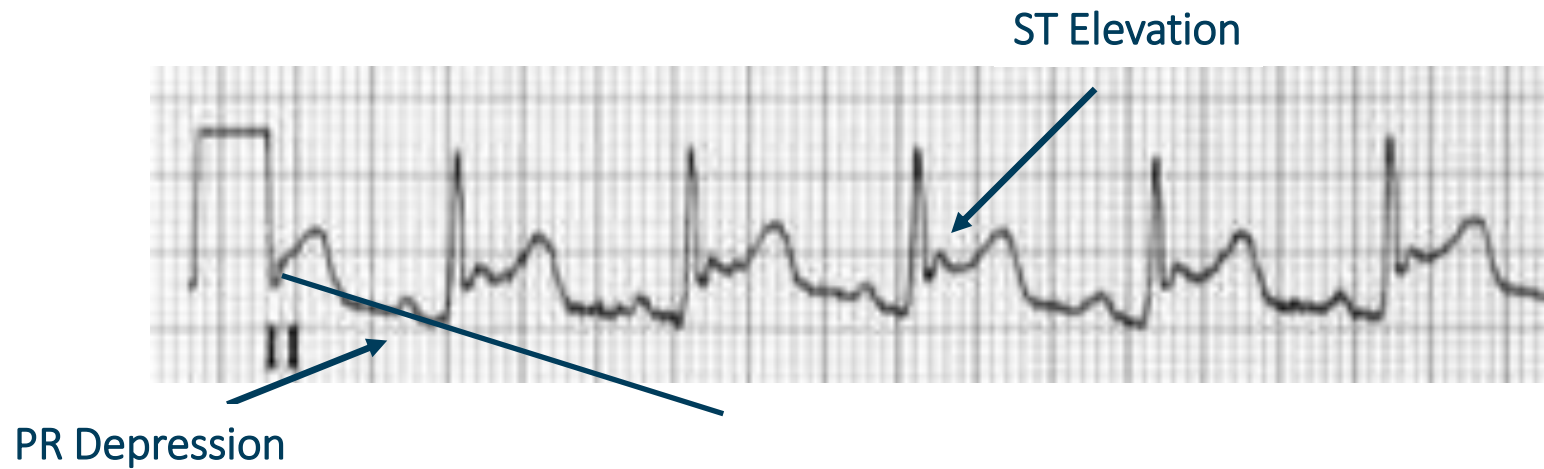
# Pericarditis

## EKG Findings



# Pericarditis

## EKG Findings



Pericarditis  
Diffuse ST elevation  
PR depression

# Pericarditis

## Physical Exam

- Pericardial friction rub
- **Scratchy** sound
- Systole and diastole





# Pericarditis

## Diagnosis

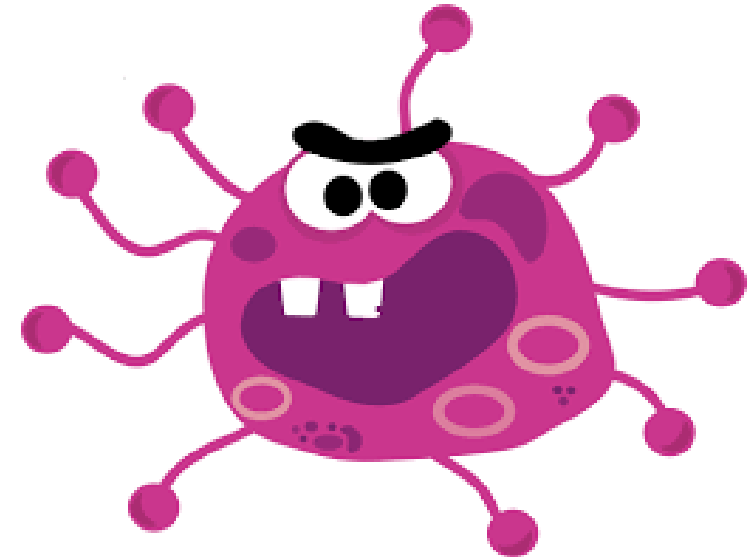
- Clinical diagnosis based on **two of four criteria**:
  - Typical pericarditis chest pain
  - Pericardial friction rub
  - Pericarditis ECG changes
  - Pericardial effusion
- All patients: **transthoracic echocardiogram**
  - Evaluate for effusion



# Pericarditis

## Etiology

- Usually idiopathic
- Viral
  - Classic cause is Coxsackievirus
  - Often follows viral **upper respiratory infection (URI)**
- Bacterial
  - Spread of pneumonia
  - Complication of surgery
  - Tuberculosis
- Fungal

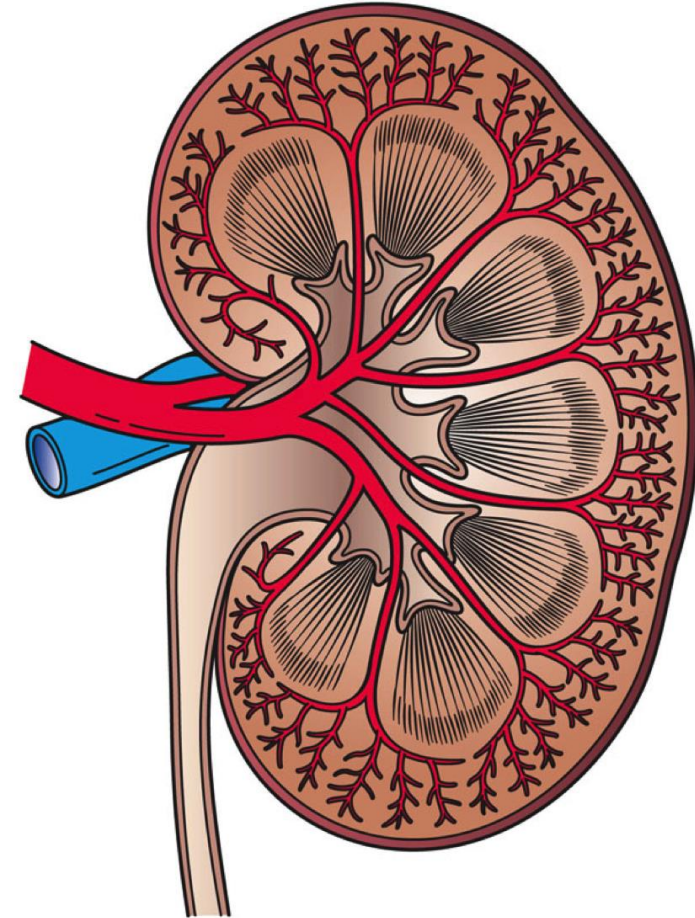


Public Domain

# Pericarditis

## Etiology

- Uremic (renal failure)
  - Treatment: hemodialysis (not drugs!)
- Post-myocardial infarction
  - Fibrinous (days after MI)
  - Dressler's syndrome (weeks after MI)
- Autoimmune disease (RA, Lupus)



Public Domain

# Pericarditis

## Treatment

- NSAIDs
- Glucocorticoids
- Colchicine
  - Inhibits WBCs via complex mechanism
  - Useful in gout and familial Mediterranean fever
  - Added to NSAIDs to lower risk of recurrence
- **NSAIDs plus colchicine** used in most cases

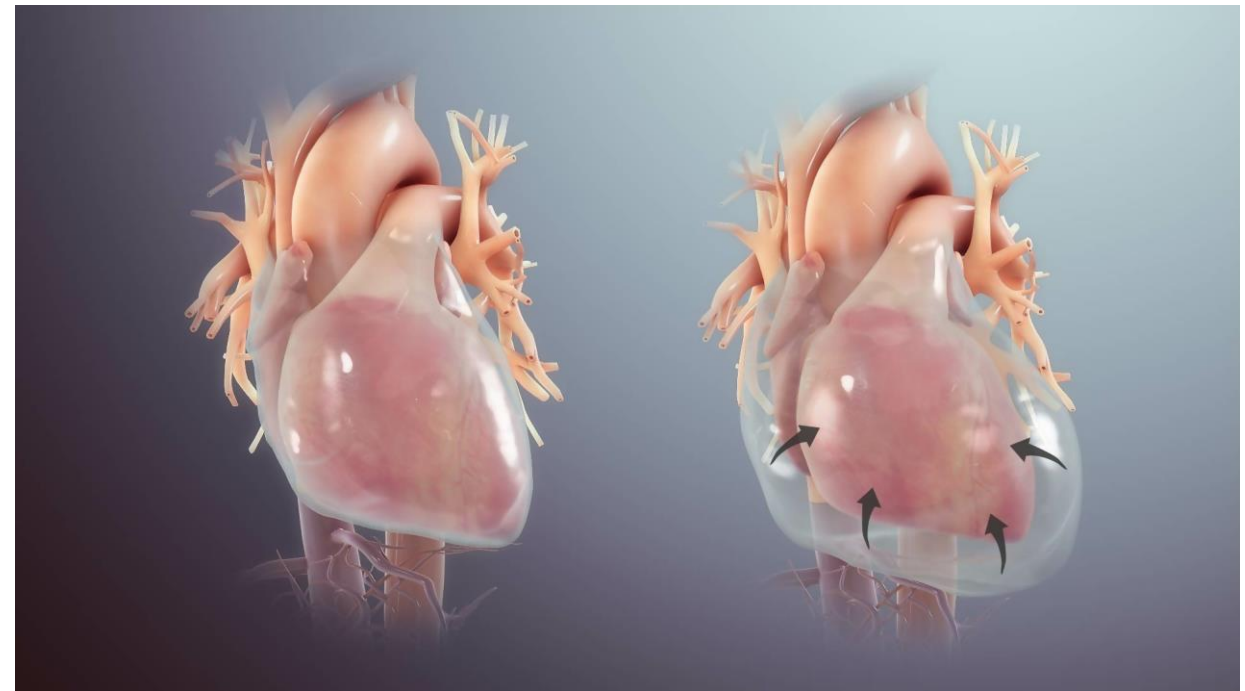
# Post-Infarction Pericarditis

## Treatment

Fibrinous Pericarditis	Dressler Syndrome
Presents < 1 week post MI	Presents weeks after MI
Inflammatory pericarditis	Autoimmune pericardial inflammation
Tx: ASA +/- acetaminophen (NSAIDs avoided)	Tx: NSAIDs or ASA +/- colchicine

# Pericardial Effusion

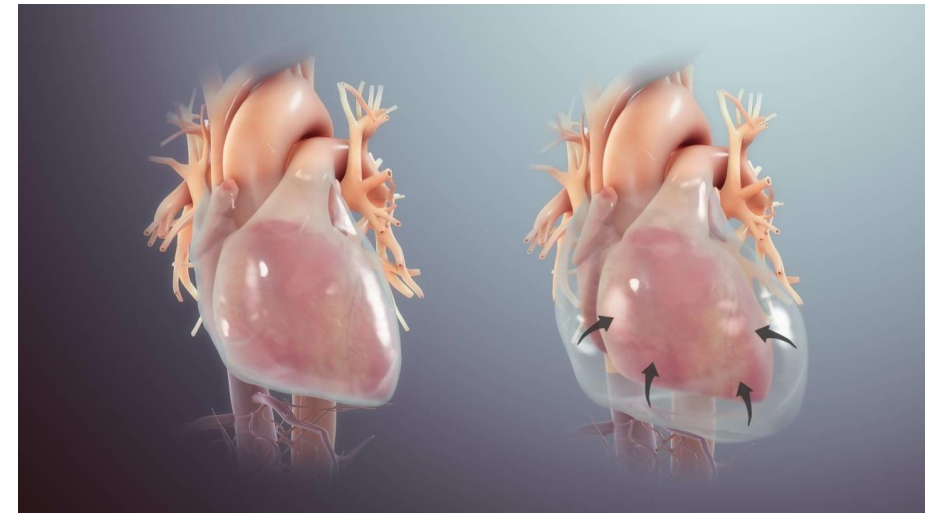
- **Fluid in the pericardial space**
- Often asymptomatic
- May cause pericardial tamponade



Wikipedia/Public Domain

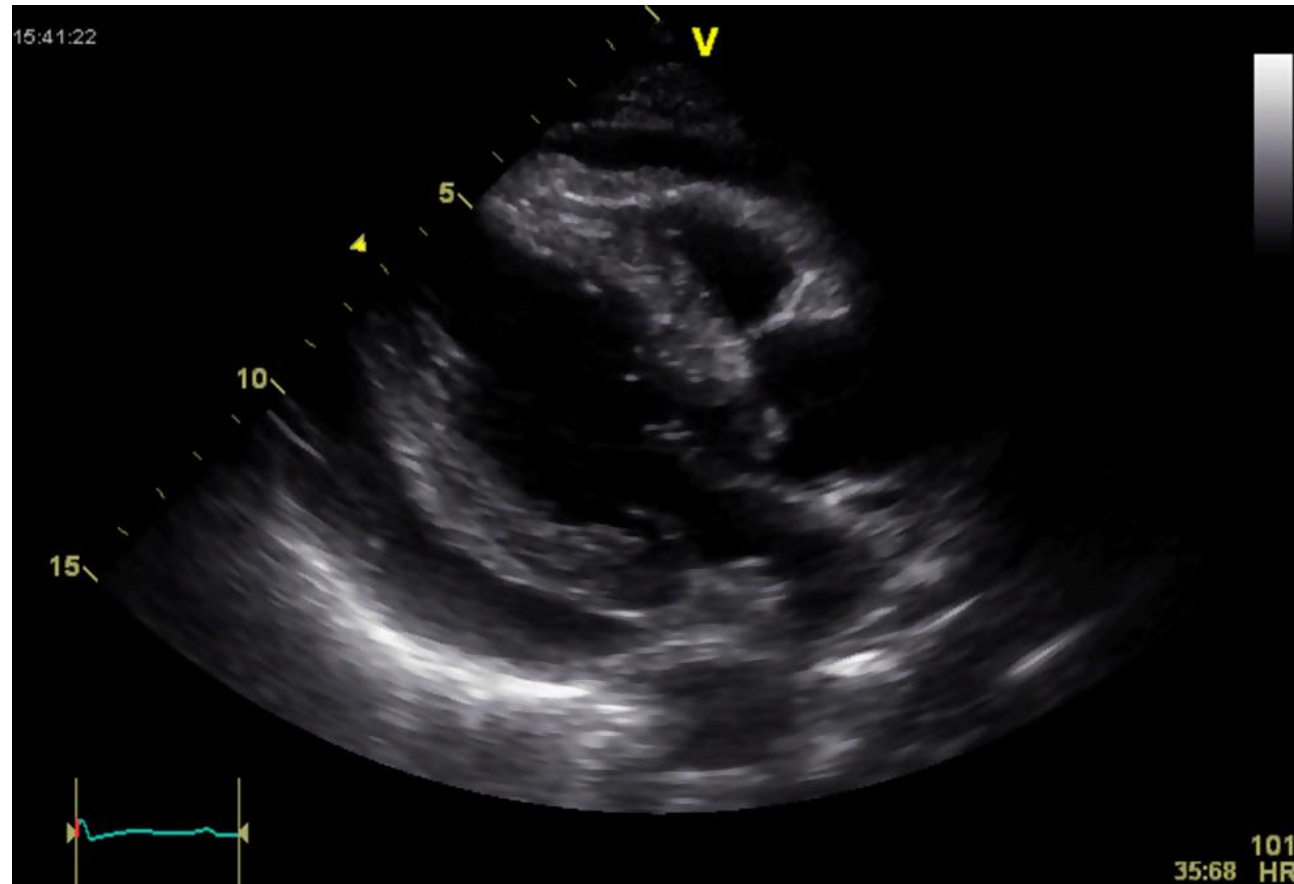
# Pericardial Tamponade

- Caused by **pericardial effusions**
- High pericardial pressure → ↓ filling of ventricles in diastole
- Amount of fluid required for tamponade varies
  - Acute accumulation (bleeding): small amount of fluid
  - Chronic accumulation (cancer): large amount of fluid



Wikipedia/Public Domain

# Pericardial Effusion





# Pericardial Effusion



# Pericardial Tamponade

## Clinical features

- Distant heart sounds
- Dyspnea with absence of pulmonary edema
- Elevated jugular venous pressure

# Pericardial Tamponade

## Clinical features

- Beck's Triad
  - Distant heart sounds
  - Elevated JVP
  - Hypotension
- Seen in rapidly-developing traumatic effusions
- **Low cardiac output**
  - Decreased filling of right and left ventricles
  - Decreased preload
- Slower effusions: Pericardium stretches/dilates

# Pulsus Paradoxus

- Classic finding in tamponade
- Systolic BP always falls slightly on inspiration
- Exaggerated fall ( $> 10$  mmHg) = pulsus paradoxus
- Severe fall = pulse disappears
- Also seen in **asthma and COPD**
  - Inspiration normally  $\downarrow$  left sided flow
  - Exaggerated in lung disease



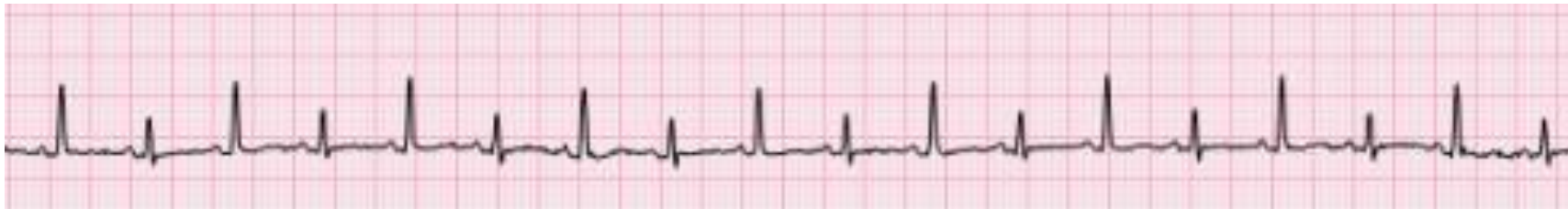
Public Domain

# Pericardial Tamponade

## EKG

- Seen in large pericardial effusions
- Usually tamponade is present
- Sinus tachycardia
- Low voltage – EKG sees less electricity due to effusion

## Electrical Alternans



# Tamponade

## Diagnosis and Treatment

- Diagnosis:
  - Pulsus paradoxus (clinical evidence of tamponade)
  - Transthoracic echocardiography
- Treatment:
  - Intravenous fluids (do NOT give diuretics)
  - Pericardiocentesis
  - Surgical pericardial window



# Tamponade

## Right heart catheterization

- Equalization of pressures
- Occurs when cardiac chambers cannot relax
- Seen in tamponade and pericardial constriction

Parameter	Normal	Tamponade/ Constriction
RA mean	5	20
RV Pressure	20/5	44/20
PCWP Pressure	10	20
LVEDP	10	20

# Effusions/Tamponade

## Causes

- **Pericarditis**
- **Cancer metastases** to pericardium
- Trauma



# Constrictive Pericarditis



# Constrictive Pericarditis

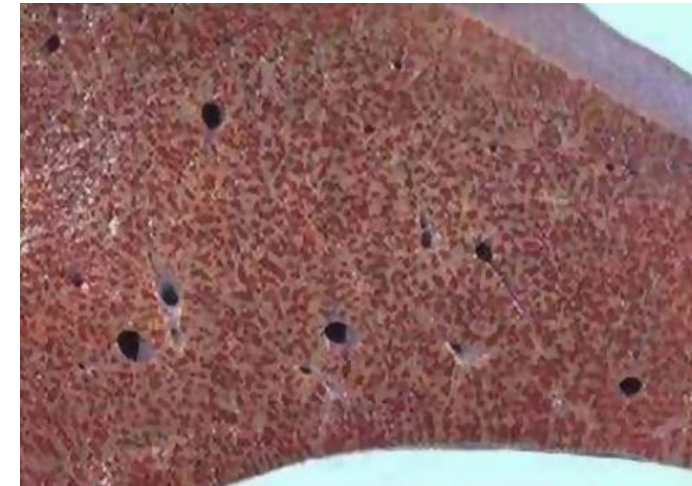
- Fibrous, calcified scar in pericardium
- Loss of elasticity: stiff, thickened, sticky
- Can result from many pericardial disease processes
  - Pericarditis
  - Radiation to chest
  - Heart surgery

# Constrictive Pericarditis

## Clinical Features

- Major pathologic process: ventricles cannot fill normally
- Filling abruptly stops
- Dyspnea (low cardiac output)
- Prominent **right heart failure**
  - Markedly-elevated jugular venous pressure
  - Lower extremity edema
  - Liver congestion
  - May lead to cirrhosis (“nutmeg liver”)

## Nutmeg Liver (dark spots)

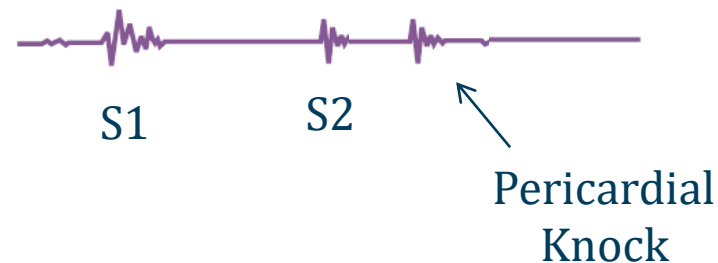


Public Domain

# Constrictive Pericarditis

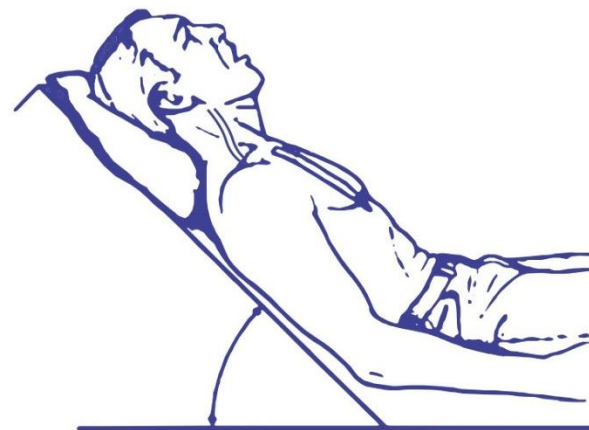
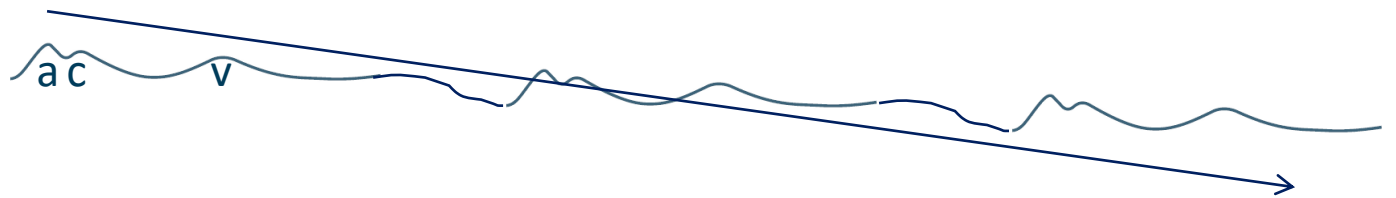
## Other Features

- Pulsus paradoxus uncommon (~20%)
- High RA, RVEDP, PCWP pressures
- Equalization of pressures
- **Pericardial knock**



# Kussmaul's Sign

- Inspiration  $\rightarrow$   $\uparrow$  VR  $\rightarrow$  slight fall in mean JVP
- **Kussmaul's sign** =  $\uparrow$  JVP with inspiration
  - Ventricle cannot accept  $\uparrow$ VR
- Constrictive pericarditis
- Restrictive cardiomyopathy
- RV myocardial infarction



# Pulsus and Kussmaul's

- Pulsus paradoxus: classic sign of tamponade
  - **Pulsus in tamPonade**
- Kussmaul's sign: classic sign of constriction
  - Also seen in restrictive heart disease
  - **Kussmaul's in Konstriction/Restriction**

	Tamponade	Constriction	Restrictive
Pulsus	Yes	No	No
Kussmaul's	No	Yes	Yes

# Constrictive Pericarditis

## Diagnosis and Treatment

- ECG: nonspecific findings
- Chest X-ray
- Echocardiography:
  - Poor pericardial visualization
  - Shows normal LVEF
  - Enlarged atria
  - Abnormal filling velocities
- Cardiac MRI or CT
- Cardiac catheterization
- Treatment: pericardiectomy



# Valvular Heart Disease

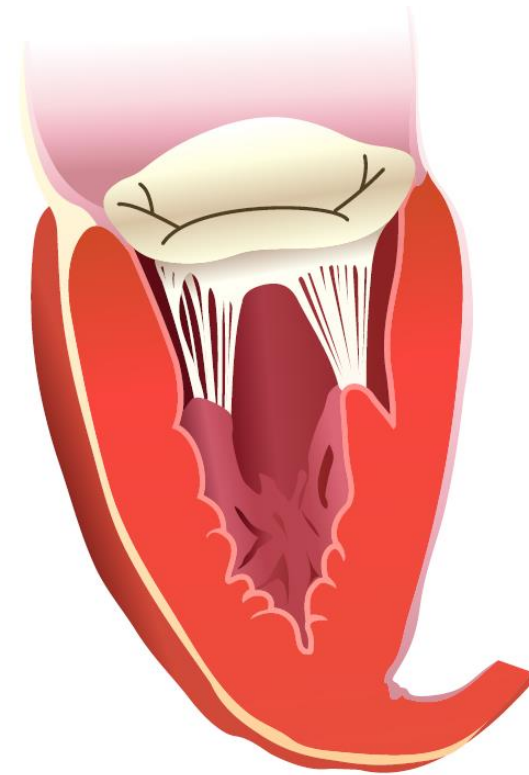
Jason Ryan, MD, MPH





# Valvular Heart Disease

- **Stenosis**
  - Stiffening/thickening of valve leaflets
  - Obstruction to forward blood flow
- **Regurgitation**
  - Malcoaptation of valve leaflets
  - Leakage of blood flow backwards across valve



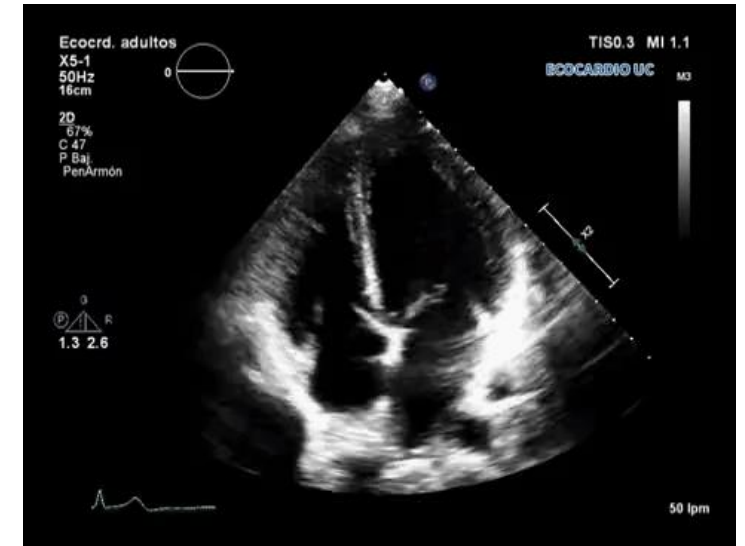
# Regurgitant Lesions

- **Acute and chronic forms**
- Acute regurgitation (often from endocarditis)
  - May cause shock
- Chronic regurgitation
  - No shock
  - Leads to chronic heart failure

# Valve Disorders

## Diagnosis and treatment

- Best initial test: **transthoracic echocardiography**
  - EKG not helpful but may show signs of chamber enlargement
- Only severe valvular lesions treated
- Mostly **surgical diseases**
  - Surgical repair
  - Valve replacement
  - Bioprosthetic (pig or cow)
  - Mechanical (requires life-long anticoagulation)
  - Valvuloplasty (mitral and aortic stenosis)



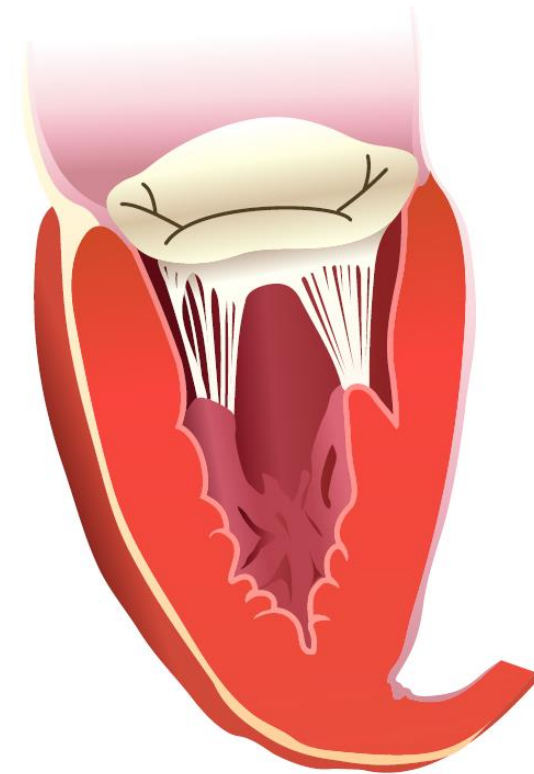
# Valve Disorders

## Medical treatment

- Medical therapy used rarely in patients with heart failure
  - Loop diuretics
- Afterload reduction
  - Vasodilators
  - In theory could improve forward flow in regurgitant valve disease (AR, MR)
  - Clinical trials have shown little benefit of drugs

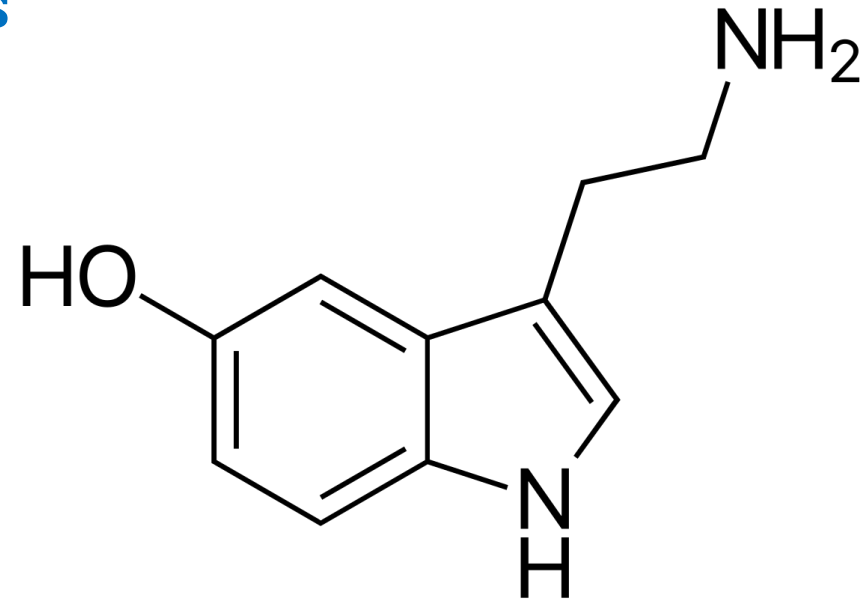
# Rheumatic Heart Disease

- Damage to heart valves by rheumatic fever
- Often presents years after acute rheumatic fever
- Many patients do not recall acute symptoms
- **Mitral valve** most commonly involved
- Common in **developing countries**
  - Limited access to medical care for pharyngitis
  - Often seen in **immigrants** to US



# Carcinoid Heart Disease

- Caused by carcinoid tumors of intestines
- Secrete **serotonin**
- Fibrous deposits **tricuspid/pulmonic valves**
- Leads to stenosis and regurgitation
- Serotonin inactivated by lungs
- Left-sided lesions rare



Serotonin

# Aortic Stenosis

## Pathophysiology

- Fibrotic/calcified aortic valve
- **Increased afterload**



CDC/Public Domain

# Aortic Stenosis

## Hemodynamics

- **LV systolic pressure >> aortic systolic pressure**
  - LVSP = 160 mmHg (normal = 120)
  - SBP = 120 mmHg (normal = 120)
  - Gradient = 40 mmHg



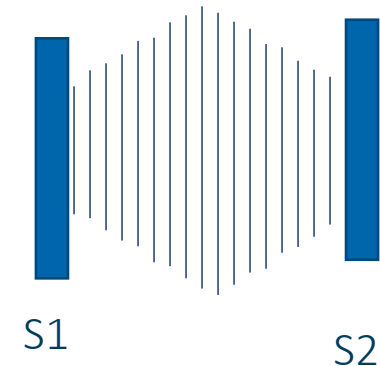


# Aortic Stenosis

## Clinical features

- Physical Exam
  - **Systolic crescendo-decrescendo murmur at 2<sup>nd</sup> right intercostal space**
  - Often radiates to carotids
- Severe disease findings
  - Soft, single S2 (restricted leaflet motion)
  - Pulsus parvus et tardus
- Symptoms
  - Angina
  - Syncope
  - Left heart failure (worst prognosis)

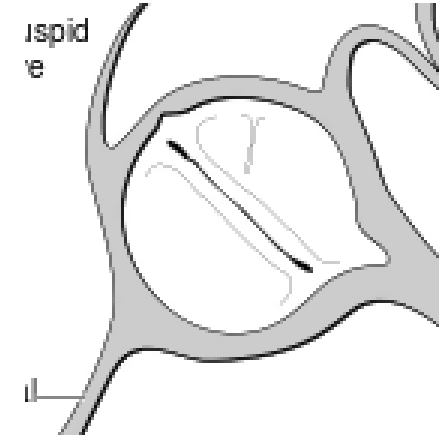
Crescendo-Decrescendo  
Murmur



# Aortic Stenosis

## Causes

- **Senile aortic stenosis**
  - “Wear and tear”
  - Collagen breakdown
  - Calcium deposition
- **Bicuspid aortic valve**
- Rarely rheumatic heart disease



Patrick J. Lynch, medical illustrator

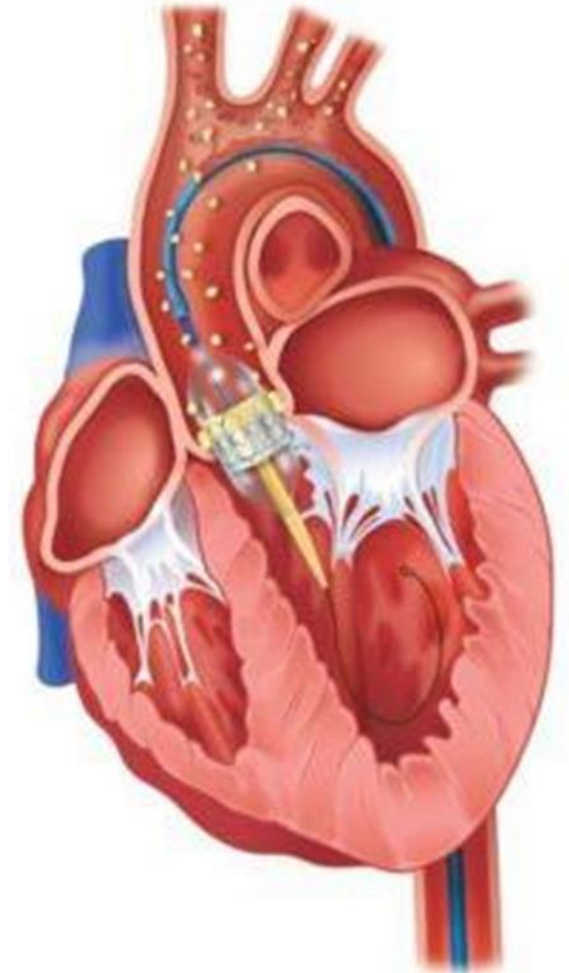


CDC/Public Domain

# Aortic Stenosis

## Special treatments

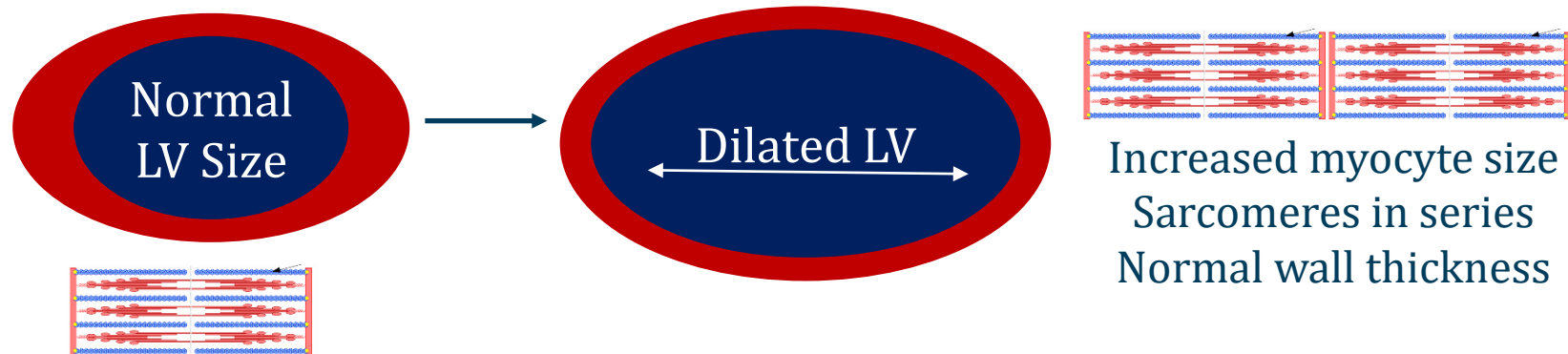
- **Transcatheter aortic valve replacement (TAVR)**
  - No chest incision
  - Faster recovery



# Aortic Regurgitation

## Pathophysiology

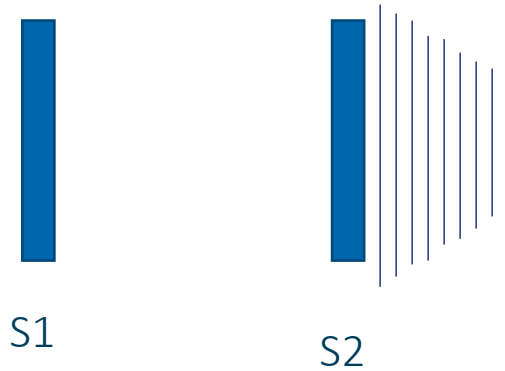
- Inadequate closure of leaflets → blood leaks across aortic valve in diastole
- **Increased preload, stroke volume**
- Eccentric hypertrophy eventually leading to heart failure



# Aortic Regurgitation

## Clinical features

- Blowing, decrescendo diastolic murmur at lower left sternal border



# Aortic Regurgitation

## Clinical features

- Leaking blood back into LV causes **low diastolic BP**
  - 120/80 (normal) → 120/40
  - Low diastolic pressure
- **Wide pulse pressure**
  - High cardiac output with low diastolic pressure
- Wide pulse pressure symptoms
  - “Water hammer” pulses
  - Head bobbing
  - Many, many others (mostly historical)

# Aortic Regurgitation

## Causes

- **Dilated aortic root** → leaflets pull apart
  - Often from HTN or other aortic aneurysm (Marfan)
  - Rarely from tertiary syphilis (aortitis)
- **Bicuspid aortic valve**
  - Turner syndrome
  - Coarctation of the aorta
- Endocarditis
- Rheumatic heart disease
  - Almost always with mitral disease

# Mitral Stenosis

## Pathophysiology

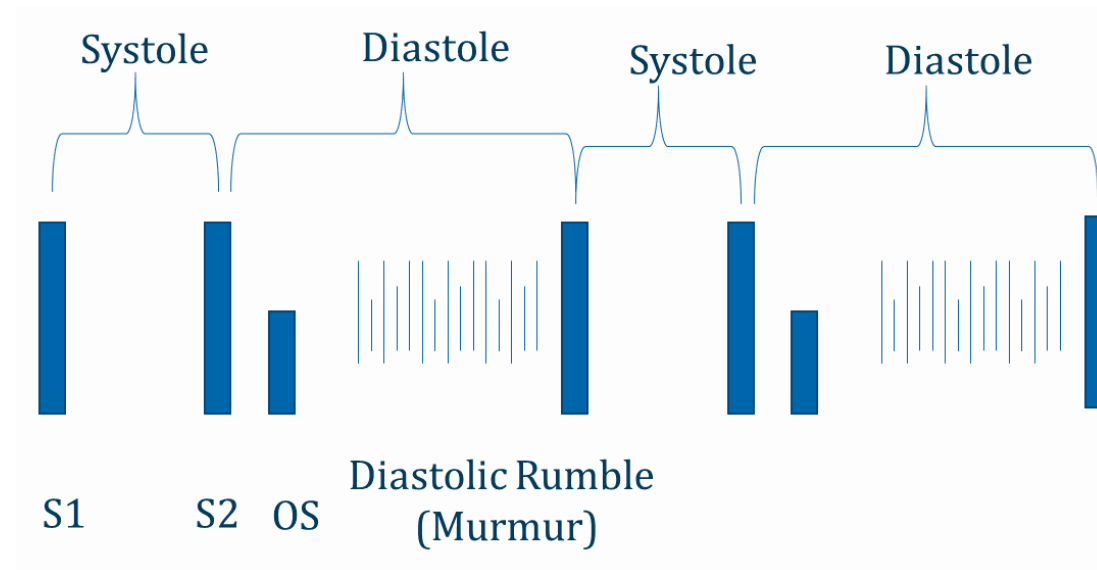
- Most cases caused by **rheumatic heart disease**
- Stiff mitral valve
- **LA pressure >> LV diastolic pressure**
  - Left atrial pressure 20 mmHg (normal = 10)
  - LVEDP 5 mmHg (normal = 10)
  - Gradient = 15 mmHg
- Left atrium may become massively dilated
  - Commonly causes atrial fibrillation



# Mitral Stenosis

## Clinical features

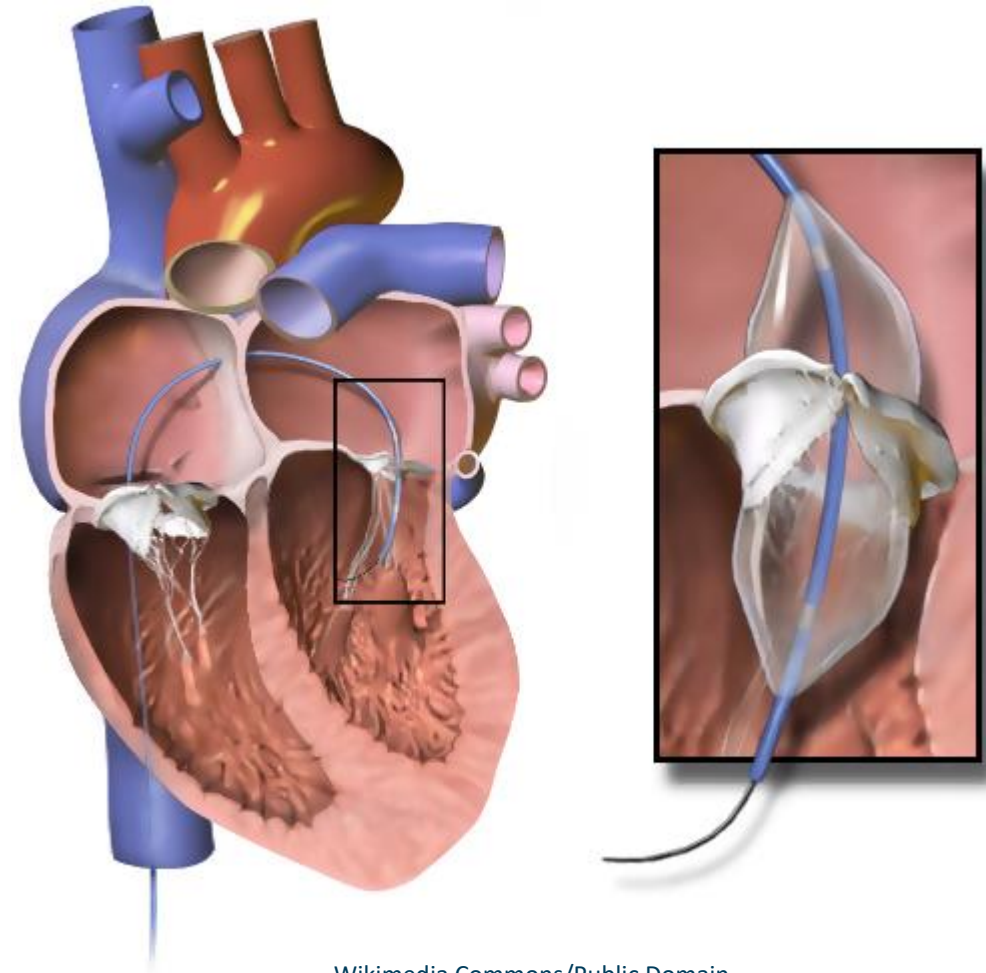
- Most common symptom: **dyspnea**
  - ↑ LA pressure → pulmonary congestion
- Murmur: diastolic rumble with opening snap



# Mitral Stenosis

## Special treatments

- **Balloon valvuloplasty**
  - Used in rheumatic mitral stenosis
  - Breaks up fibrous tissue
  - Valve must have little/no calcium deposition

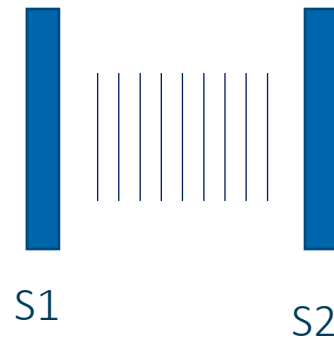


Wikimedia Commons/Public Domain

# Mitral Regurgitation

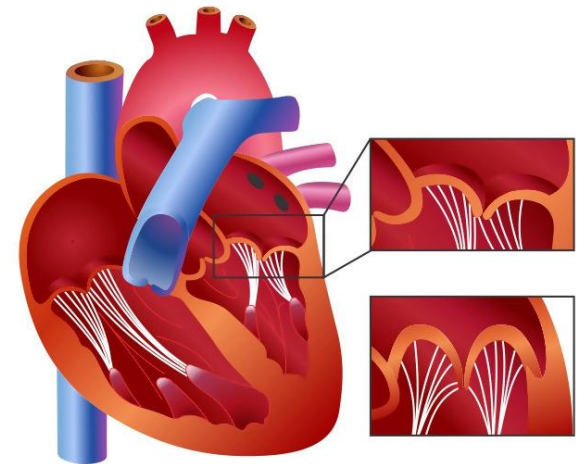
## Clinical Features

- Holosystolic murmur at apex
- Radiates to the axilla



# Mitral Valve Prolapse

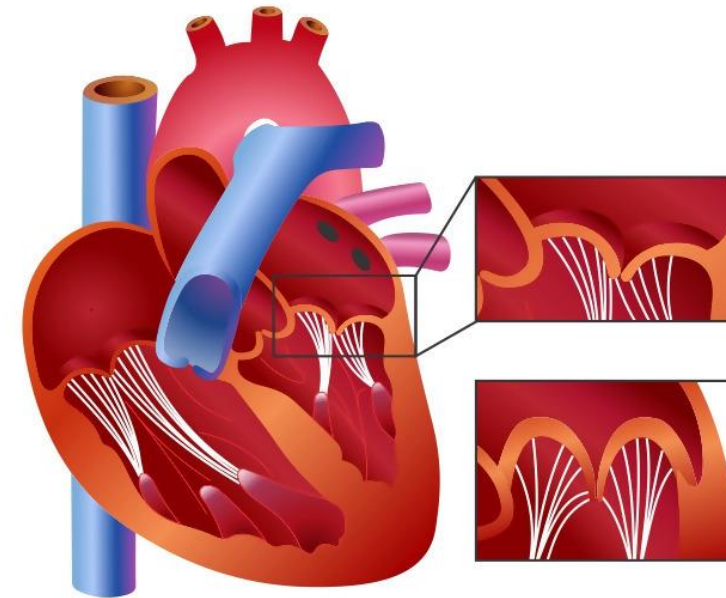
- Primary mitral regurgitation
  - Also called degenerative or myxomatous
  - Billowing of mitral valve leaflets above annulus
- Causes a **systolic click**
  - Don't confuse with opening snap of mitral stenosis
- Systolic murmur from MR
  - Increases with standing or Valsalva
  - Decreases with squatting



# Mitral Regurgitation

## Secondary causes

- Ischemia → damage to papillary muscle
- Left ventricular dilation
  - Dilated cardiomyopathy
  - Leaflets pulled apart
  - **“Functional” MR**
- Hypertrophic cardiomyopathy
  - Systolic anterior motion (SAM)



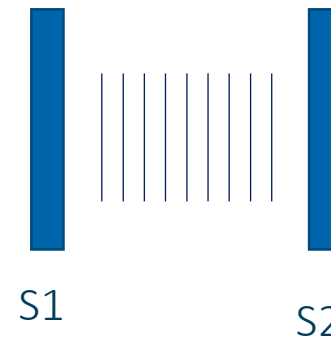
# Mitral Regurgitation

## Secondary causes

- Endocarditis
- Rheumatic heart disease
- Congenital
  - Cleft mitral valve
  - Endocardial cushion defect
  - Down syndrome

# Tricuspid Regurgitation

- Holosystolic murmur at left sternal border
- Small amount of TR normal (“physiologic TR”)
- Pathologic causes
  - Functional TR from **RV enlargement**
  - **Endocarditis - classically IV drug users**
  - Carcinoid
  - Ebstein’s anomaly



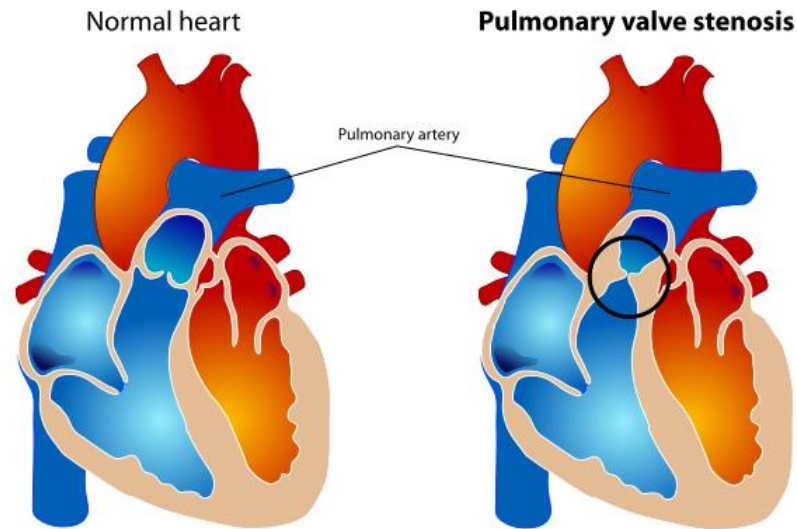
# Tricuspid Stenosis

- Very rare valve disorder
- **Diastolic murmur at left lower sternal border**
- Caused by rheumatic heart disease (with mitral disease)
  - Tricuspid regurgitation more common
- Carcinoid heart disease



# Pulmonic Stenosis

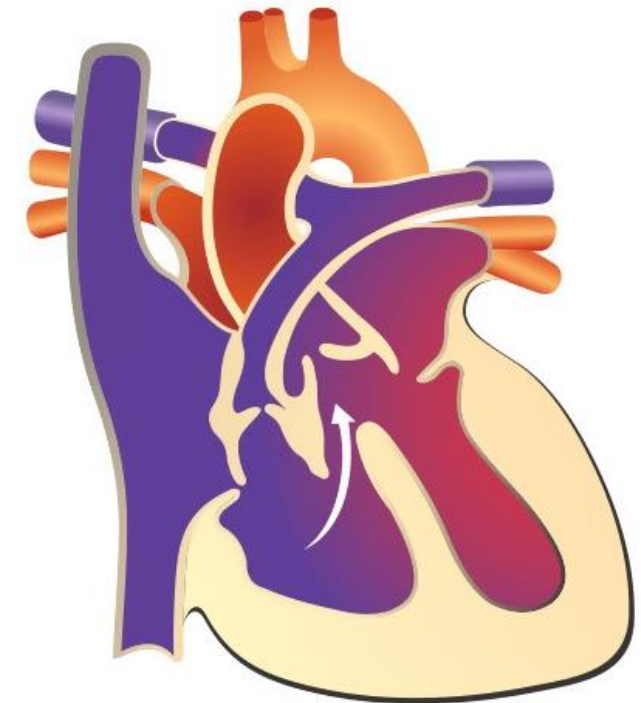
- **Congenital defect** in children
  - Fused commissures with thickened leaflets
- Carcinoid heart disease
- Systolic crescendo-decrescendo murmur at left upper sternal border



# Pulmonic Regurgitation

- Most common cause: repaired **Tetralogy of Fallot**
  - Repair of RVOT obstruction damages valve
- Endocarditis (rare)
- Rheumatic heart disease (rare)
- Diastolic decrescendo murmur at left upper sternal border

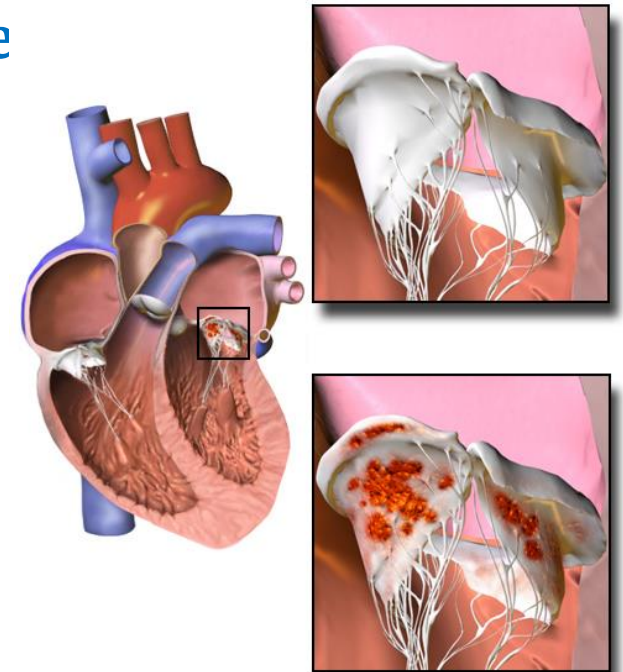
Tetralogy of Fallot



# Endocarditis Prophylaxis

- Antibiotics prior to dental work or surgical procedures
- Sometimes indicated in patients with valve disease
- Indicated in patients with **prior endocarditis**
- Indicated only after **valve replacement with prosthetic valve**
- NOT indicated for patients with unrepaired valve disease

**Endocarditis**



# Heart Murmurs

Jason Ryan, MD, MPH



# Heart Murmurs

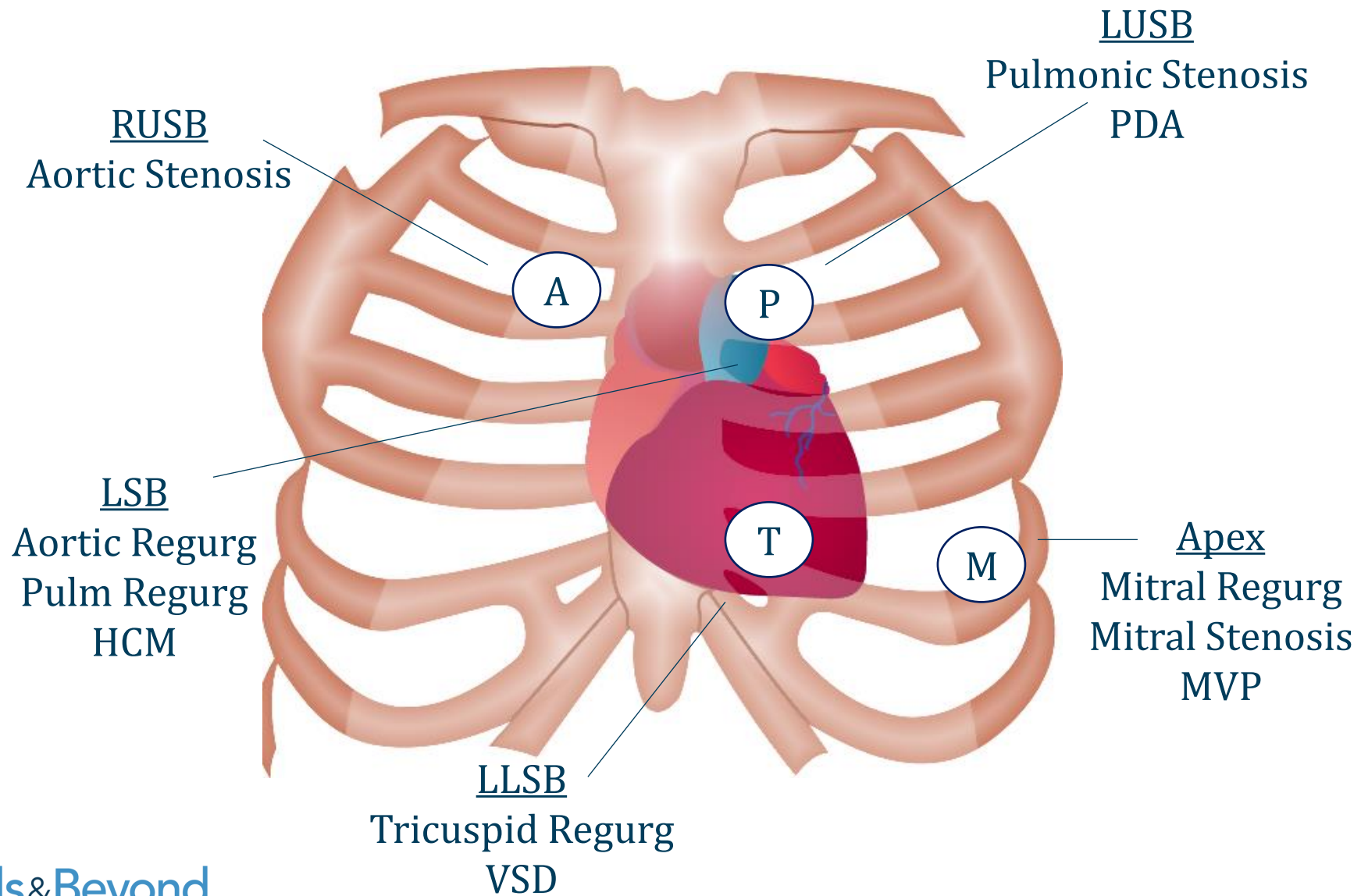
- Cardiac sound heard with stethoscope
- Caused by **turbulent blood flow**
- May be normal or pathologic



# Murmurs

## Grading

- I - barely audible on listening carefully
- II - faint but easily audible
- III - loud and easily audible, no thrill
- IV - loud murmur with a thrill
- V - heard with scope barely touching chest
- VI - audible with scope not touching the chest



# Innocent/Functional Murmurs

- Caused by normal flow of blood
- Common in children
- Also young, thin patients
- Generally soft murmurs
- No signs/symptoms of heart disease
- Still's murmur
- Pulmonic flow murmur
- Venous hum



# Systolic Murmurs

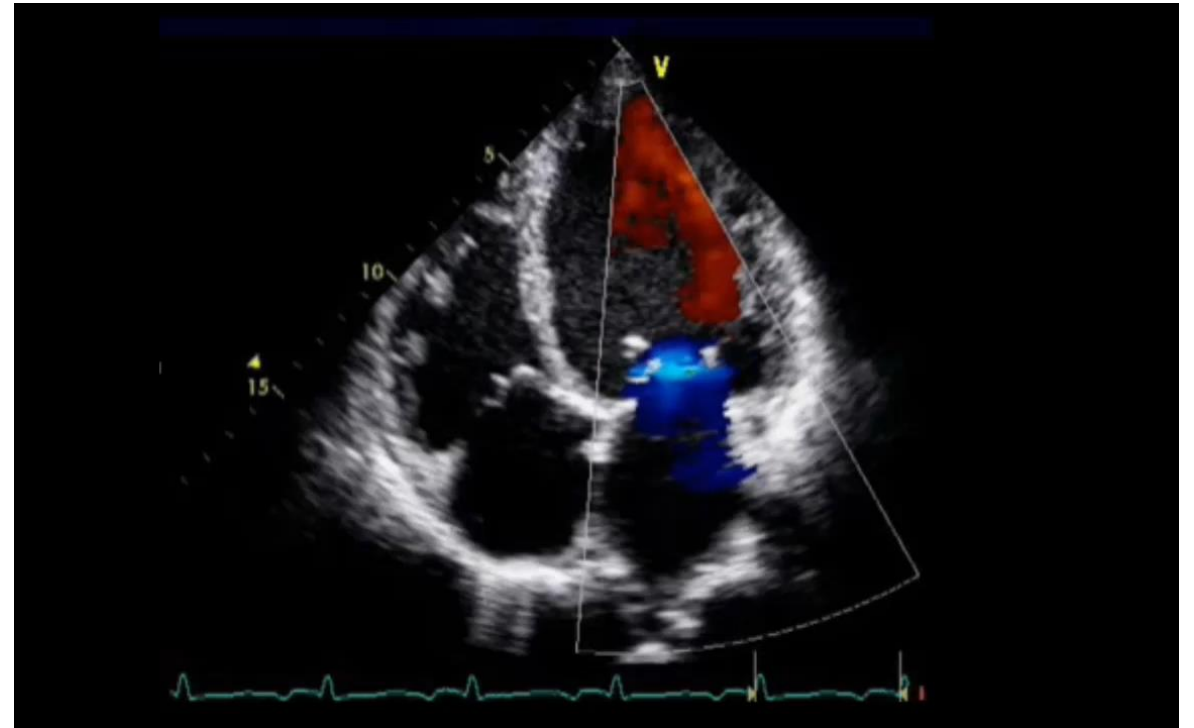
- Occur when heart contracts/squeezes
- Between S1-S2
- Flow murmur (benign)
- Aortic stenosis
- Mitral regurgitation
- Pulmonic stenosis
- Tricuspid regurgitation
- Hypertrophic cardiomyopathy
- Ventricular septal defect (VSD)

# Diastolic Murmurs

- Occur when heart relaxes/fills
- Between S2-S1
- Aortic regurgitation
- Mitral stenosis
- Pulmonic regurgitation
- Tricuspid stenosis

# Murmur Evaluation

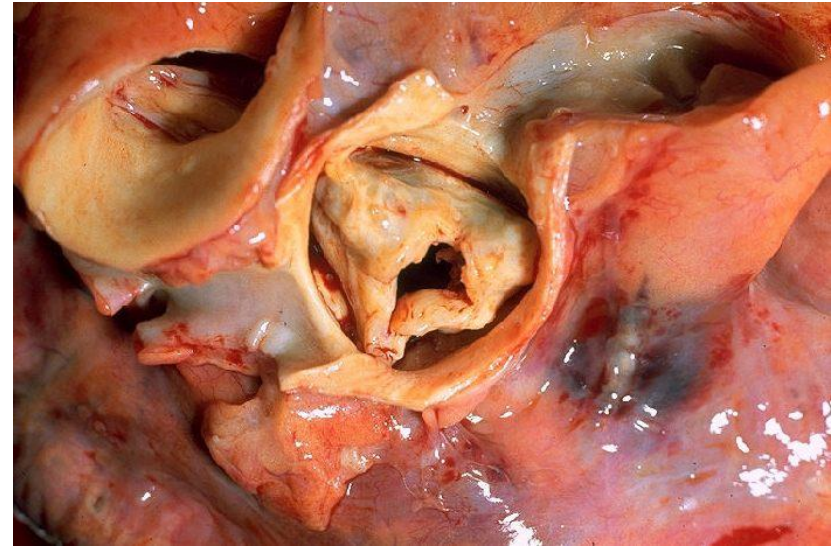
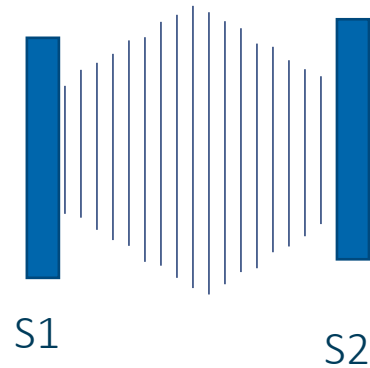
- Test of choice: **transthoracic echocardiography**
  - Visualize valves
  - Measure flow velocities



# Aortic Stenosis

## Murmur

- Systolic crescendo-decrescendo murmur
- Also called an “ejection murmur”



# Aortic Stenosis

## Severe Disease Findings

- **Late-peaking murmur**
  - Slow flow across stenotic valve
- **Soft/quiet S2**
  - Stiff valve can't slam shut
- **Pulsus parvus et tardus**
  - Weak and small carotid pulses
  - Delayed carotid upstroke

# HCM

## Hypertrophic Cardiomyopathy

- Same murmur as aortic stenosis
- Differentiated by maneuvers
- **Valsalva**
  - Decreases venous return/preload
  - Increases HCM murmur
  - Decreases AS murmur

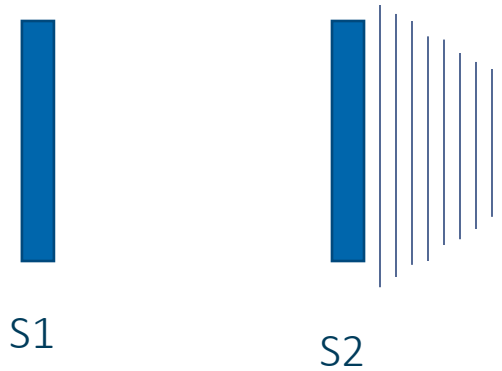


HCM

# Aortic Regurgitation

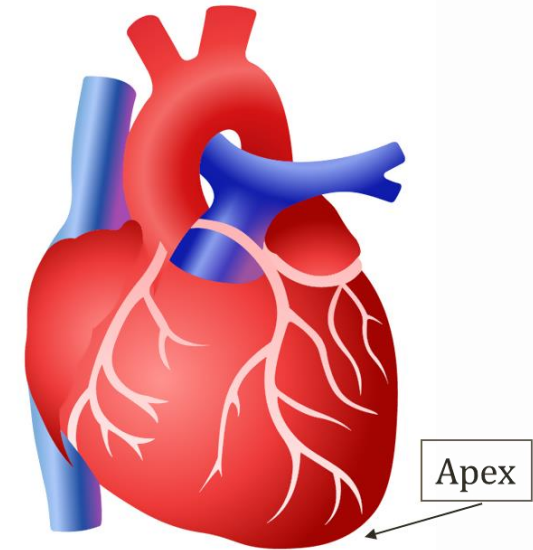
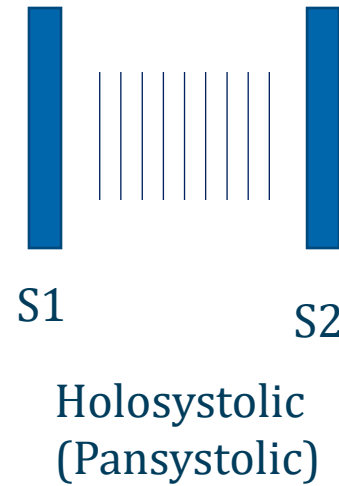
Aortic insufficiency, aortic incompetence

- Decrescendo, **blowing** diastolic murmur



# Mitral Regurgitation

- **Holosystolic murmur heard best at the apex**
  - 5<sup>th</sup> intercostal space, mid-clavicular line

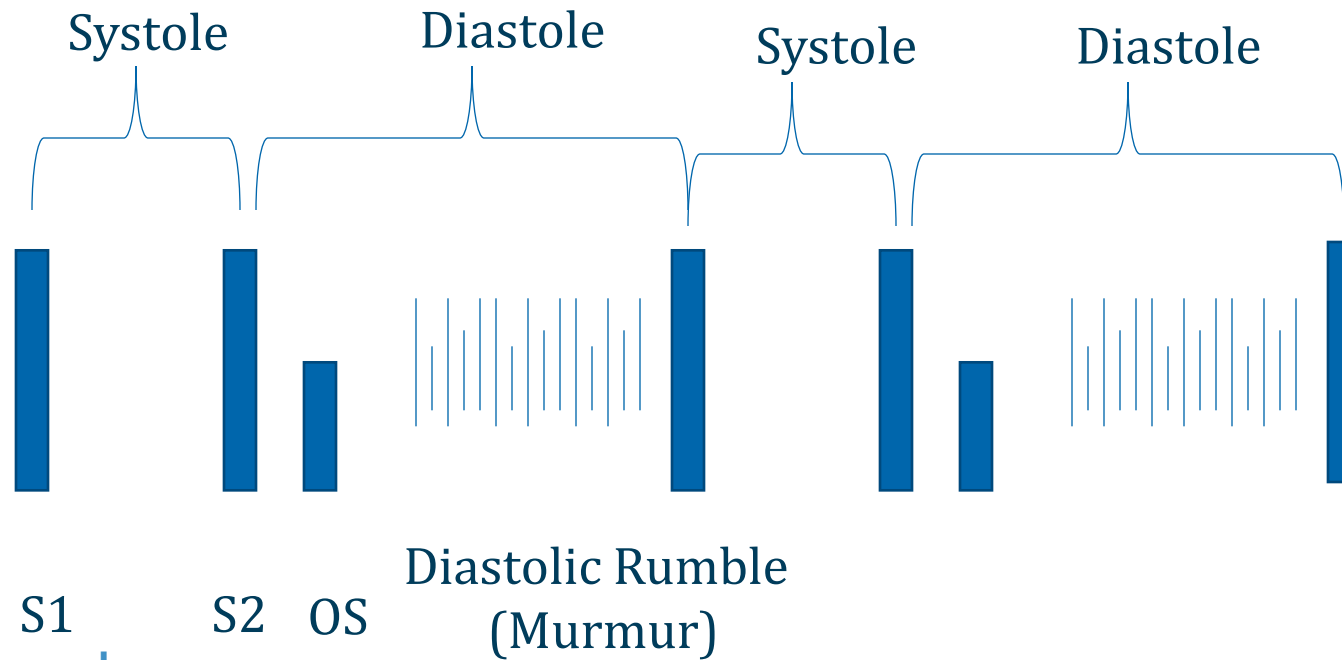




# Mitral Stenosis



- **Diastolic rumbling murmur** preceded by **opening snap**
- Loud S1

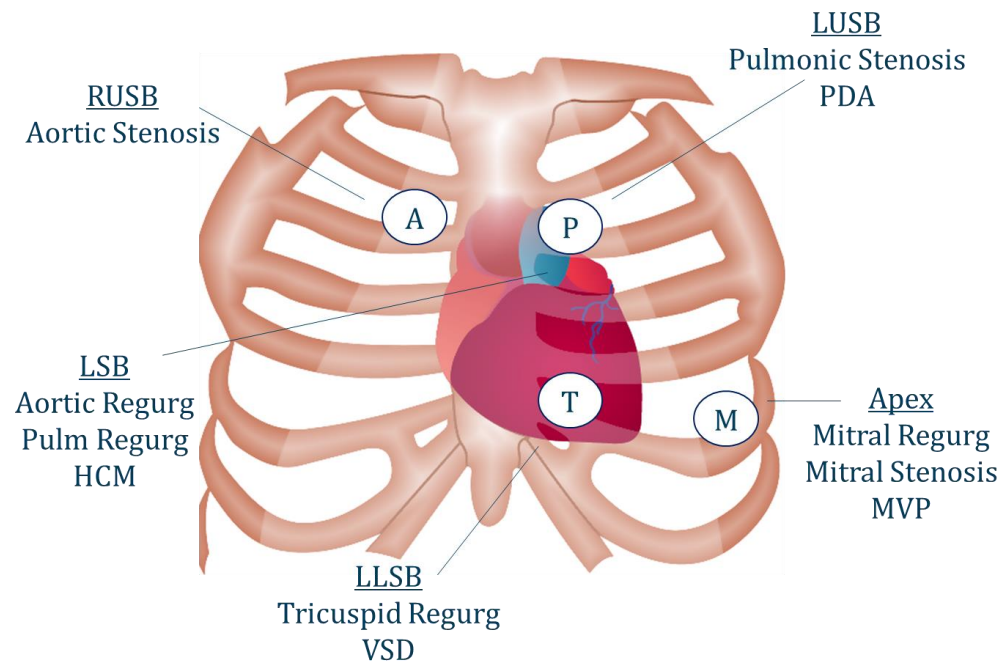


# Mitral Stenosis

- No left sided S3, S4 in mitral stenosis
- **Time to opening snap** associated with severity
  - **High left atrial pressure** in severe disease
  - Higher left atrial pressure → ↓ time to opening snap
  - Short time to opening snap seen in severe disease

# Tricuspid/Pulmonic Disease

- Valve lesions sound like left-sided counterparts
- Heard in different locations



# Carvallo's Sign

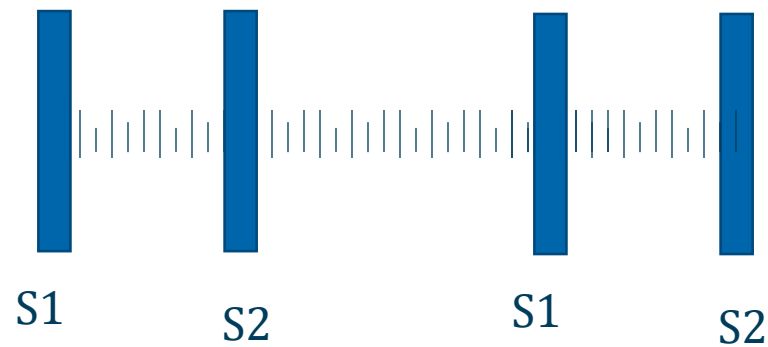
- Tricuspid regurgitation gets louder during inspiration
- Mitral regurgitation gets softer during inspiration
- Inspiration draws blood volume to lungs
- Louder right sided murmurs
- Softer left-sided murmurs
- Exhalation does the opposite
- **right-sided** murmurs increase with Inspiration
- **Left-sided** murmurs increase with Exhalation

# PDA

Patent Ductus Arteriosus

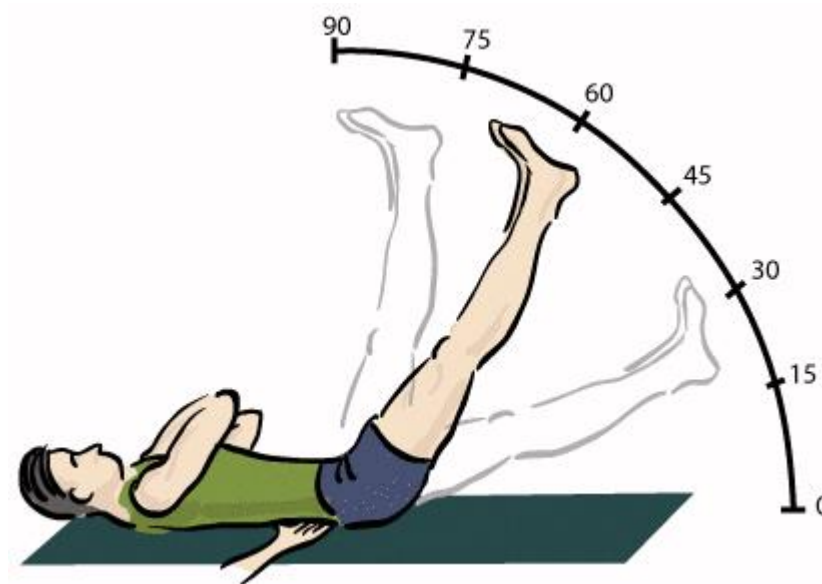


- **Continuous, “machine-like” murmur**



# Maneuvers

- Performed at bedside with patient
- May increase or decrease murmur
- Used to make diagnosis



Davidjr74/Wikipedia

# Maneuvers

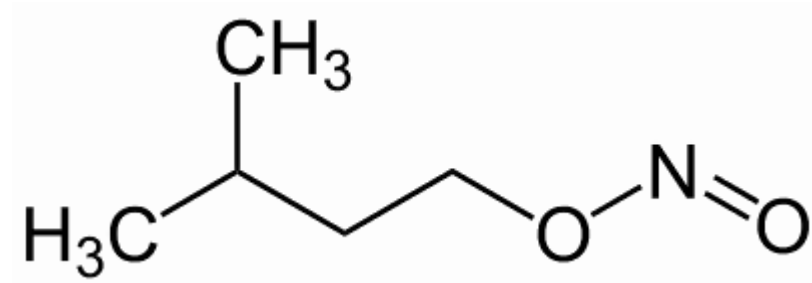
## Preload/Venous Return

- Increase preload/venous return
  - **Leg raise** – blood falls back toward heart
  - **Squatting** – blood in legs forced back toward heart
- Decrease preload/venous return
  - **Valsalva** –  $\uparrow$  intra-thoracic pressure  $\rightarrow$  vein compression  $\rightarrow \downarrow$  VR
  - **Standing** – Blood falls toward feet, away from heart
- Most murmurs INCREASE with more preload except:
  - HCM
  - MVP

# Maneuvers

## Afterload

- Increase Afterload
  - **Hand grip** - clench fist
- Decrease Afterload
  - **Amyl Nitrate** - vasodilator



Amyl Nitrate



# Maneuvers

## Afterload

- Backward Disorders
  - AR, MR, VSD
  - Louder with more afterload
- Forward Disorders
  - MS, AS
  - Softer with more afterload
- MVP, HCM
  - Softer
  - Increased LV cavity size

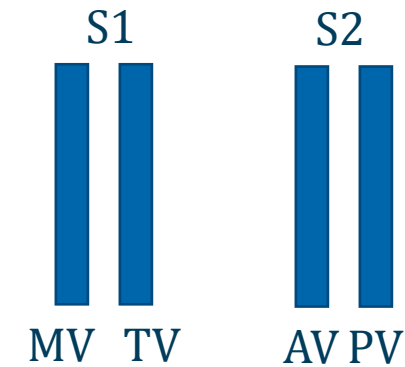
# Heart Sounds

Jason Ryan, MD, MPH



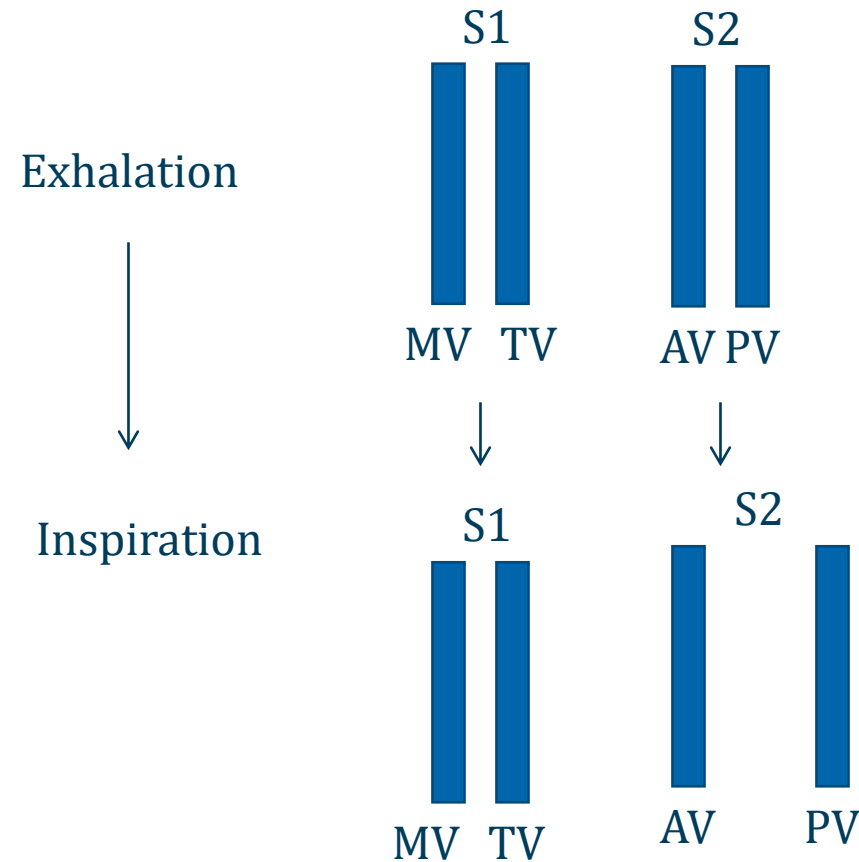
# S1 and S2

- **Normal** heart sounds
- Each has **two components**
  - One from left-sided valves (aortic, mitral)
  - One from right-sided valves (tricuspid, pulmonic)
- S1 usually “single”
  - Two components close together
  - Cannot distinguish separate sounds
- S2 can be “split”
  - Two components far enough apart to be audible



Wikipedia/Public Domain

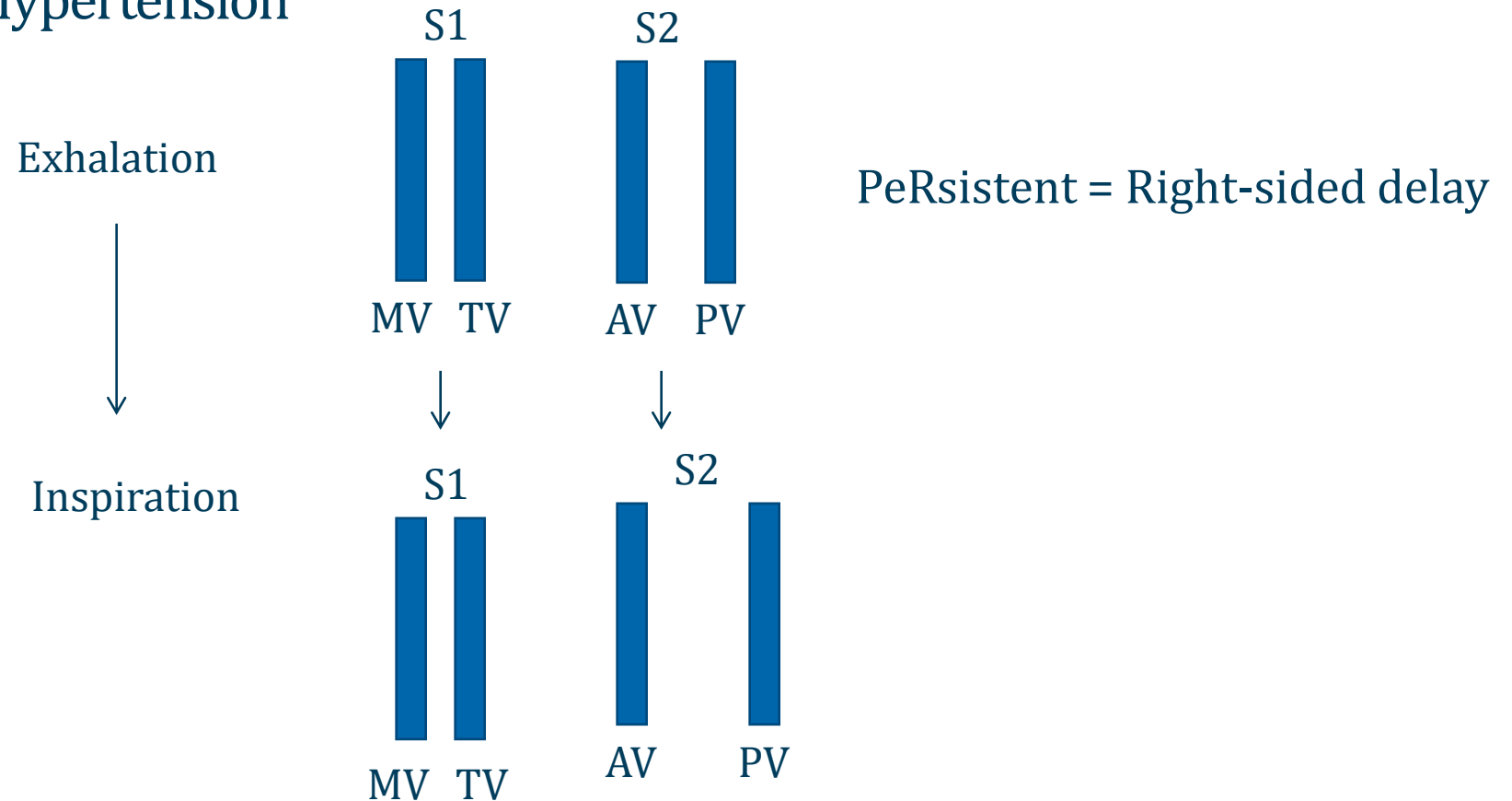
# Physiologic S2 splitting



Increased venous return delays P2 by 40-60 ms  
**Single to split with inspiration**

# Persistent S2 splitting

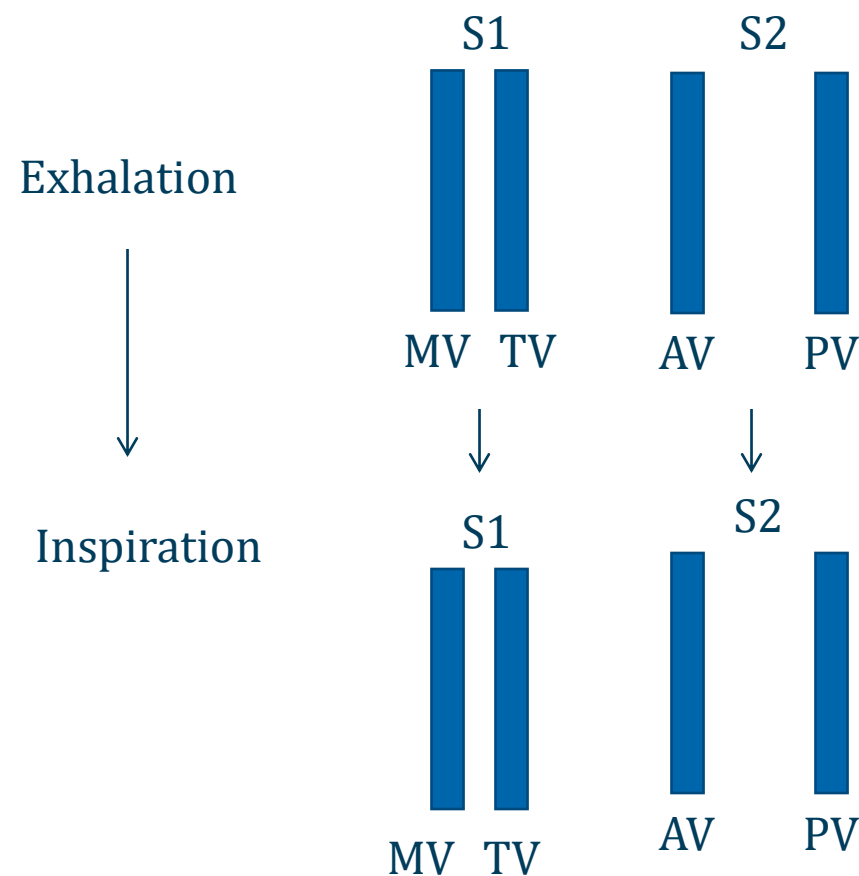
RBBB or Pulmonary Hypertension



Delayed PV closure even during exhalation

# Fixed S2 splitting

Atrial septal defect

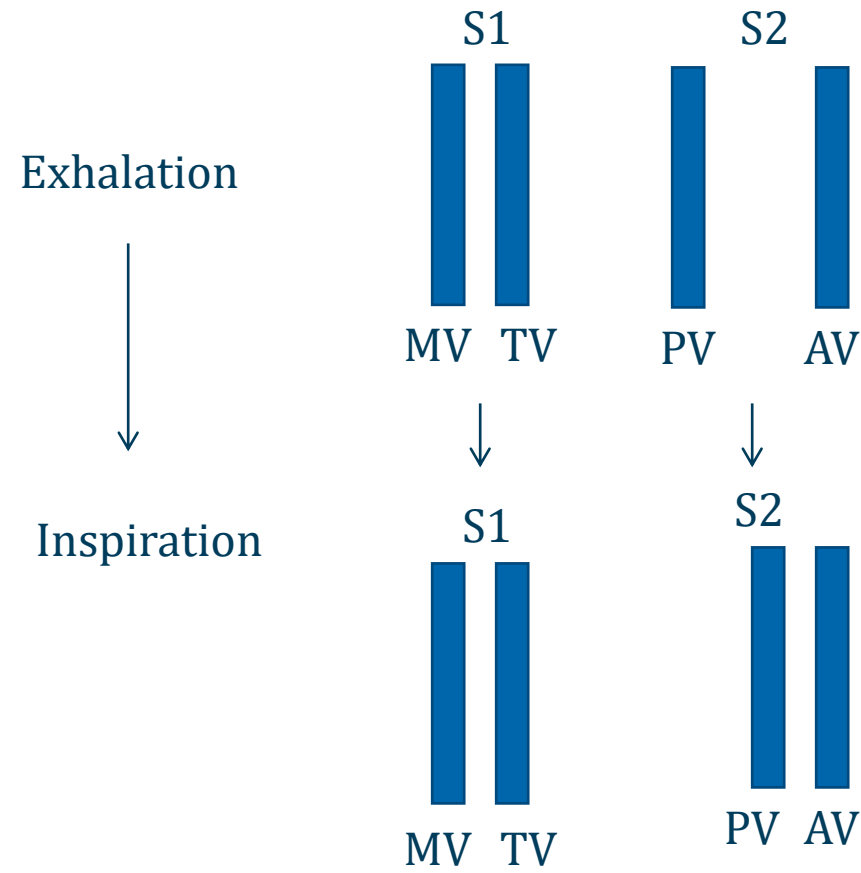


Atrial Septal Defect  
Fixed split S2  
Systolic Ejection Murmur LSB



# Paradoxical S2 splitting

Delayed closure of aortic valve



# Paradoxical Splitting

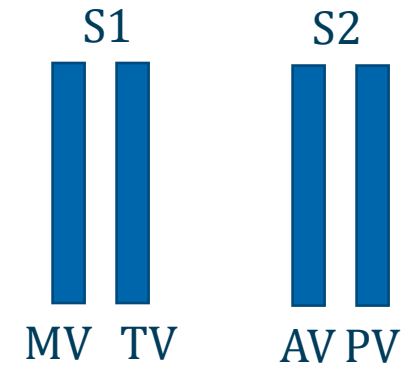
- Electrical causes → delayed LV activation
  - LBBB
  - RV pacing
- Mechanical causes → delayed LV outflow
  - LV systolic failure
  - Aortic stenosis
  - Hypertrophic cardiomyopathy

**ParadoxicalL = Left-sided delay**



# Loud P2

- Loud pulmonic component of S2
- **Pulmonary hypertension**
- Forceful closure of pulmonary valve
- Normally P2 not heard at apex
  - If you hear it here, it's "loud"



# S3 and S4

- Pathologic/abnormal heart sounds
- Occur in **diastole** during filling of left ventricle
- **Low-pitched** sounds heard best with bell
- S3: Early filling sound
- S4: Late filling sound



Tama988/Wikipedia

# S3

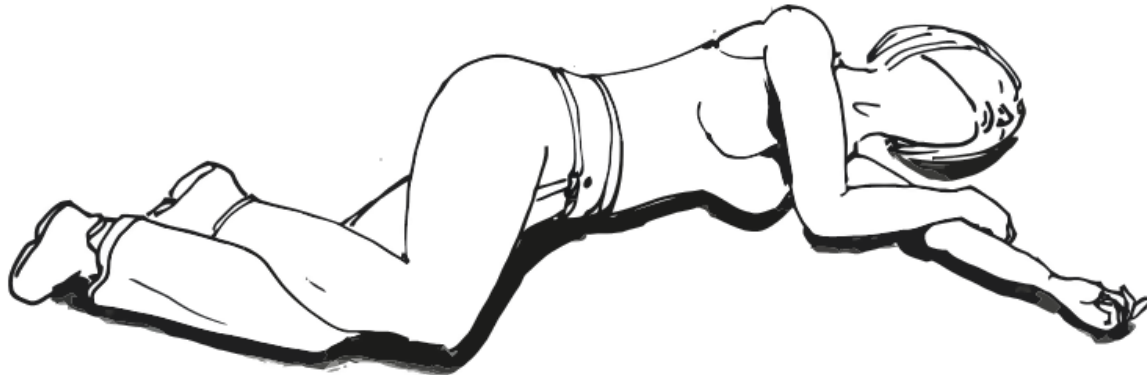
- Commonly seen in **acute heart failure**
  - High LA pressure → rapid early filling of LV → S3
  - Associated with ↑ LAP & ↑ LVEDP
  - Very specific sign of high left atrial pressure
- **May be heard in normal hearts**
  - Young patients (< 30), pregnant women
  - Vigorous LV relaxation



Wikipedia/Public Domain

# S3

- Louder in **left lateral decubitus position**
- Loudest at **apex**



# S4



- Heard in patients with **stiff left ventricle**
  - Long-standing hypertension
  - Hypertrophic cardiomyopathy
  - Diastolic heart failure
- Rapid late filling of LV due to atrial kick
- Not heard in **atrial fibrillation**



# Systolic Clicks



## Ejection Click

Early in systole  
BEFORE carotid pulse  
**Bicuspid Aortic Valve**  
Pulmonic stenosis



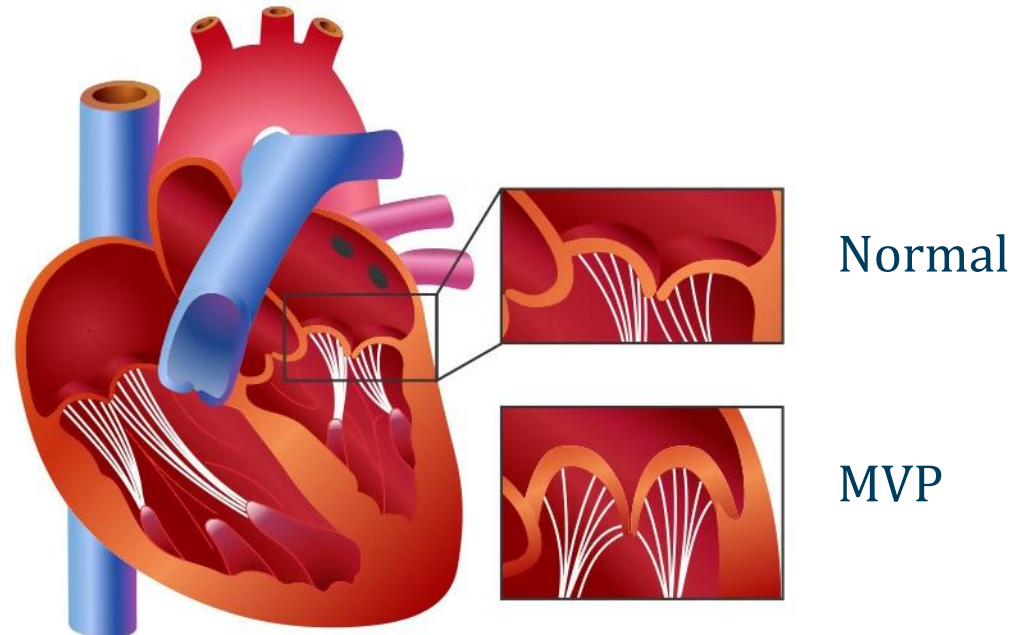
## Non-Ejection Click

Late in systole  
AFTER carotid pulse  
**Mitral Valve Prolapse**

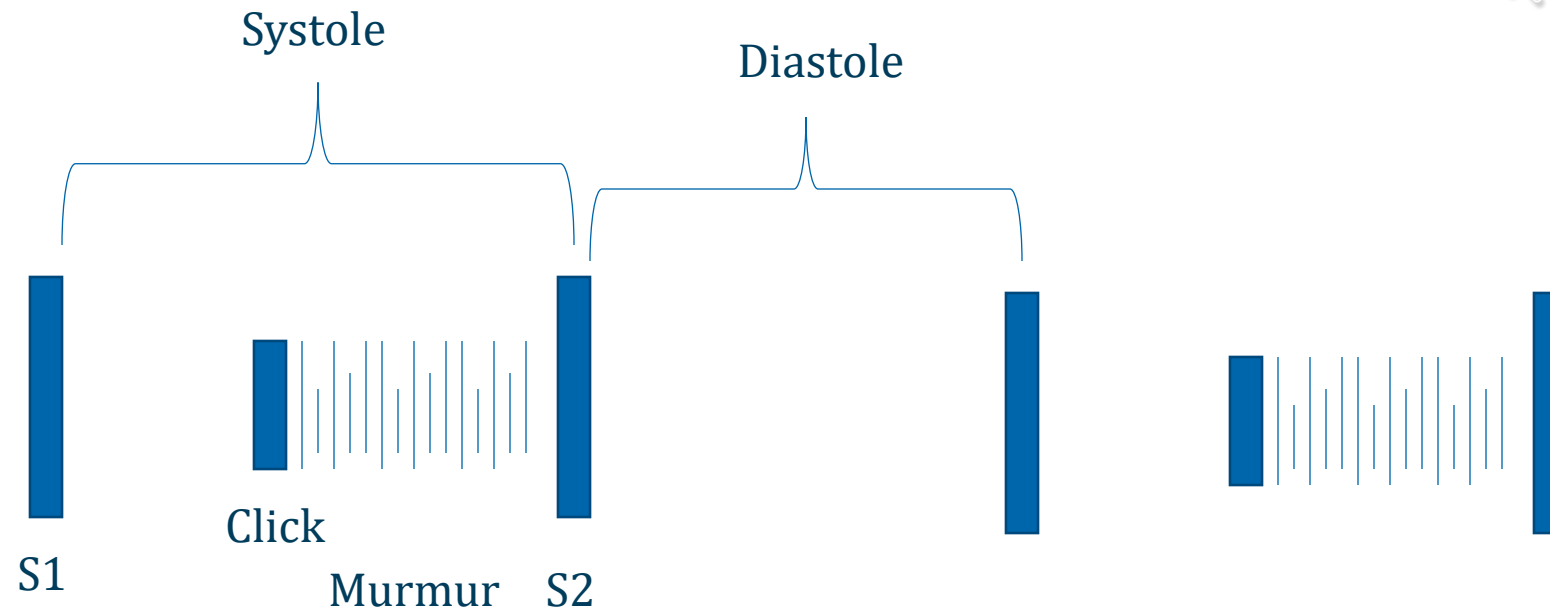
# Mitral Valve Prolapse

- Billowing of mitral valve leaflets above annulus
- Common cause of mitral regurgitation
- Causes a systolic click
  - Don't confuse with opening snap of mitral stenosis (diastole)

Classic Patients  
Young women  
Marfan syndrome



# Mitral Valve Prolapse



**Murmur intensity increases with Valsalva**



# Bradycardia

Jason Ryan, MD, MPH



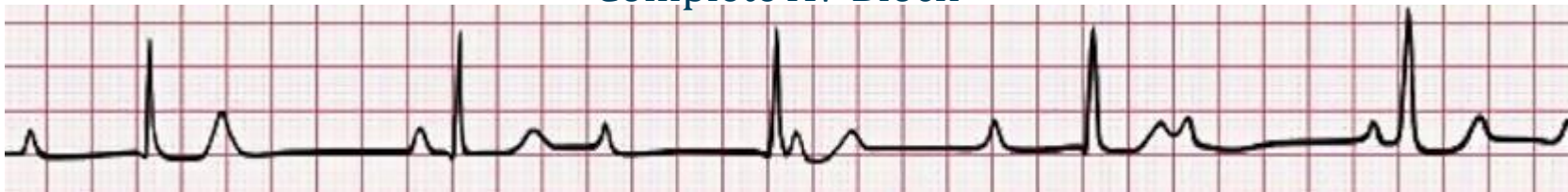
# Bradycardia

- Pulse < 60/min
- Sinus bradycardia: slow SA node depolarization
- AV Block: blocked conduction through AV node

Sinus Bradycardia



Complete AV Block



# Bradycardia

## Symptoms

- Often asymptomatic
- Symptoms with severe/persistent forms only
- Fatigue
- Exercise intolerance
- Dizziness
- Syncope

# Sinus Bradycardia

- Sinus rate  $< 60/\text{min}$
- Often an incidental finding
- Drugs: beta-blockers, calcium channel blockers
- Well-trained athletes

Sinus Bradycardia



# Sinus Bradycardia

- Usually no treatment required
- Rare, severe cases treated with:
  - Atropine (muscarinic antagonist)
  - Dopamine or epinephrine (beta-1 agonists)
  - Pacemaker implantation

Sinus Bradycardia



# Sinus Node Dysfunction

## Sick Sinus Syndrome

- Bradycardia due to abnormal SA node function
- Usually due to age-related changes
- Slow or absent SA node function after atrial fibrillation conversion
  - “Conversion pause”
- Treatment: **pacemaker implantation**

### Atrial Fibrillation Conversion Pause



# AV Block

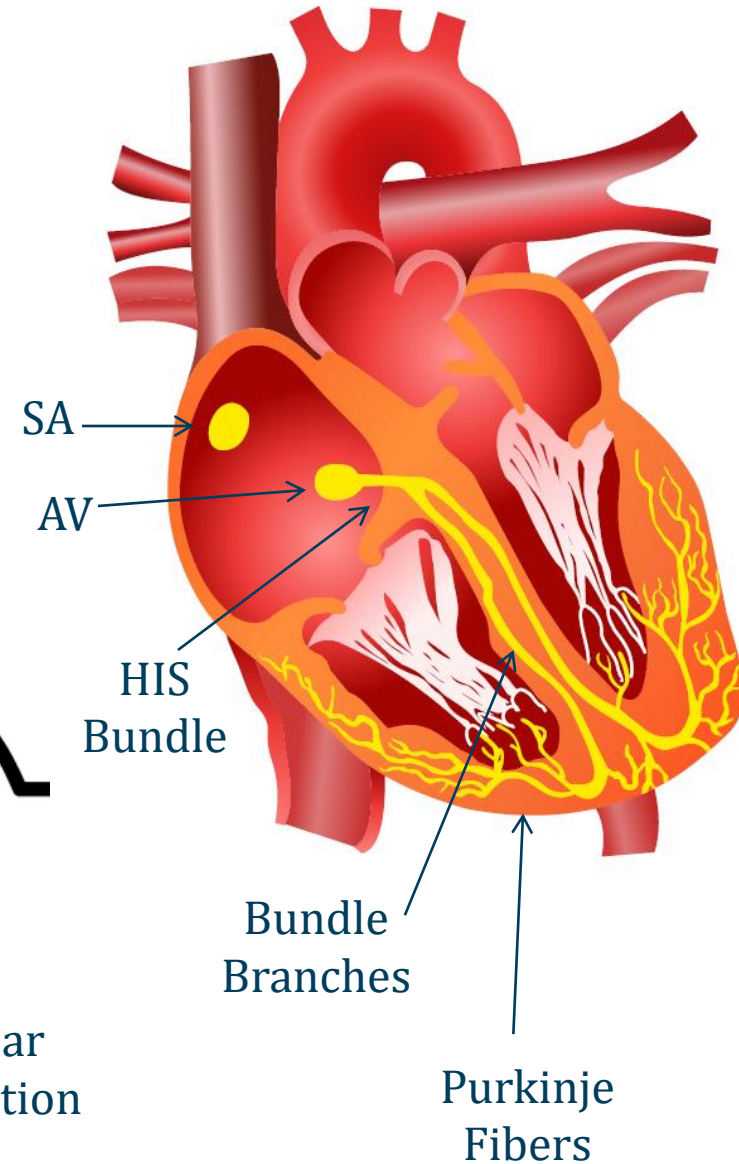
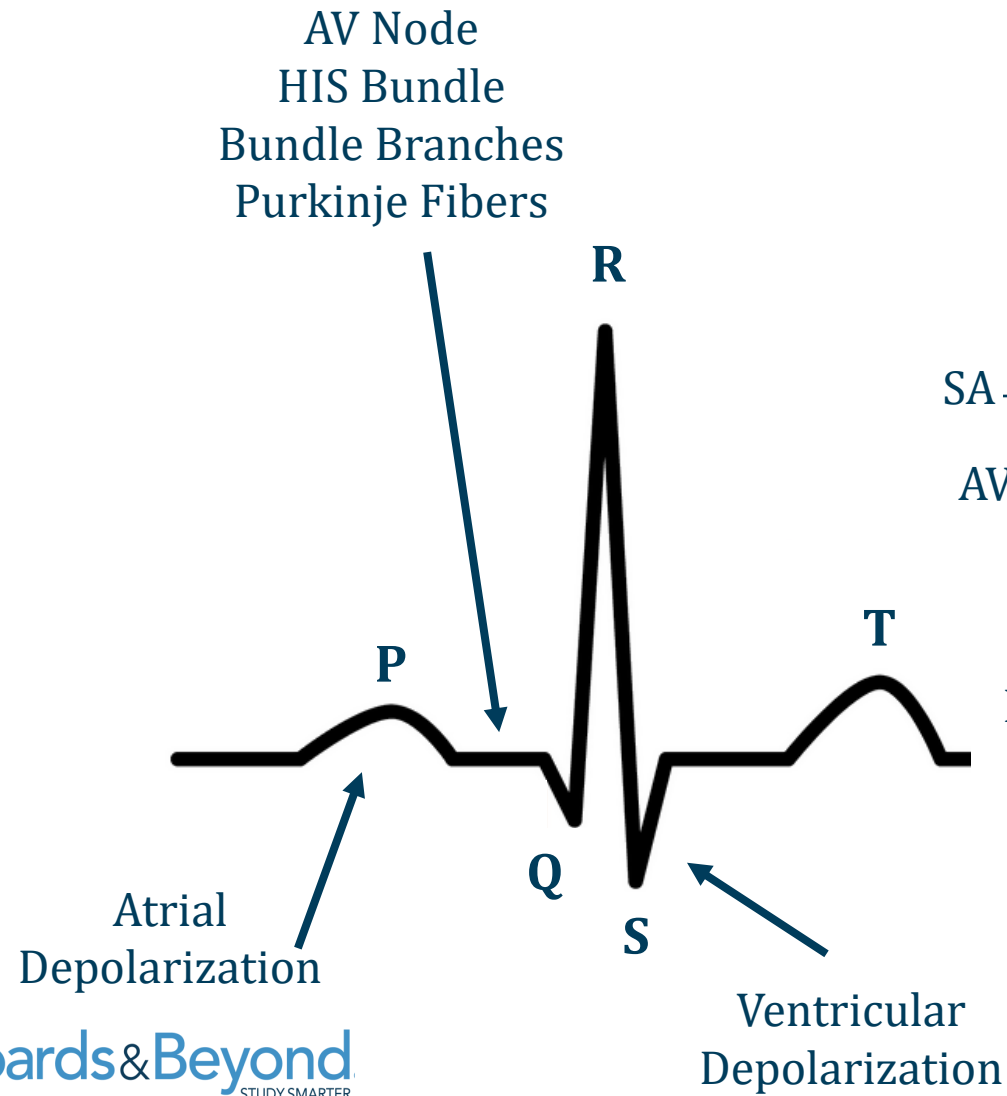
- Slowed or blocked conduction atria → ventricles
- Can cause prolonged PR interval
- Can cause non-conducted p wave



Prolonged PR Interval



Non-conducted P wave





# AV Block

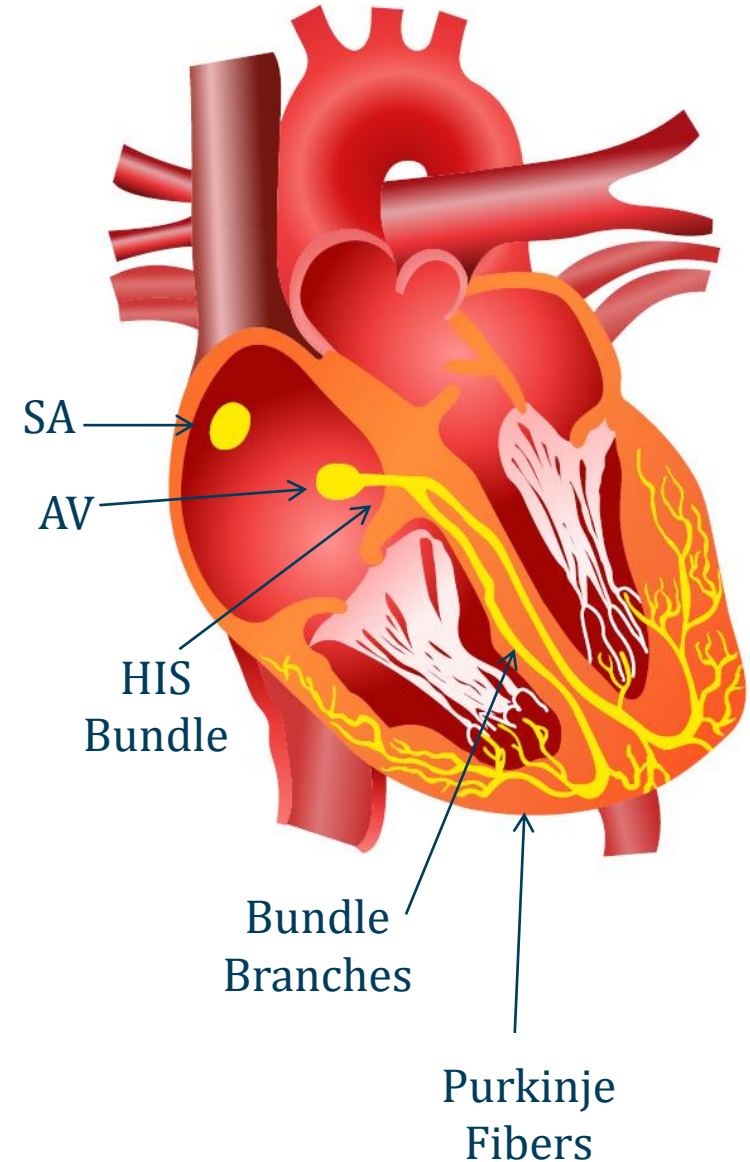
## Symptoms

- Often incidentally noted on EKG
  - Especially milder forms with few/no non-conducted p waves
- Can cause bradycardia symptoms
  - Occurs when many or all p waves not conducted
  - Fatigue, dizziness, syncope
  - Symptomatic AV block often treated with a pacemaker

# AV Blocks

## Anatomy

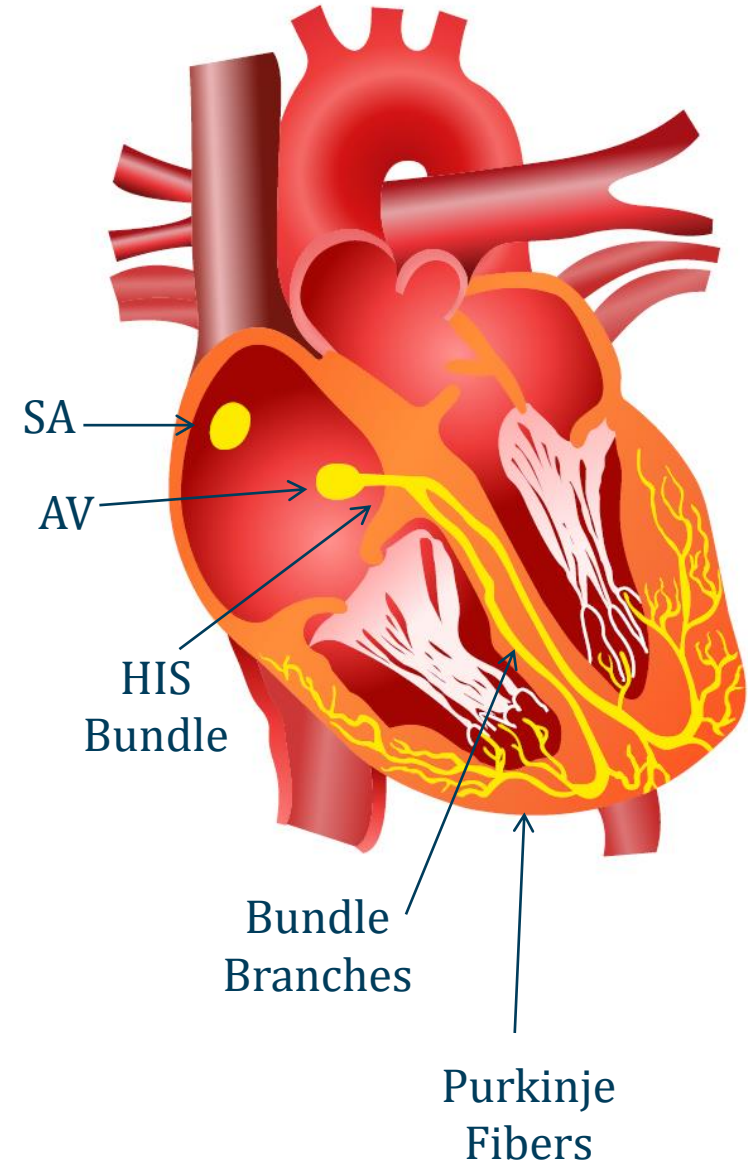
- Caused by disease in AV conduction system
  - AV node → HIS → Bundle Branches → Purkinje fibers
- Divided into two causes
  - **AV node disease**
  - **HIS-Purkinje disease**



# AV Blocks

## Anatomy

- **AV node disease**
  - Usually less dangerous
  - Conduction improves with exertion (sympathetic activity)
- **HIS-Purkinje disease**
  - More dangerous
  - Usually does not improve with exertion
  - Often progresses to complete heart block
  - Often requires a pacemaker



# AV Blocks

## Four Types

- Type 1
  - **Prolongation of PR interval only**
  - All p waves conducted
- Type II
  - **Some p waves conducted**
  - **Some p waves NOT conducted**
  - Two sub-types: Mobitz I and Mobitz II
- Type III
  - **No impulse conduction** from atria to ventricles

# 1<sup>st</sup> degree AV Block



Prolonged PR (normal < 200-210 ms)

**Block usually in AV Node**

Beta-blockers

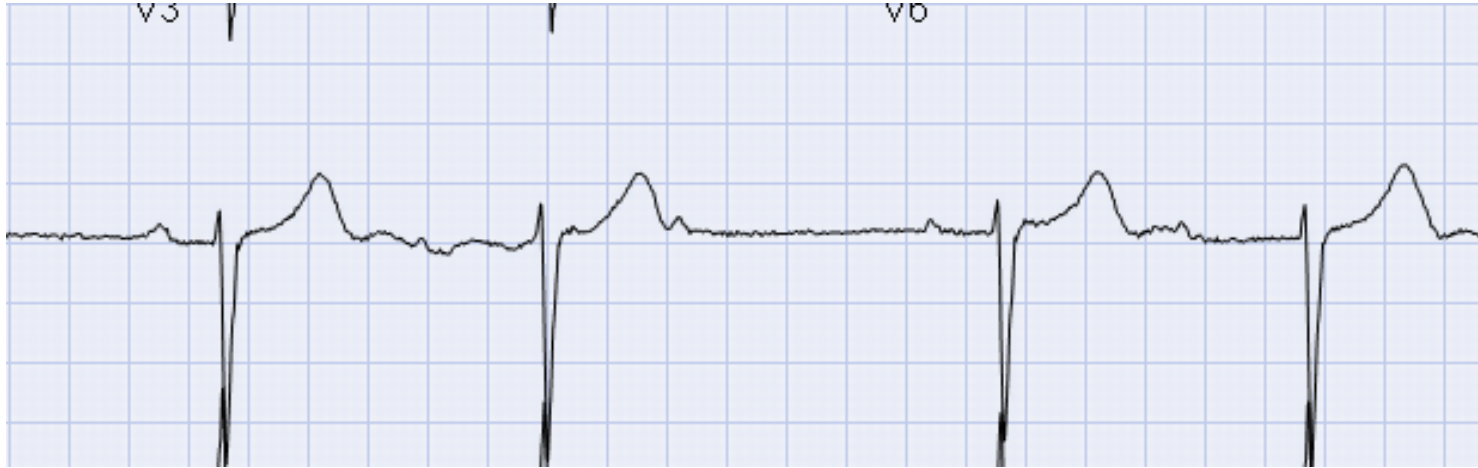
Calcium channel blockers

Well-trained athletes

**Treatment: Usually none**

# 2<sup>nd</sup> degree AVB

Mobitz I/Wenckebach



**Block usually in AV Node**

Progressive PR prolongation

Grouped Beating

RR intervals NOT regular

Similar causes as 1<sup>st</sup> degree AV block

**Treatment: Usually none**

# 2<sup>nd</sup> degree AVB

Mobitz I/Wenckebach



**Block usually in AV Node**

Progressive PR prolongation

Grouped Beating

RR intervals NOT regular

Similar causes as 1<sup>st</sup> degree AV block

**Treatment: Usually none**



# 2<sup>nd</sup> degree AVB

Mobitz II



**Block usually in the HIS-Purkinje System**

Often seen with bundle branch block

Usually symptomatic

Dizziness, syncope

**Treatment: Pacemaker**



# 3<sup>rd</sup> degree AVB



**Block usually in the HIS-Purkinje System**

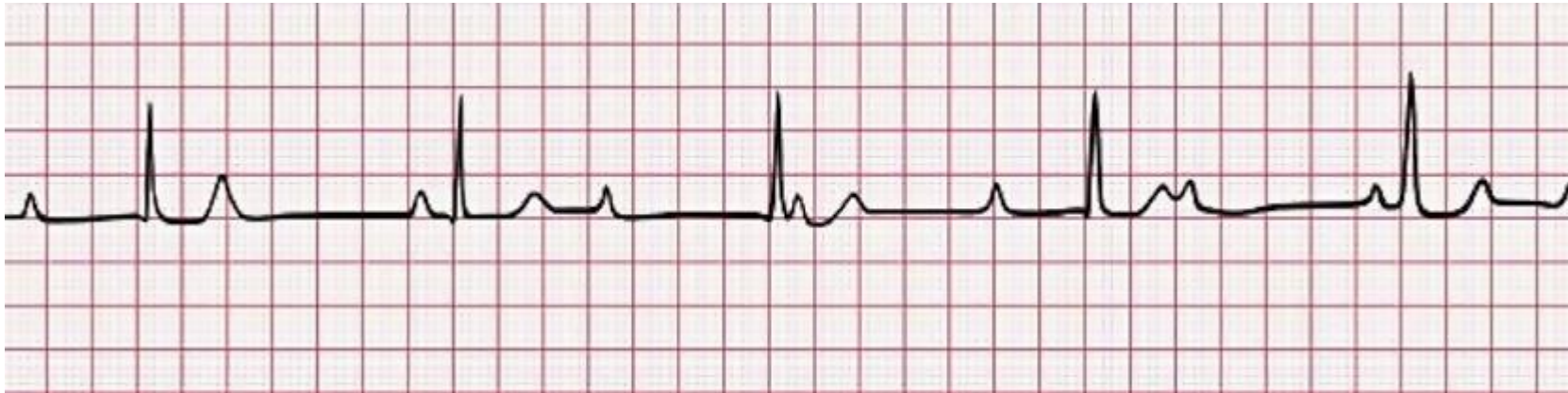
Regular RR intervals excludes Wenckebach

Usually symptomatic

Dizziness, syncope

**Treatment: Pacemaker**

# 3<sup>rd</sup> degree AVB



**Block usually in the HIS-Purkinje System**

Regular RR intervals excludes Wenckebach

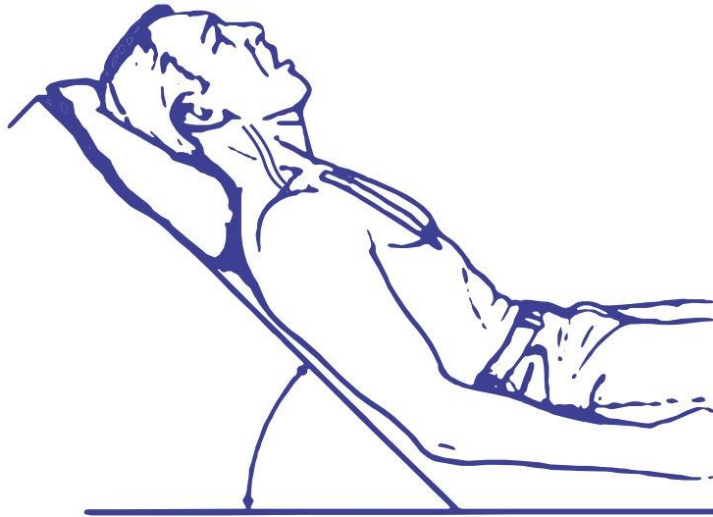
Usually symptomatic

Dizziness, syncope

**Treatment: Pacemaker**

# Cannon a waves

- See in complete heart block (3<sup>rd</sup> degree)
- Caused by atrial contraction with closed tricuspid valve
- Visible as large venous pulsations



# Lyme Disease

- Spirochete infection with **Borrelia burgdorferi**
- Stage 2: Lyme carditis
- Varying degrees of AV block
  - 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup>
- AV block improves with antibiotics



Image courtesy of Wikipedia/Public Domain

# Causes of AV Block

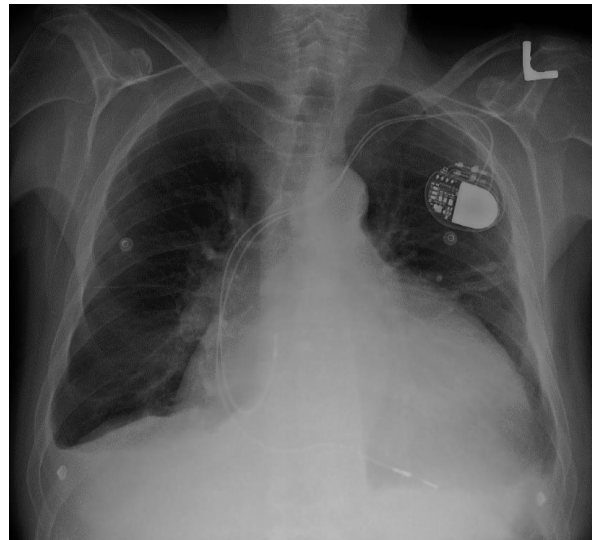
- Drugs
  - Beta-blockers, calcium channel blockers
  - Digoxin
- Athletes
  - At rest: sinus bradycardia plus slow AV node conduction
- **Fibrosis and sclerosis of conduction system**



Flickr/Public Domain

# Pacemaker

- Treatment for sinus node dysfunction
- Also “high-grade” AV block
  - Usually Mobitz II or 3<sup>rd</sup> degree
- Often in patients with symptoms (syncope, dizziness)



# Atrial Fibrillation and Flutter

Jason Ryan, MD, MPH





# Atrial Fibrillation

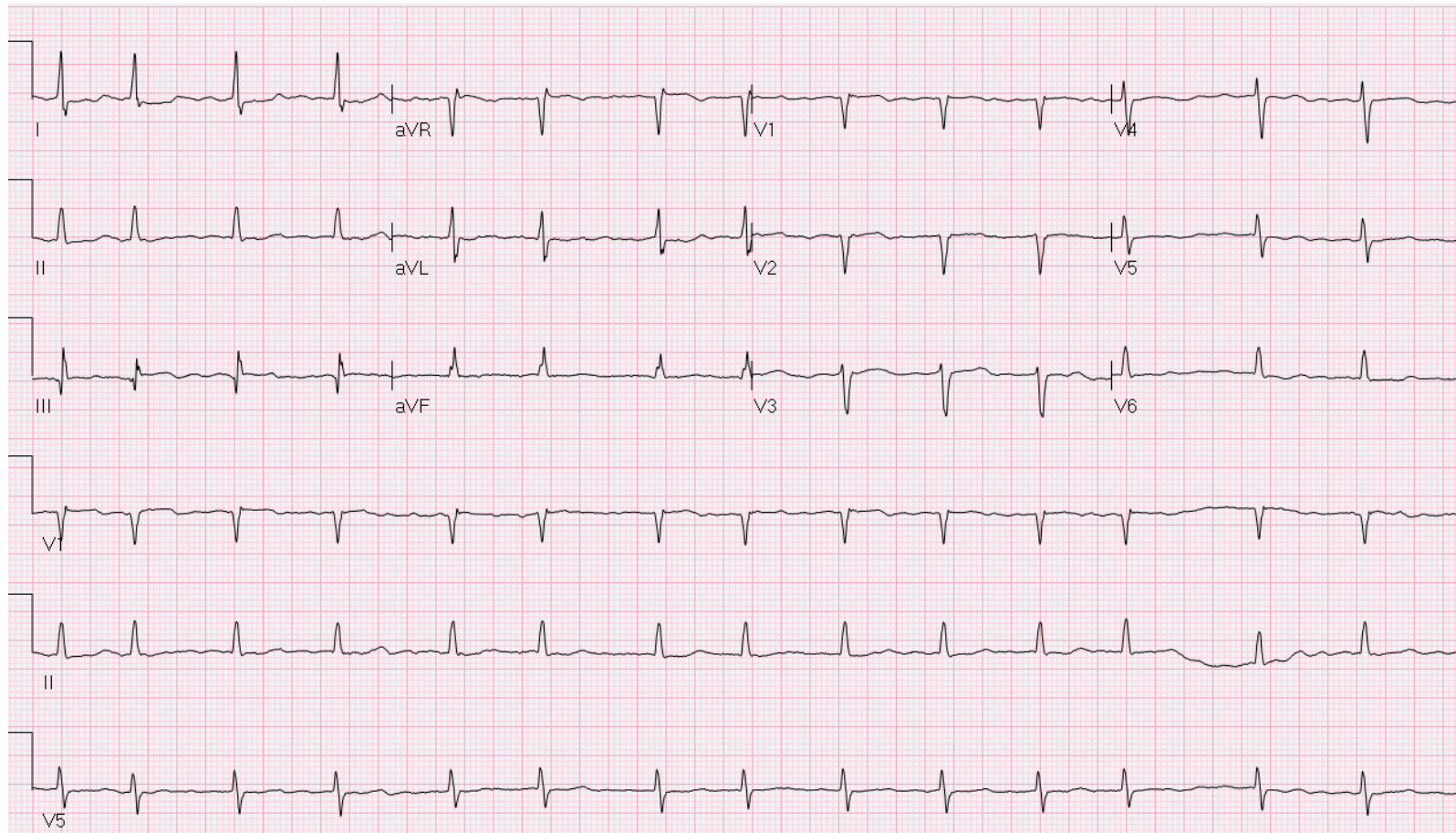
- Cardiac arrhythmia
- Results in an **irregularly, irregular** pulse
- Can cause palpitations, fatigue, dyspnea
- Diagnosis: EKG



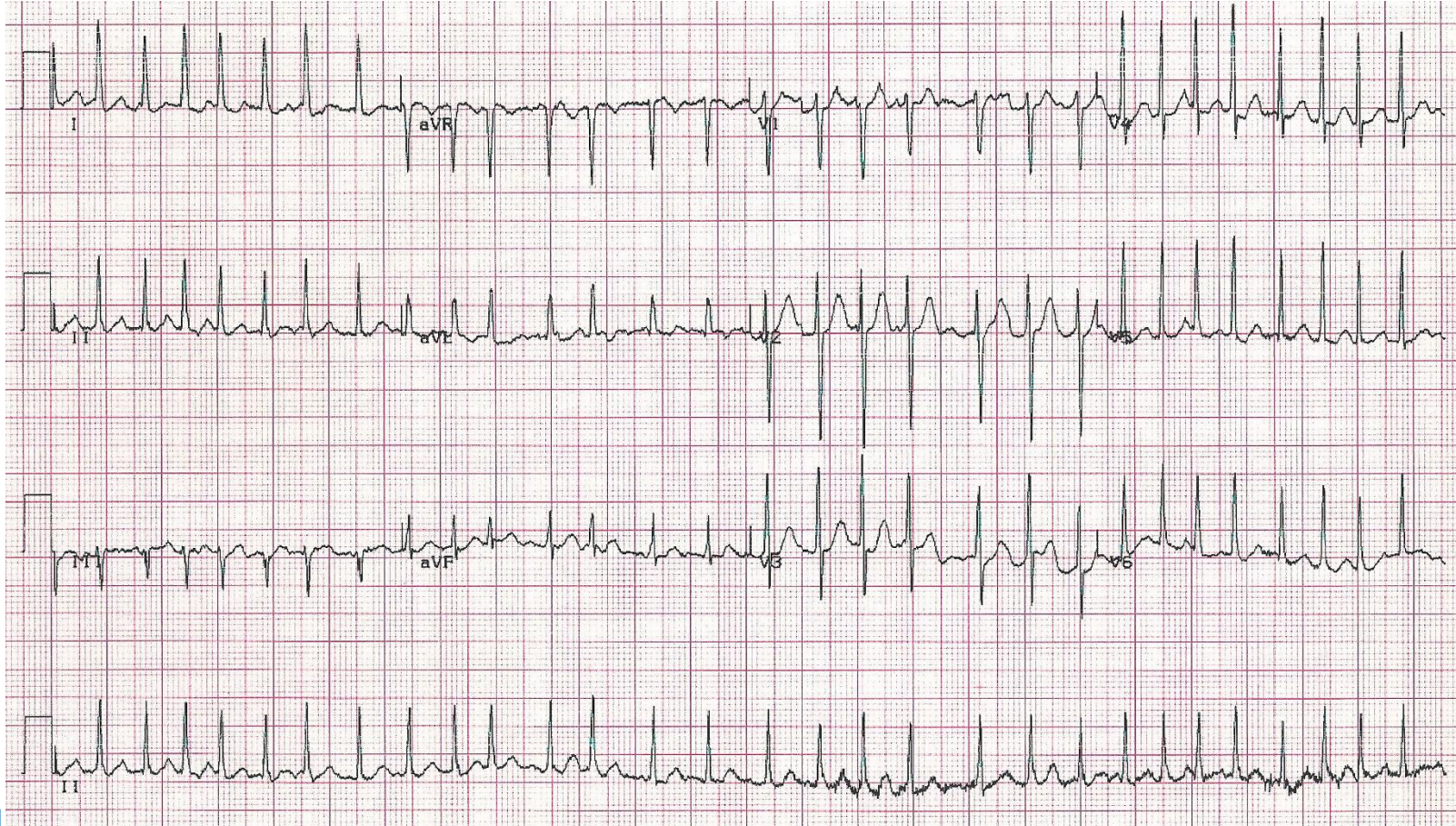
J. Heuser/Wikipedia



# Atrial Fibrillation



# Atrial Fibrillation



# Atrial Fibrillation

## Terminology

- **Paroxysmal**
  - Comes and goes; spontaneous conversion to sinus rhythm
- **Persistent**
  - Lasts days/weeks; often requires cardioversion
- **Permanent**

# Atrial Fibrillation

## Symptoms

- Wide spectrum of symptoms



**Asymptomatic**

Heart Rate < 100 bpm

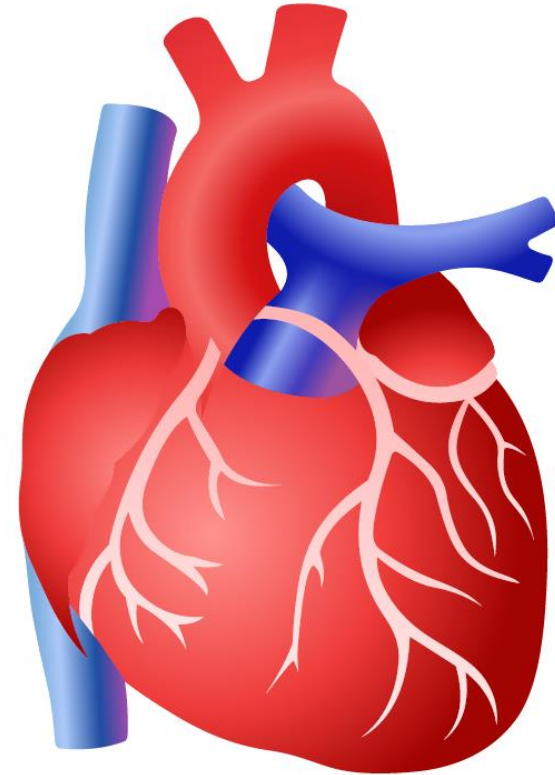
**Palpitations, Dyspnea, Fatigue**

Heart Rate > 100 bpm



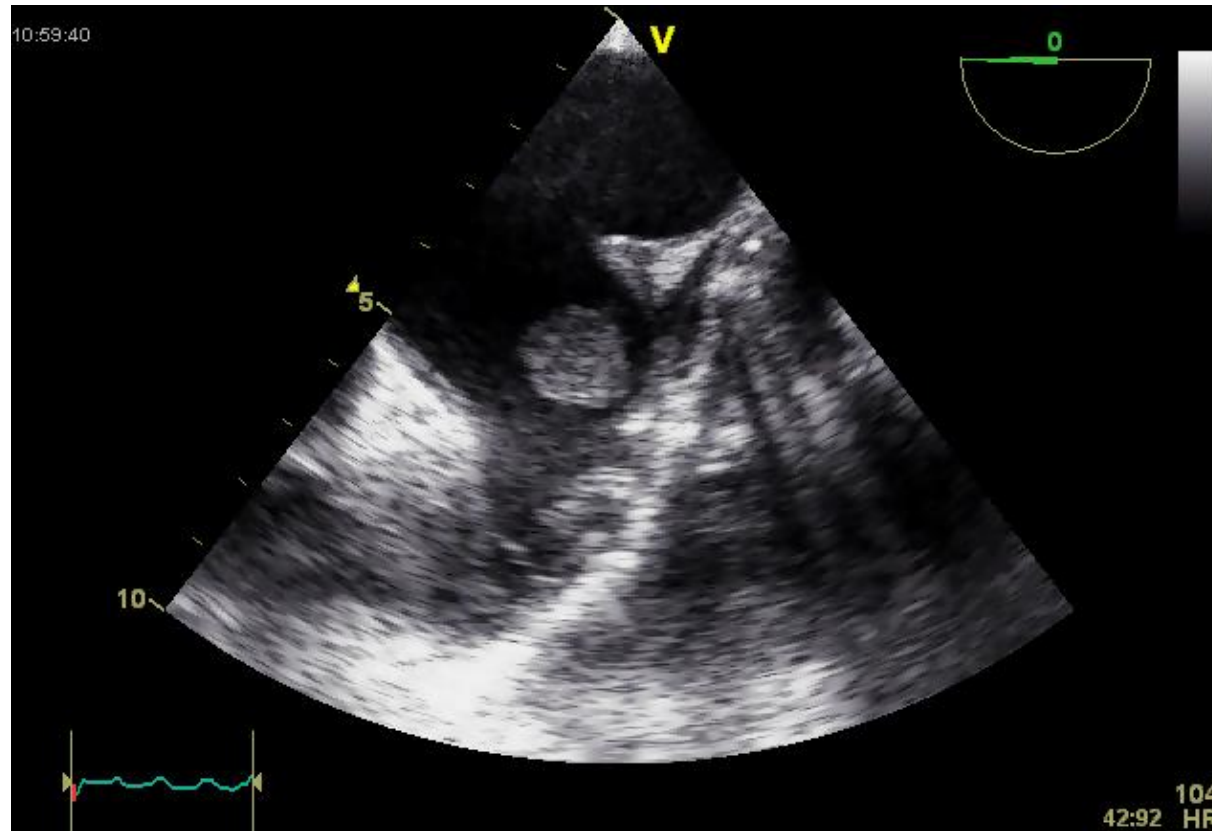
# Cardiomyopathy

- Caused by untreated, **rapid** atrial fibrillation
- “Tachycardia-induced cardiomyopathy”
- ↓ LVEF
- Systolic heart failure



# Atrial Fibrillation

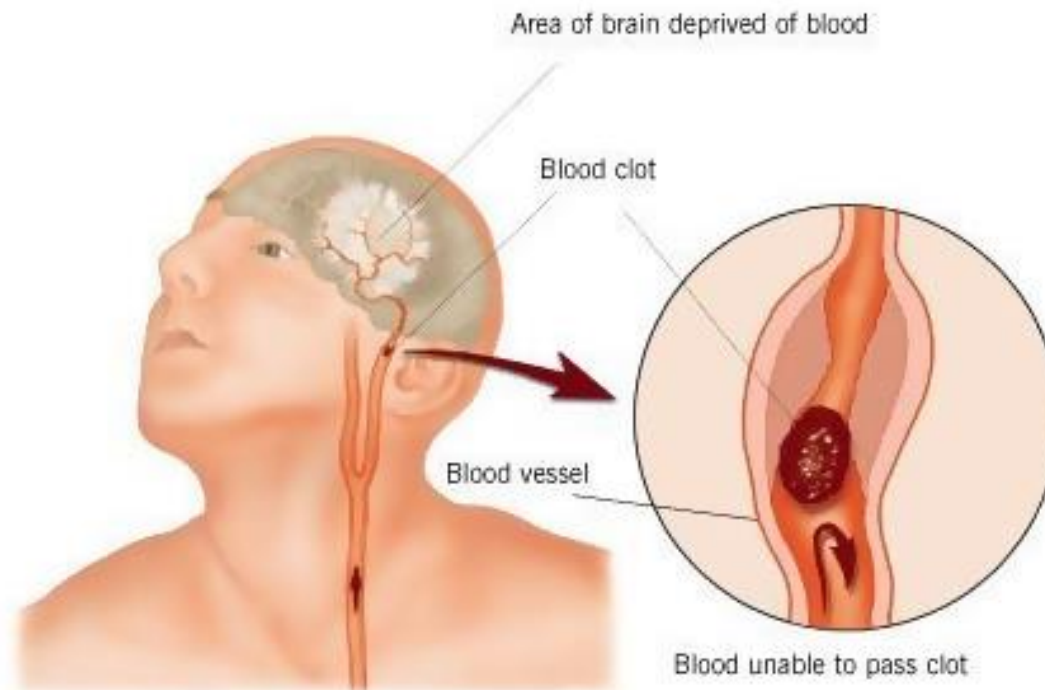
## Thrombus in Left Atrial Appendage



# Atrial Fibrillation

## Cardiac Embolism

- Brain (stroke)
- Gut (mesenteric ischemia)
- Spleen



# Atrial Fibrillation

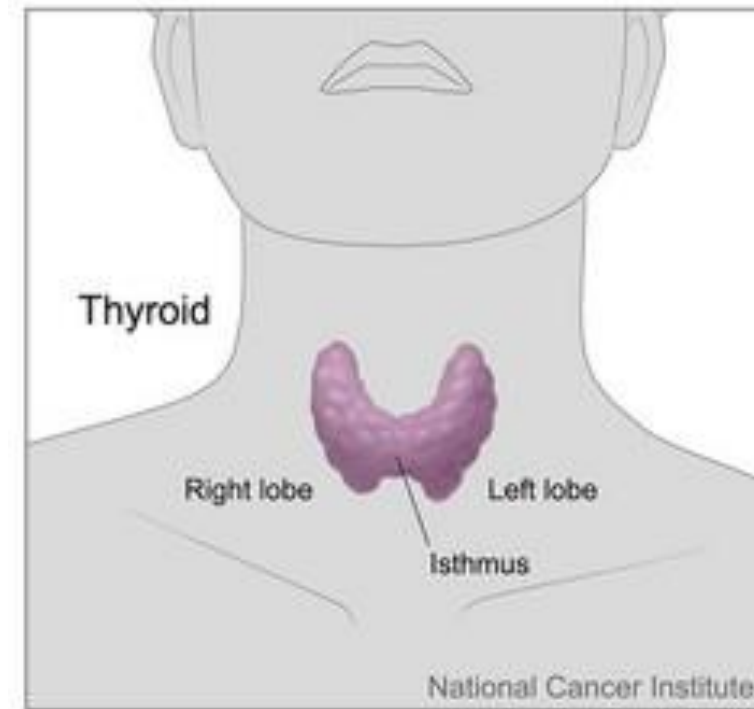
## Risk Factors

- **Age**
  - ~10% of patients > 80
  - < 1% of patients < 55
- More common in women
- Most common associated disorders: **HTN, CAD**
- Anything that dilates the atria → atrial fibrillation
  - Heart failure
  - Valvular disease
- Key diagnostic test: **Echocardiogram**



# Hyperthyroidism

- Commonly leads to atrial fibrillation
- Reversible with therapy for thyroid disease
- Atrial fibrillation therapies less effective
- Key diagnostic test: **TSH**



# Atrial Fibrillation

## Triggers

- Often no trigger identified
- Binge drinking (“holiday heart”)
- Increased catecholamines
  - Infection
  - Surgery
  - Pain



Public Domain

# Atrial Fibrillation

## Treatment

- **Rate control**
  - Control of heart rate
  - Ideally < 110 bpm
- **Rhythm control**
  - Restoration of sinus rhythm
- **Anticoagulation**

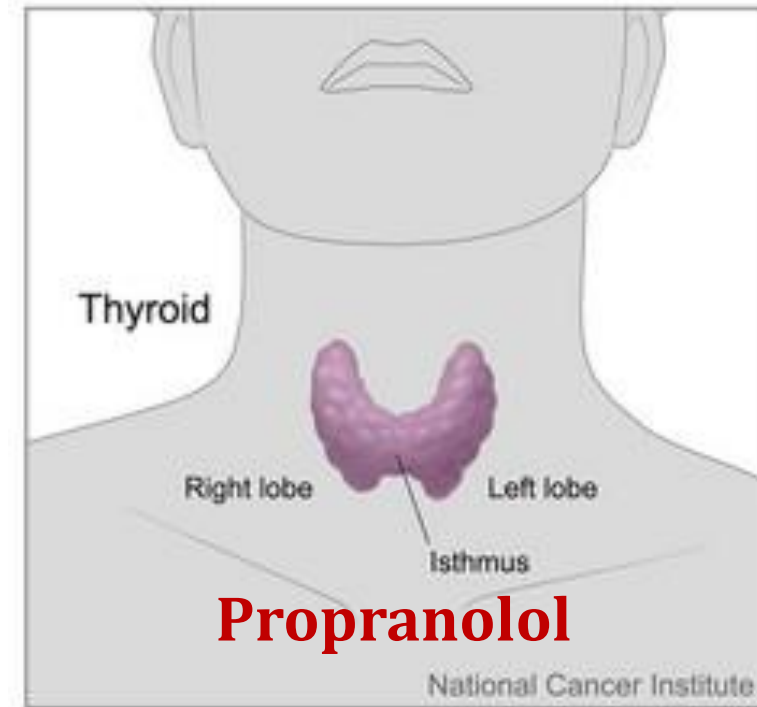
# Rate Control



Beta Blockers  
Calcium Channel Blockers  
Digoxin

# Rate Control

- **Slow AV node conduction**
- Beta-blockers
  - Usually  $\beta_1$ -selective agents
  - Metoprolol, Atenolol
  - Hyperthyroid patients: propranolol
- Calcium channel blockers
  - Verapamil, Diltiazem
- Digoxin
  - Increases parasympathetic tone to heart



# Rhythm Control

- Goal: restore sinus rhythm



**Cardioversion**

# Cardioversion

- **Electrical**
  - Deliver “synchronized” shock at time of QRS
  - Administer anesthesia
  - Deliver electrical shock to chest
  - All myocytes depolarize
  - Usually sinus node first to repolarize/depolarize



# Cardioversion

- **Chemical**
  - Administration of antiarrhythmic medication
  - Often Ibutilide (class III antiarrhythmic)
  - Less commonly used due to drug toxicity



# Cardioversion

- **Spontaneous**
  - Often occurs after hours/days



# Cardioversion

## Risk of Stroke

- Chemical/electrical cardioversion may cause stroke
- 48 hours required for thrombus formation
- Symptoms < 48 hours: cardioversion safe
- Symptoms > 48 hours (or unsure)
  - Anti-coagulation 3 weeks → cardioversion
  - Transesophageal echocardiogram to exclude thrombus
- Exception: Hypotension/shock
  - Emergent cardioversion performed

# Rhythm Control

- **Antiarrhythmic medications**
- Administered before/after cardioversion
- Class I drugs
  - Flecainide, propafenone
- Class III drugs
  - Amiodarone, sotalol, dofetilide
- AFFIRM trial: no mortality difference between rate and rhythm control

# Stroke Prevention

- Warfarin
  - Requires regular INR monitoring
  - Goal INR usually 2-3
- Rivaroxaban, Apixaban
  - Factor Xa inhibitors
- Dabigatran
  - Direct thrombin inhibitor
- Aspirin
  - Less effective
  - Only used if risk of stroke is very low
  - Less risk of bleeding

# Anticoagulation

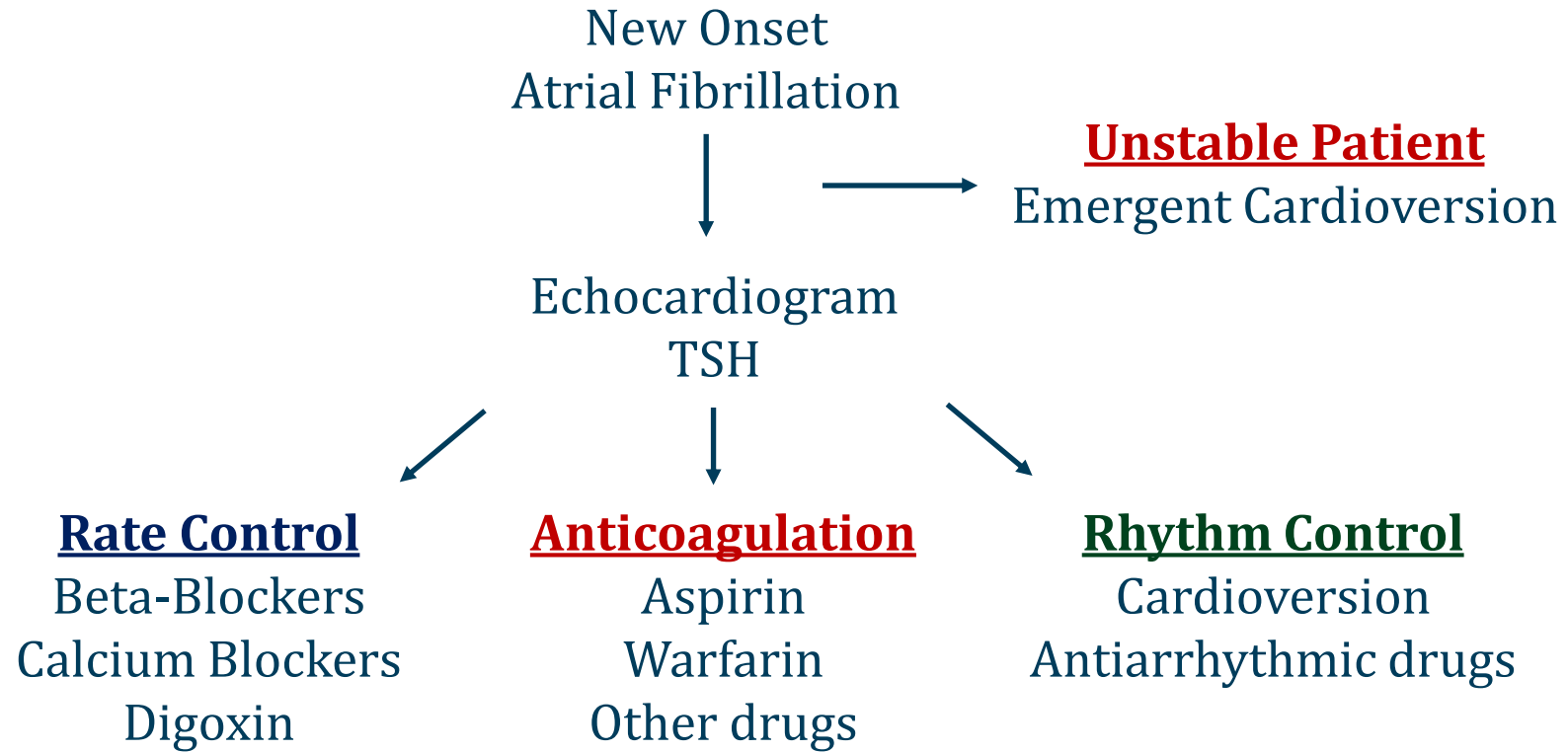
- Anticoagulation MUST be administered
- Does not matter whether atrial fibrillation persists, or sinus rhythm restored
- Studies show similar stroke risk for rate control versus rhythm control

# Stroke Risk

- **CHADS VASC Score**
  - CHF (1 point)
  - HTN (1 point)
  - Diabetes (1 point)
  - Stroke (2 points)
  - Female (1 point)
  - Age 65-75 (1 point)
  - Age > 75yrs (2 points)
  - Vascular disease (1 point)
- Score  $\geq 2$  = Warfarin or other anticoagulant
- Score 0 -1 = Aspirin or no therapy

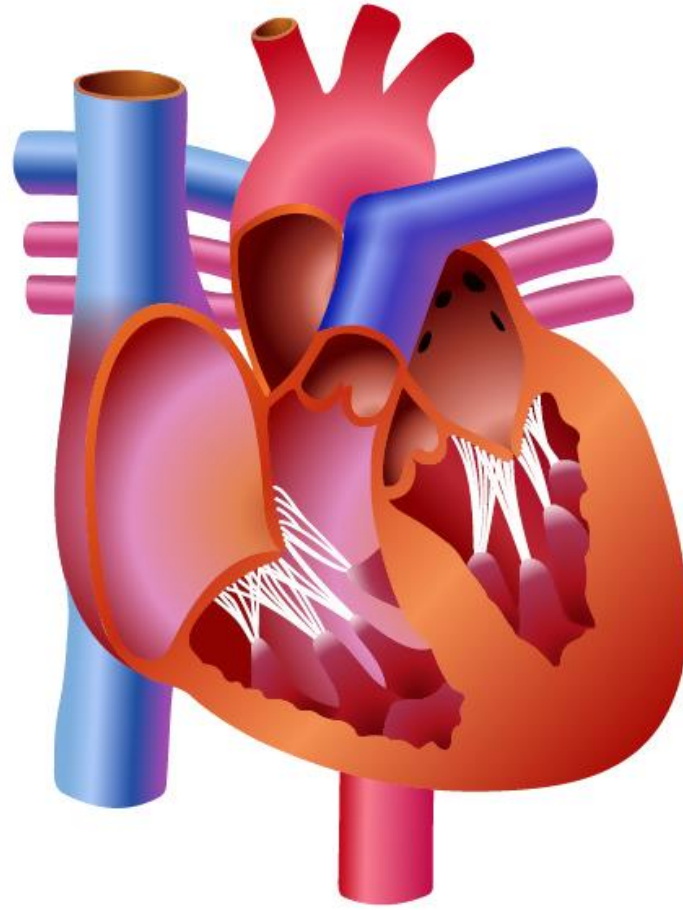
# Atrial Fibrillation

## Summary



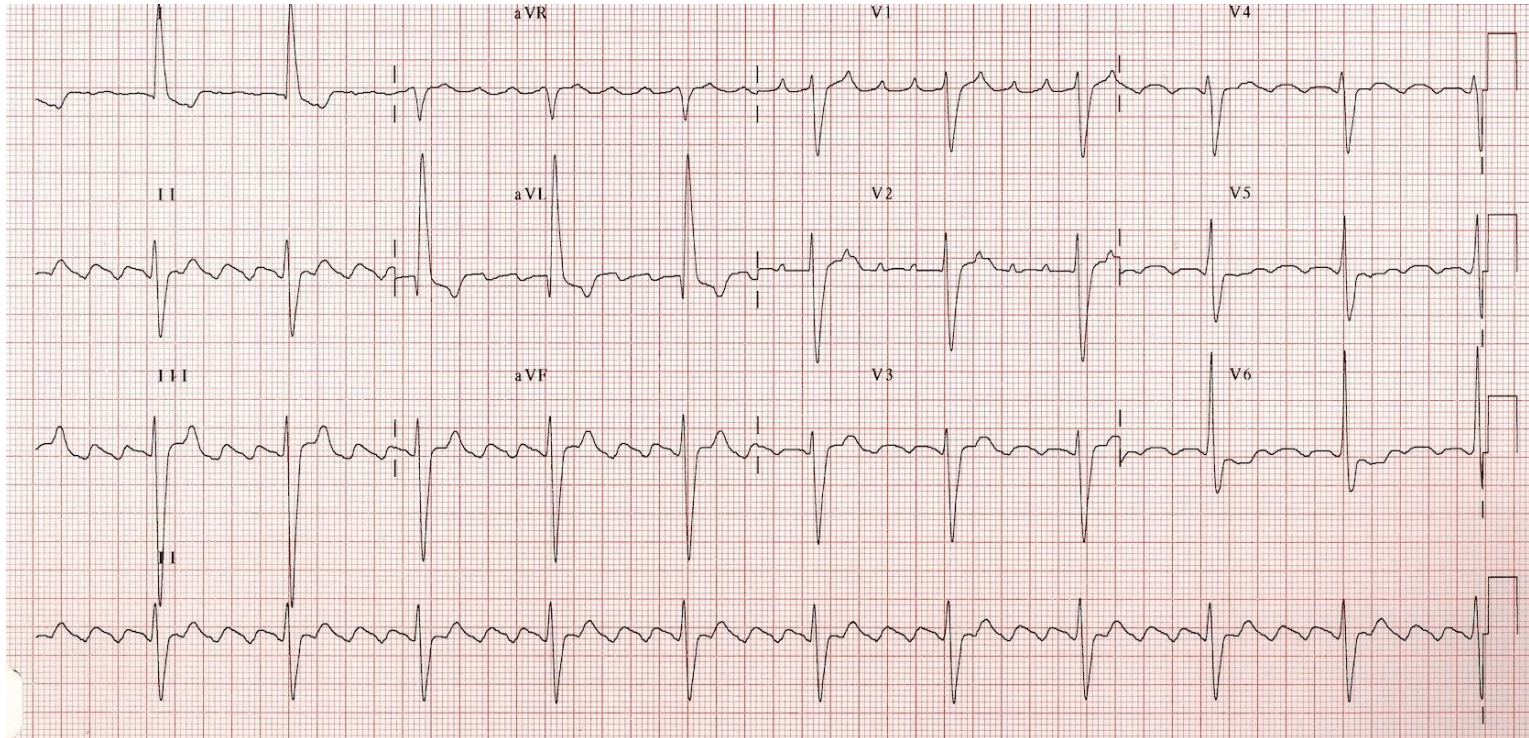
# Pulmonary Vein Isolation

Surgical Therapy for Atrial Fibrillation





# Atrial Flutter

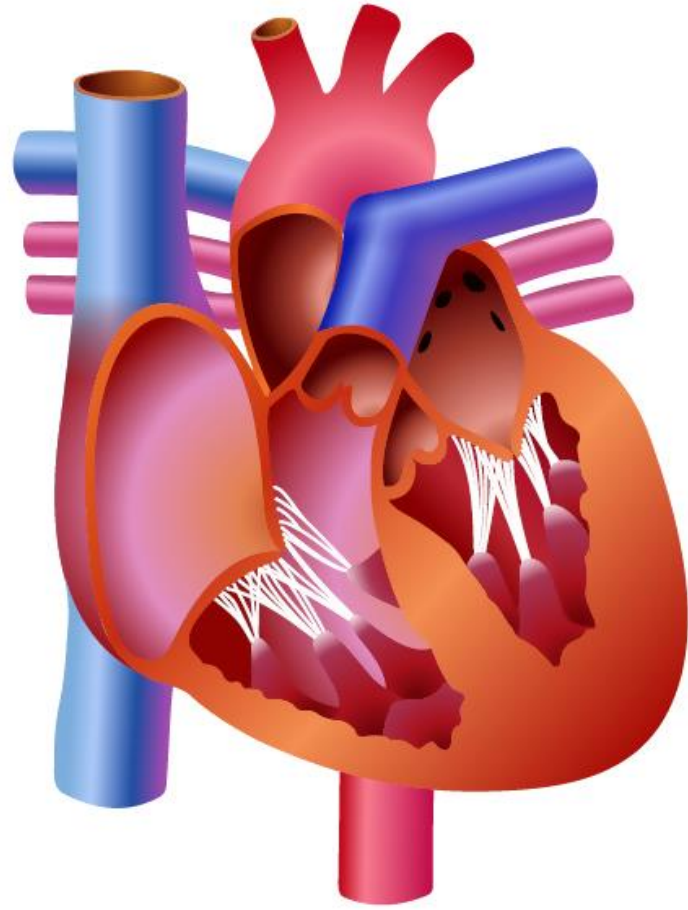


# Atrial Flutter

## Symptoms

- Symptoms
  - Generally the same as atrial fibrillation
  - May be asymptomatic
  - Palpitations, dyspnea, fatigue
- Treatment
  - Generally the same as atrial fibrillation
  - Rate or rhythm control
  - Rate-slowing drugs
  - Cardioversion
  - Anticoagulation based on stroke risk

# Atrial Flutter Ablation



# ACLS and Tachycardias

Jason Ryan, MD, MPH



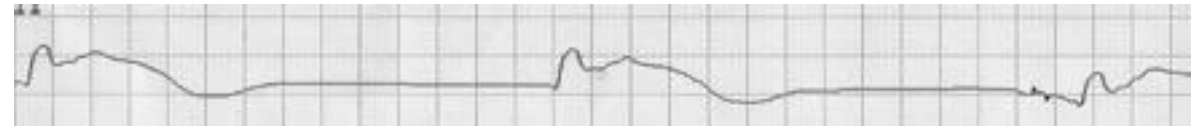
# Cardiac Arrest

- Sudden cessation of cardiac activity with hemodynamic collapse
- Usually associated with one of four underlying cardiac rhythms

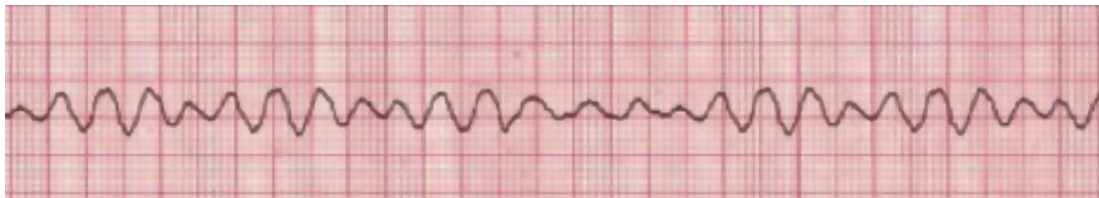
Ventricular Tachycardia



Pulseless Electrical Activity



Ventricular Fibrillation



Asystole





# ACLS

## Advanced cardiac life support

- Clinical algorithm for treatment of life-threatening cardiac emergencies
- Applied to unresponsive patients



Public Domain

# ACLS

## Advanced cardiac life support

- Unresponsive, pulseless patient → call for help
- Start chest compressions (CPR)
- Apply oxygen
- Attach monitor and defibrillator



# ACLS

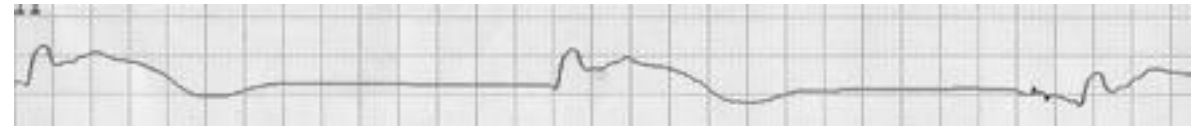
## Advanced cardiac life support

- Is the rhythm shockable?
- YES if ventricular tachycardia or fibrillation
- NO if PEA or asystole

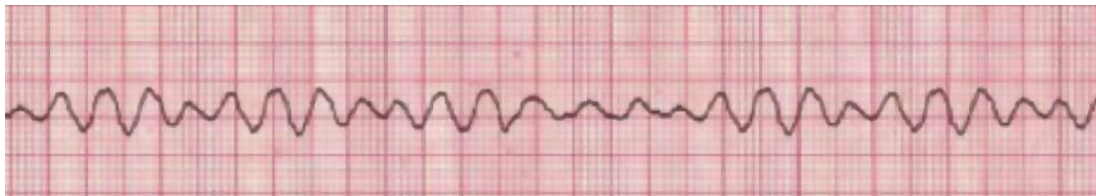
Ventricular Tachycardia



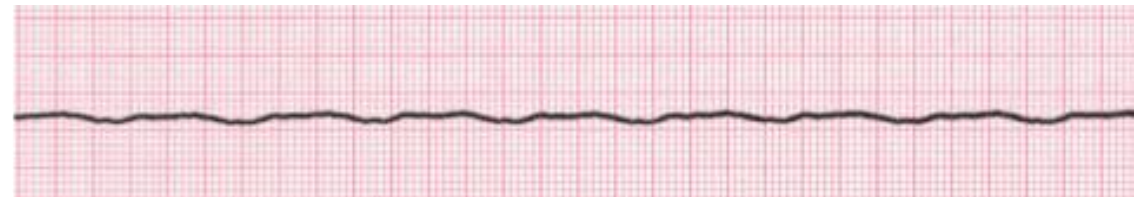
Pulseless Electrical Activity



Ventricular Fibrillation



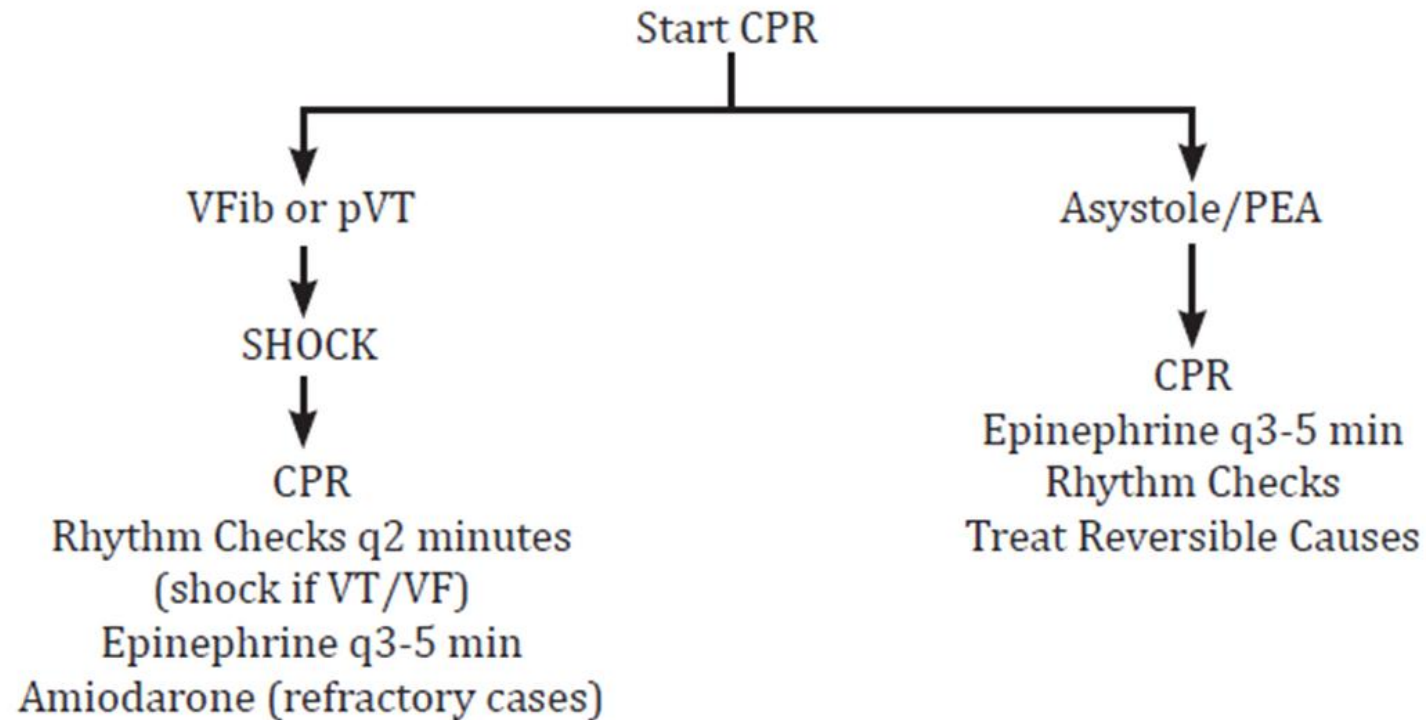
Asystole





# ACLS

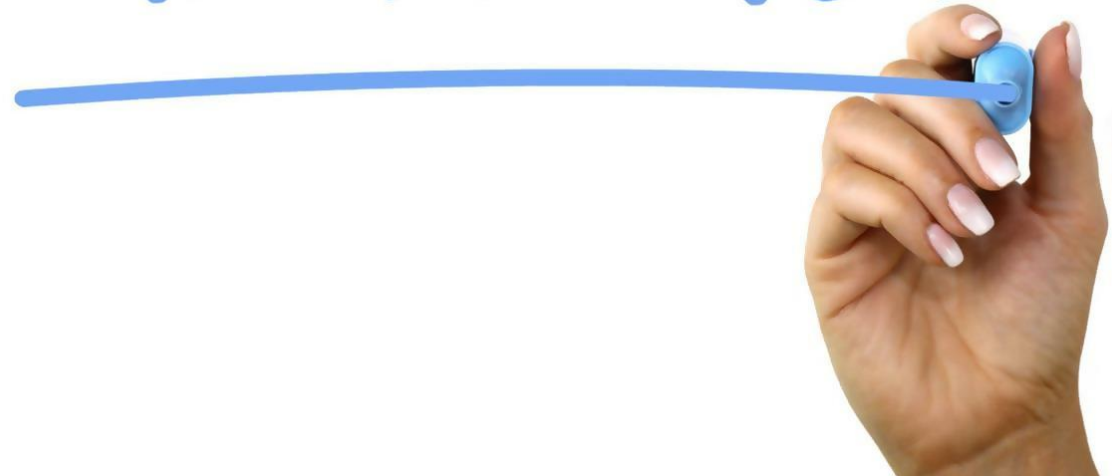
## Advanced cardiac life support



# Reversible Causes

- Hypovolemia
- Hypoxia
- Acidosis
- Hypo/hyperkalemia
- Hypothermia
- Myocardial infarction
- Tension pneumothorax
- Cardiac tamponade
- Pulmonary embolism

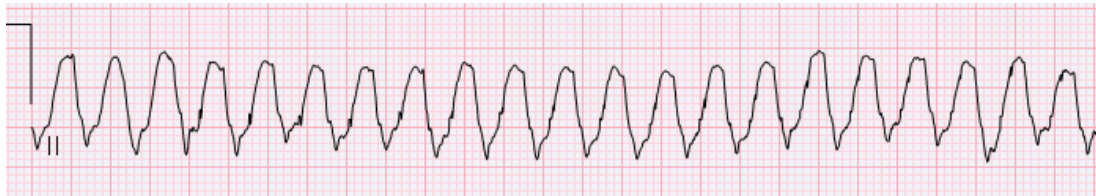
REVERSE



# Stable Ventricular Tachycardia

- Pulse intact
- Patient remains awake
- No evidence of hemodynamic compromise (hypotension, chest pain)
- **Intravenous amiodarone**
  - Alternatives: lidocaine or procainamide
- Do not perform cardioversion while patient is conscious

Ventricular Tachycardia



# Polymorphic Ventricular Tachycardia

- Subtype of ventricular tachycardia
- Continuously varying QRS complex morphology
- Caused by multiple foci of QRS complexes within the ventricle
- Unstable rhythm that often leads to cardiac arrest
- Almost always caused by **myocardial ischemia**

Polymorphic Ventricular Tachycardia

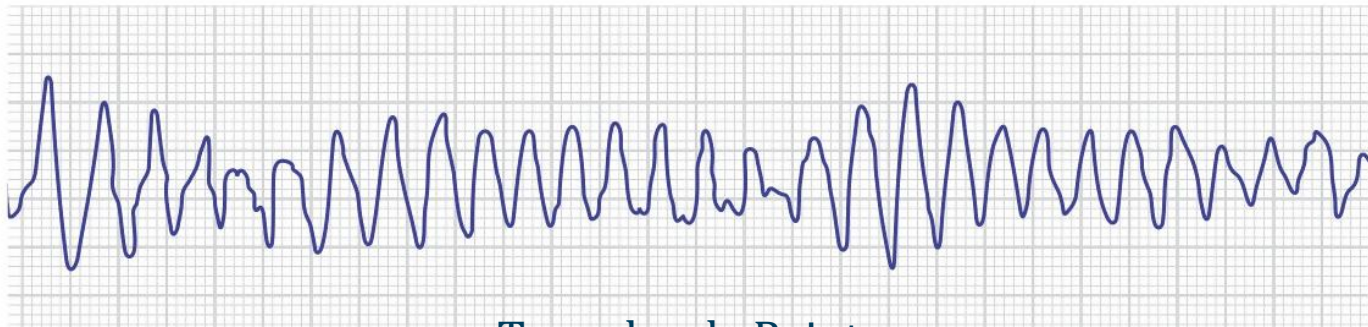


Monomorphic Ventricular Tachycardia



# Torsades de Pointes

- Polymorphic ventricular tachycardia that occurs with **prolonged QT segment**
- Specific subtype of polymorphic ventricular tachycardia
- Urgent defibrillation indicated in hemodynamically unstable patients
- For patients with recurrent episodes: **IV magnesium sulfate**



Torsades de Pointes



Prolonged Qt Interval

# Out-of-Hospital Cardiac Arrest

- **Time to resuscitation:** strongest predictor of survival
  - Short time: good survival
  - Long time: poor prognosis
- Other poor prognostic signs
  - Initial PEA or asystole
  - Prolonged CPR > 5 minutes
  - Advanced age



Pxhere/Public Domain

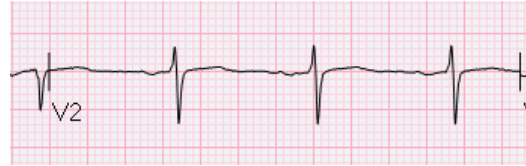
# Tachycardias

## Unstable Patients

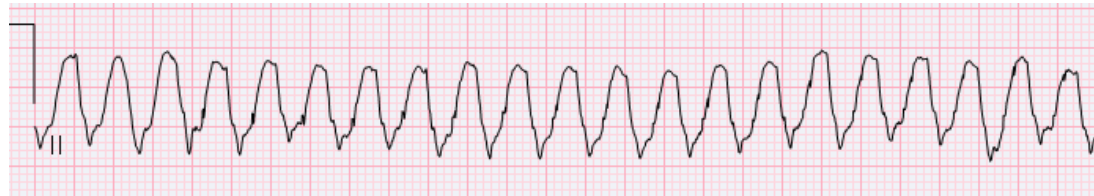
- Hemodynamic instability: hypotension, chest pain or respiratory distress
- Often associated with tachycardia
- Tachycardia may be cause or consequence of hemodynamic instability
- Key distinction: **wide versus narrow QRS complex**

# QRS Interval

Normal QRS



Ventricular Tachycardia



Right Bundle Branch Block



Left Bundle Branch Block





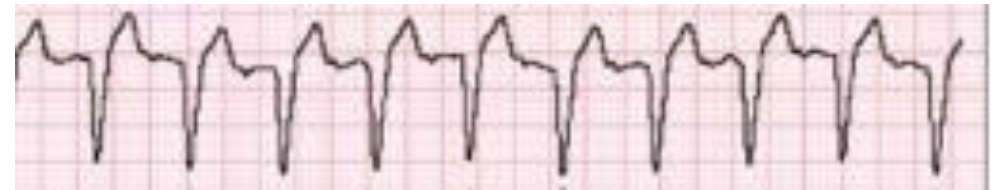
# Wide Complex Tachycardias

- Rapid heart rate with wide QRS complex ( $> 120$  ms)
- Differentiation based on ECG
  - Ventricular tachycardia
  - SVT with aberrancy (LBBB, RBBB)
- **Sudden onset/unstable WCT: shock**

Ventricular Tachycardia



Sinus Tachycardia with LBBB



# Narrow Complex Tachycardias

- Rapid heart rate with narrow/normal QRS complex (<120ms)
- Electrical rhythm originating above the ventricle
  - Sinus node, atrial, AV node
  - “Supraventricular tachycardias” or SVTs
- Many causes
  - Sinus tachycardia
  - Atrial fibrillation/flutter
  - Atrial tachycardia
  - AVNRT
- Treatment based on underlying cause
- **Sudden onset/unstable SVT: shock**

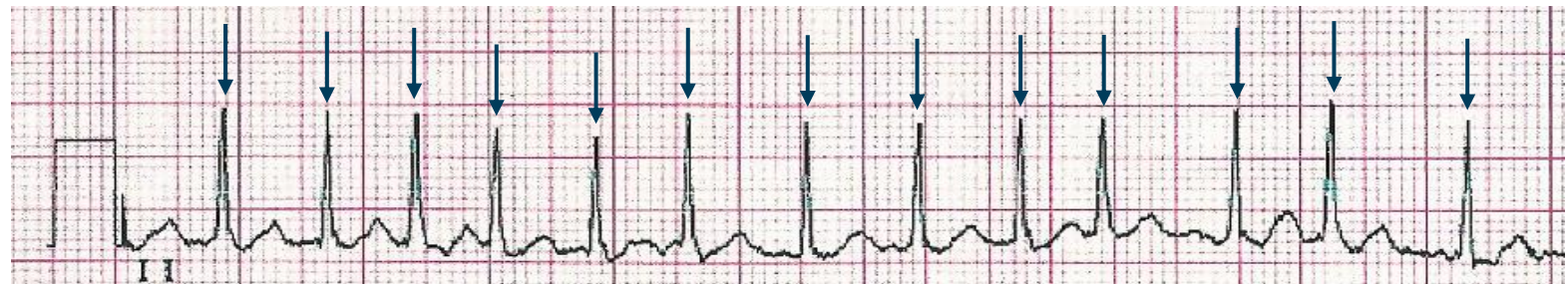
Narrow Complex Tachycardia



# Electrical Cardioversion

- Unsynchronized
  - High energy shock delivered immediately
  - Used for ventricular fibrillation and pulseless ventricular tachycardia
- Synchronized
  - Low energy shock synchronized to occur during QRS complex
  - Avoids shock during T wave which can cause ventricular fibrillation
  - Used for SVT (atrial fibrillation, flutter)
- **Unstable SVT: *synchronized* cardioversion**

Rapid Atrial Fibrillation

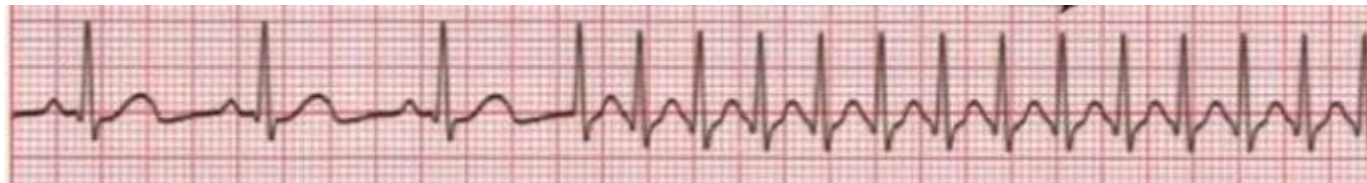


# PSVT

## Paroxysmal Supraventricular Tachycardia

- Subtype of SVT
- **Regular**, supraventricular rhythm with **abrupt onset**
- Often causes **palpitations**
- May cause chest discomfort
- Rarely syncope or hypotension

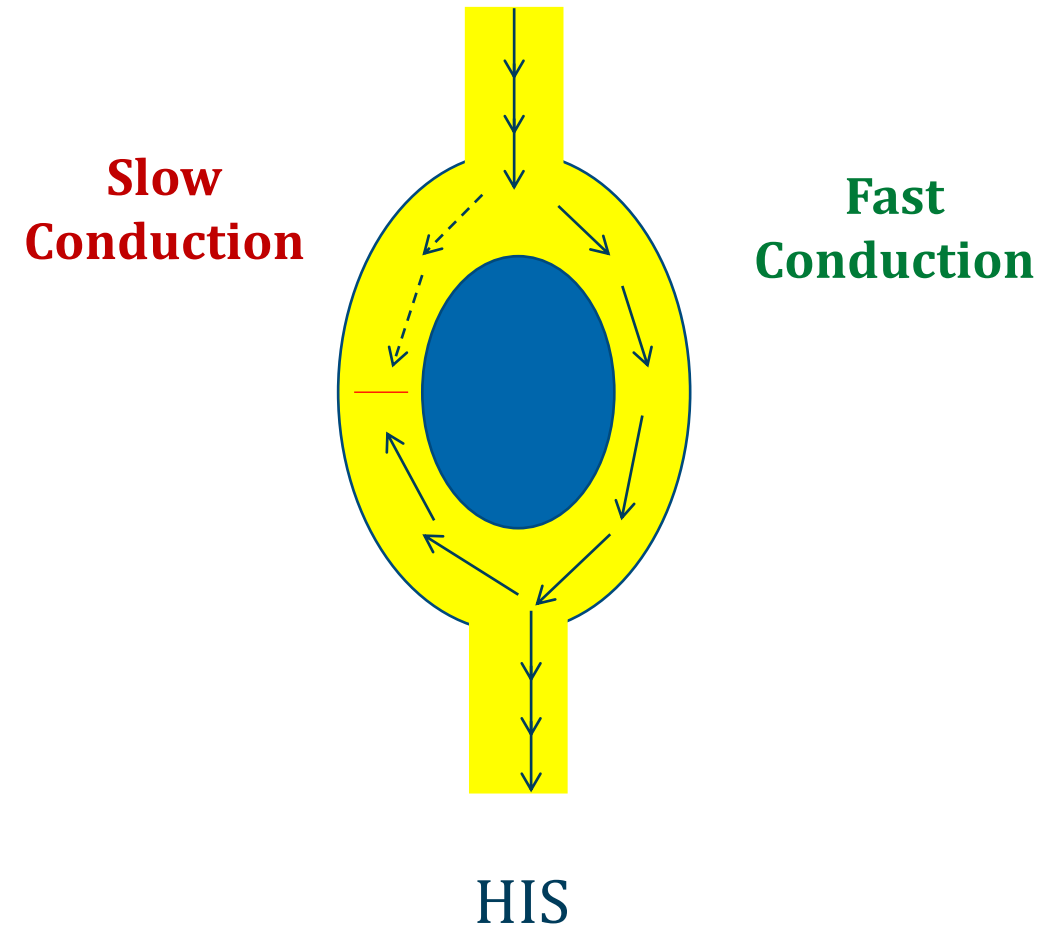
PSVT



# AVNRT

Atrioventricular nodal reentrant tachycardia

- **Most common cause of PSVT**
- More common in young women
- Mean age onset: 32-years-old
- Requires **dual AV nodal pathways**



# Retrograde P Waves

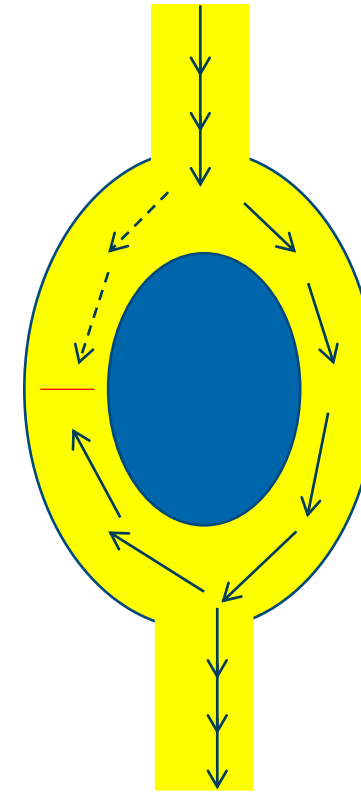


# AVNRT

- Recurrent episodes of palpitations
- Episodes usually spontaneously resolve
- **↓ conduction in AV node breaks arrhythmia**
  - Will halt conduction in slow pathway
- Carotid massage
- Vagal maneuvers
- Adenosine

**Slow  
Conduction**

**Fast  
Conduction**



HIS

# Carotid Massage

- Examiner presses on neck near carotid sinus
- **Stretch of baroreceptors**
- CNS response as if **high blood pressure**
- Increased vagal tone
- ↓ AV node conduction

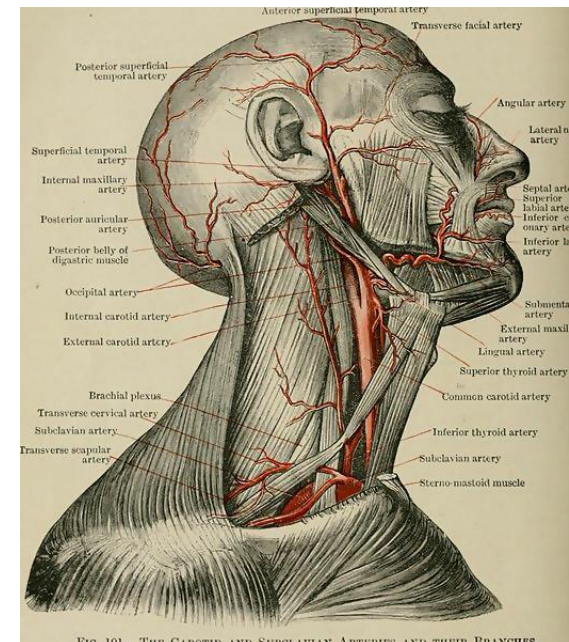


FIG. 101.—THE CAROTID AND SUBCLAVIAN ARTERIES AND THEIR BRANCHES.



# Vagal Maneuvers

- **Valsalva**
  - Patient bears down as if moving bowels
  - Increased thoracic pressure
  - Aortic pressure rises → ↓ heart rate and AV conduction
- Breath holding
- Coughing
- Deep respirations
- Gagging
- Swallowing

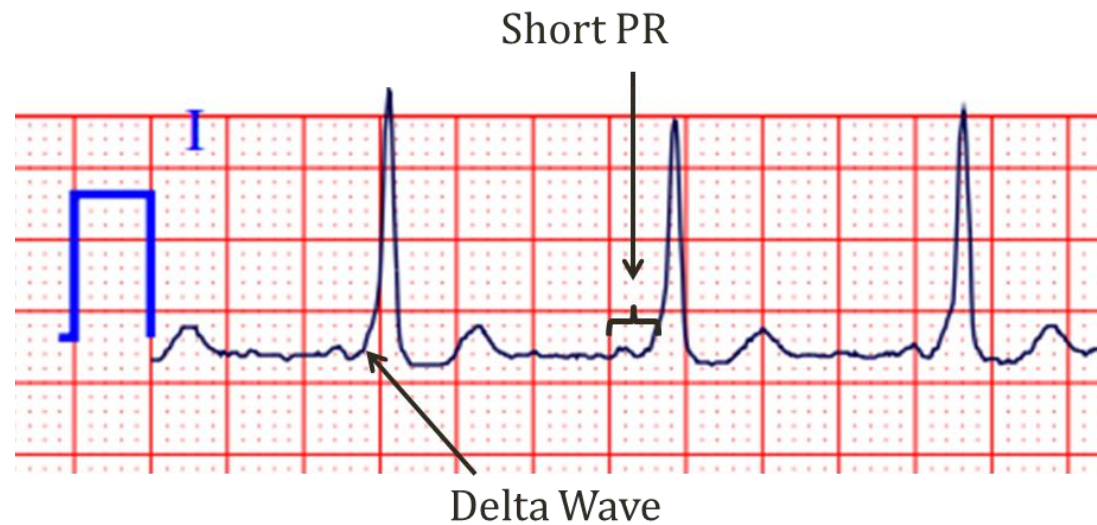
# AVNRT

## Chronic Treatment

- Many patients need no therapy
- Beta-blockers, Verapamil/Diltiazem
  - Slow conduction in slow pathway
- Surgical ablation of slow pathway

# AVRT

- AV node reentrant tachycardia
- Different from AVNRT
- Requires a bypass tract (WPW syndrome)
- Suspect in patients with SVT and prior EKG with delta wave



# Hyperlipidemia

Jason Ryan, MD, MPH



# Lipid Measurements

- Total Cholesterol
- LDL
- HDL
- Triglycerides

# LDL Cholesterol

- **“Bad” cholesterol**
- Associated with CV risk
- < 100 mg/dl very good
- > 200 mg/dl high
- Evidence that treating high levels reduces risk

# HDL Cholesterol

- **“Good” cholesterol**
- Inversely associated with risk
- < 45mg/dl low
- Little evidence that raising low levels reduces risk

# Triglycerides

- Normal TG level < 150mg/dl
- Levels > 1000 can cause **pancreatitis**
- Elevated TG levels modestly associated with CAD
- Little evidence that lowering high levels reduces risk



# Hyperlipidemia

- Elevated total cholesterol, LDL or triglycerides
- Risk factor for **coronary disease and stroke**
- Modifiable – often related to lifestyle factors
  - Sedentary lifestyle
  - Saturated and trans-fatty acid foods
  - Lack of fiber

# Secondary Hyperlipidemia

Selected Causes of Hyperlipidemia
Alcohol
Pregnancy
Beta-blockers
HCTZ
Thyroid disease
Nephrotic syndrome

# Hyperlipidemia

## Treatment

- **Lifestyle modification** recommended for all patients
  - Healthy diet, weight loss, quit smoking
- Major clinical decision is related to **statin therapy**



Wikimedia Commons

# Hyperlipidemia

## Treatment

- **Moderate-intensity statins**
  - Many choices
  - Atorvastatin 10 to 20 mg/day
  - Rosuvastatin 5 to 10 mg/day
  - Simvastatin 20 to 40 mg/day
- **High-intensity statins**
  - Atorvastatin 40 to 80 mg/day
  - Rosuvastatin 20 to 40 mg/day



Wikimedia Commons

# Hyperlipidemia

## Treatment

Indication	Statin
CAD, Stroke or PAD	High-intensity
LDL > 190 mg/dL	High-intensity
Diabetics > 40 years old	Moderate- or High-Intensity
ASCVD Risk > 7.5% over 10 years	Moderate- or High-Intensity

# Hyperlipidemia

## Treatment

Age (years)	<input type="text" value="40-79"/>
Gender	<input checked="" type="radio"/> Male <input type="radio"/> Female
Race	<input type="radio"/> African American <input checked="" type="radio"/> Other
Total cholesterol (mg/dL)	<input type="text" value="130-320"/>
HDL cholesterol (mg/dL)	<input type="text" value="20-100"/>
Systolic blood pressure (mmHg)	<input type="text" value="90-200"/>
Diastolic blood pressure (mmHg)	<input type="text" value="30-140"/>

Treated for high blood pressure	<input checked="" type="radio"/> No <input type="radio"/> Yes
Diabetes	<input checked="" type="radio"/> No <input type="radio"/> Yes
Smoker	<input checked="" type="radio"/> No <input type="radio"/> Yes
<input type="button" value="Calculate"/>	

2.2%

10-year risk of heart disease or stroke

# Hyperlipidemia

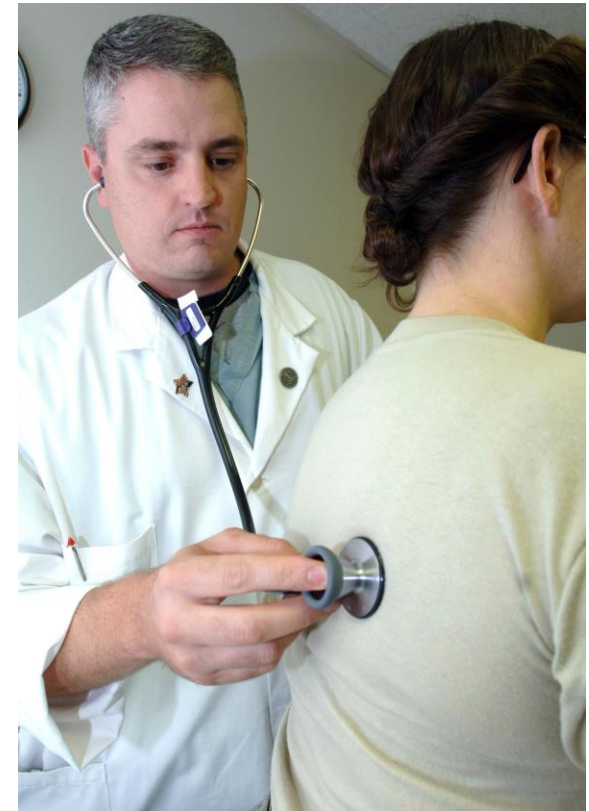
## Treatment

- Treatment goal usually  $< 100$  mg/dL
- For patients with known vascular disease goal often  $< 70$  mg/dL



# Signs of Hyperlipidemia

- Most patients have **no signs/symptoms**
- Physical findings occur in patients with severe  $\uparrow$  lipids
- Usually familial syndrome

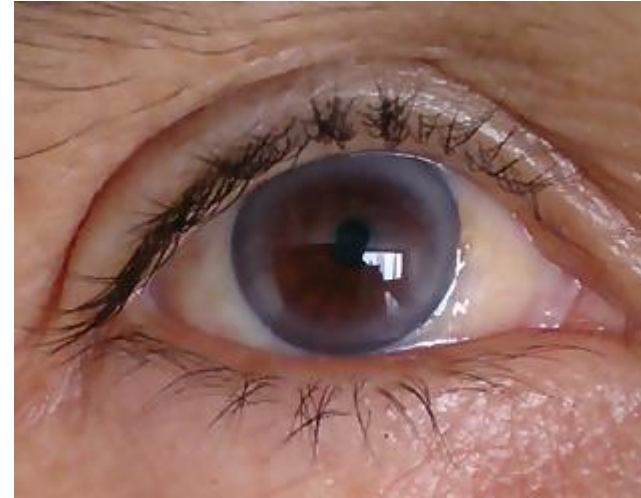


Wikipedia/Public Domain



# Signs of Hyperlipidemia

- Xanthomas
  - Plaques of lipid-laden cells
  - Appear as skin bumps or on eyelids
- Tendinous Xanthoma
  - Lipid deposits in tendons
  - Common in Achilles
- Corneal arcus
  - Lipid deposit in cornea
  - Ring around iris



Wikipedia/Public Domain



Min.neel/Wikipedia



Klaus D. Peter, Gummersbach, Germany

# Familial Dyslipidemias

Type	Name	Mxn	Clinical
I (AR)	Hyperchylomicronemia	LPL Deficiency	Trigs up → Pancreatitis
IIa (AD)	Hypercholesterolemia	LDL-R Def.	Elevated cholesterol (LDL)
III (AR)	Dysbetalipoproteinemia	APO-E Def.	Atherosclerosis
IV (AD)	Hypertriglyceridemia	VLDL Overpdx	Trigs up → Pancreatitis

# Type I Dyslipidemia

## Hyperchylomicronemia

- **↑↑↑ triglycerides ( > 1000; milky plasma appearance)**
- LPL deficiency or dysfunction
- **Recurrent pancreatitis**
- Enlarged liver, xanthomas
- Treatment: **very low-fat diet**
  - Reports of normal lifespan
  - No apparent ↑risk atherosclerosis

# Type II Dyslipidemia

## Familial Hypercholesterolemia

- Autosomal dominant
- Few or zero LDL receptors
- **Very high LDL ( > 300 heterozygote; > 700 homozygote)**
- Tendon xanthomas, corneal arcus
- **Severe atherosclerosis (can have MI in 20s)**

# Type III Dyslipidemia

## Familial Dysbetalipoproteinemia

- Mutations of **apolipoprotein E gene**
- Poorly lipid particle cleared by liver
  - Accumulation of chylomicron remnants and VLDL
  - Collectively know as  $\beta$ -lipoproteins
- Elevated total cholesterol and triglycerides
- Usually mild (TC > 300 mg/dl)
- Xanthomas
- **Premature coronary disease**

# Type IV Dyslipidemia

## Hypertriglyceridemia

- Autosomal dominant
- VLDL overproduction or impaired catabolism
- **↑TG (200-500)**
- ↑VLDL
- Associated with diabetes type II
- Often diagnosed on routine screening bloodwork
- Increased coronary risk/premature coronary disease

# Lipid-Lowering Therapy

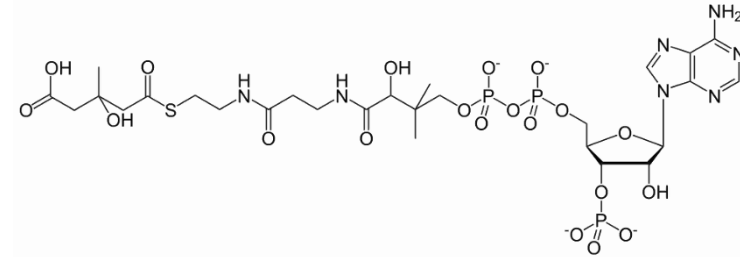
- Statins
- Niacin
- Fibrates
- Absorption blockers
- Bile acid resins
- PCSK9 Inhibitors
- Omega-3 fatty acids

# Statins

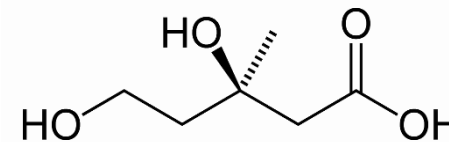
Lovastatin, Atorvastatin, Simvastatin

- HMG-CoA reductase inhibitors
- ↓cholesterol synthesis in liver
- ↑LDL receptors in liver
- **Major effect: ↓ LDL decrease**
  - Some ↓TG, ↑HDL
- **Excellent outcomes data (↓MI/Death)**
- Adverse effects:
  - Hepatotoxicity (↑ AST/ALT)
  - Muscle problems

3-hydroxy-3-methylglutaryl-coenzyme A  
HMG-CoA



**HMG-CoA  
Reductase**



Mevalonate



# Statin Muscle Problems

- Myalgias
  - Weakness, soreness
  - Normal CK levels
- Myositis
  - Like myalgias, increased CK
- Rhabdomyolysis
  - Weakness, muscle pain, dark urine
  - CKs in 1000s
  - Acute renal failure → death
  - ↑ risk with some drugs (gemfibrozil, P450 inhibitors)



Wikipedia/Public Domain

# P450

- Most statins metabolized by liver P450 system
  - Examples: atorvastatin, simvastatin and lovastatin
  - Exceptions: ravastatin and rosuvastatin
- Potential interactions with other drugs
- P450 inhibitors increase **↑ risk LFTs/myalgias**
  - Cyclosporine
  - Macrolide antibiotics
  - Azole antifungal agents
  - HIV protease inhibitors
  - Grapefruit juice



Citrus\_paradisi/Wikipedia

# Niacin

- Complex, incompletely understood mechanism
- Overall effect: LDL ↓↓ **HDL ↑↑**
  - ↓ HDL breakdown
  - Often used when HDL is low

Supplement Facts		
Serving Size: 8 fl oz (240 ml)		
Serving Per Container: About 2		
Amount Per Serving		%DV*
Calories	120	
Total Carb	29g	10%
Sugars	28g	†
Riboflavin	1.7mg	100%
Niacin	20mg	100%
Vitamin B6	2mg	100%
Vitamin B12	6mcg	100%
Sodium	120mg	5%
Protein	1g	
Ginseng Extract	200mg	†
Energy Blend	3000mg	†
Taurine, L-Carnitine, Caffeine, Guarana, Inositol, Glucuronolactone, Maltodextrin		
Percent Daily Values (DV) are based on a 2,000 calorie diet. †Daily Value not Established		

# Niacin

- Major side effects is **flushing**
  - Stimulates release of prostaglandins in skin
  - **Face** turns red, warm
  - Can blunt with **aspirin** (inhibits prostaglandin) prior to Niacin
  - Fades with time



# Niacin

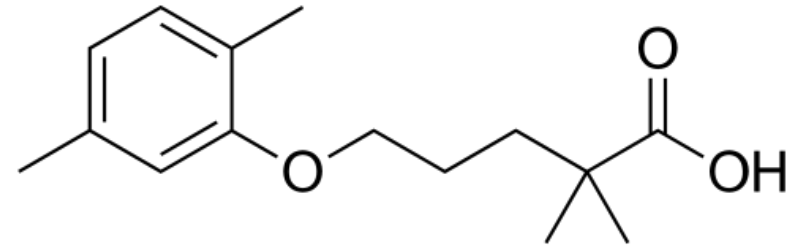
- Hyperglycemia
  - Insulin resistance (mechanism incompletely understood)
  - Avoid in diabetes
- Hyperuricemia



# Fibrates

Gemfibrozil, clofibrate, bezafibrate, fenofibrate

- Activate **PPAR-a**
  - Modifies gene transcription
  - ↑ activity lipoprotein lipase
  - ↑ liver fatty acid oxidation
- Major overall effect → TG breakdown
- Used for patients with very **high triglycerides**



Gemfibrozil

# Fibrates

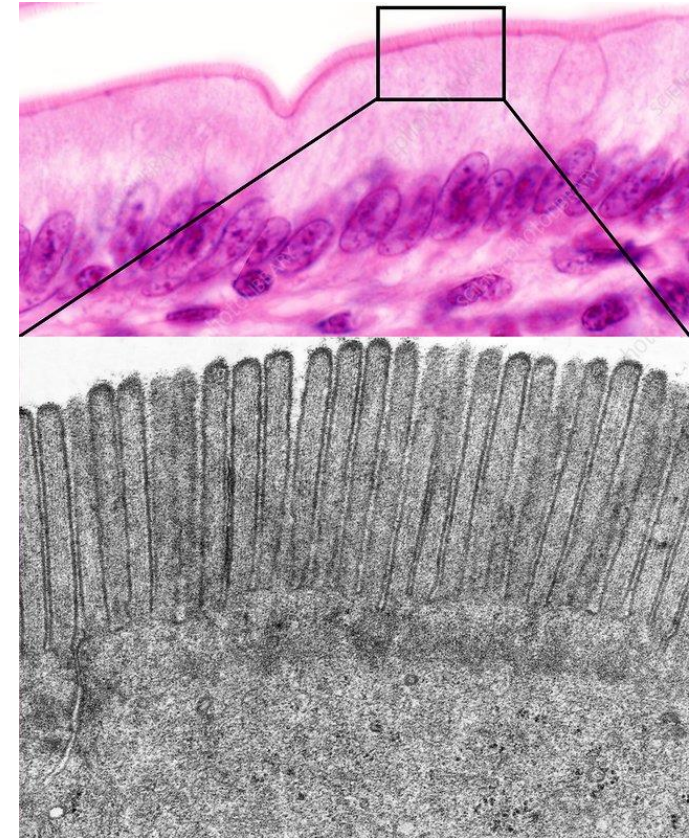
Gemfibrozil, clofibrate, bezafibrate, fenofibrate

- **Myositis**
  - Rhabdomyolysis associated with gemfibrozil
  - Caution when used with statins
- ↑ LFTs
- Cholesterol gallstones

# Absorption blockers

## Ezetimibe

- Blocks cholesterol absorption
- Works at **intestinal brush border**
- Blocks dietary **cholesterol** absorption
  - Highly selective for cholesterol
  - Does not affect fat-soluble vitamins, triglycerides



Public Domain



# Absorption blockers

## Ezetimibe

- Result: ↑ LDL receptors on liver
- Modest reduction LDL
- Some ↓ TG, ↑ HDL
- Weak data on hard outcomes (MI, death)
- ↑ LFTs
- Diarrhea

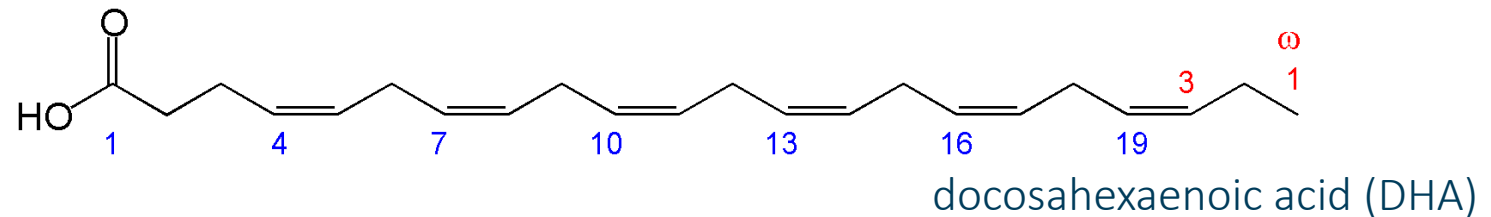
# Bile Acid Resins

Cholestyramine, colestipol, colesevelam

- Old drugs; rarely used
- Prevent intestinal reabsorption bile
  - Cholesterol → bile → GI tract → reabsorption
- Resins lead to more bile excretion in stool
- Liver converts cholesterol → bile to makeup losses
- Modest lowering LDL
- Miserable for patients: **bloating, bad taste**
- Can't absorb certain fat-soluble vitamins
- Cholesterol gallstones

# Omega-3 Fatty Acids

- Found in fish oil
- Consumption associated with ↓ CV events
- **Reduce VLDL production**
- **Lowers triglycerides** (~25 to 30%)
- Modest ↑ HDL
- Commercial supplements available (Lovaza)
- GI side effects: nausea, diarrhea, “fishy” taste

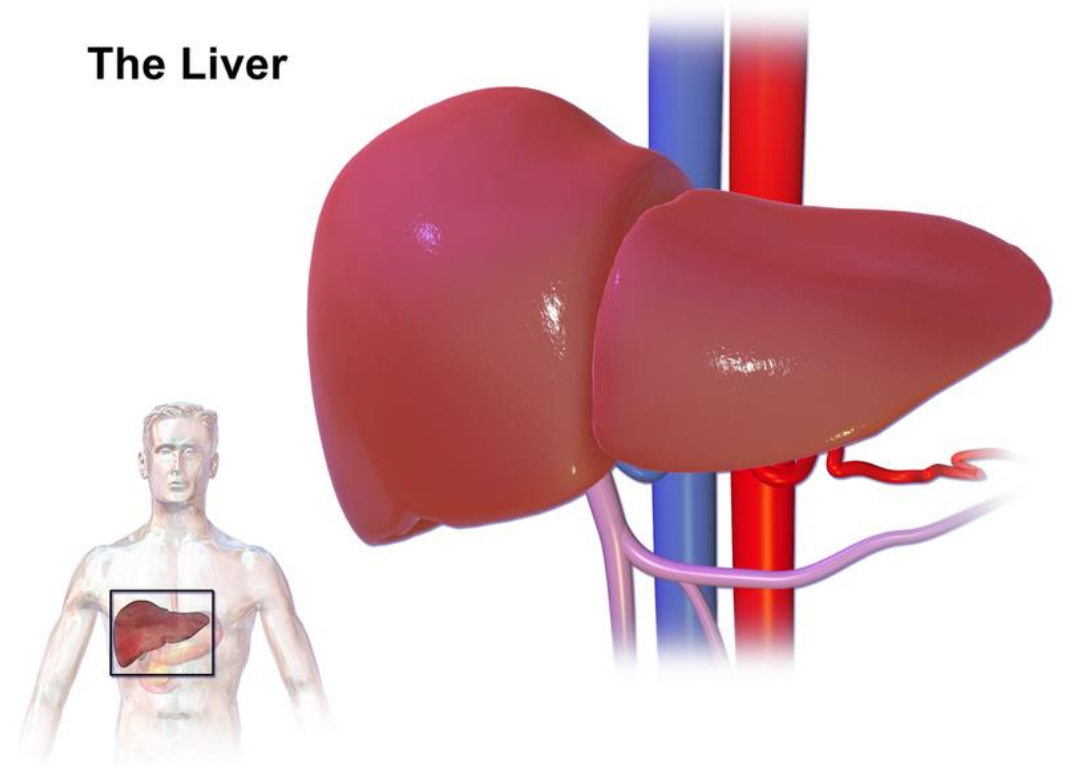


# PCSK9 Inhibitors

Alirocumab, Evolocumab

- FDA approval in 2015
- PCSK9 → **degradation of LDL receptors**
- Alirocumab/Evolocumab: Antibodies
- Inactivate PCSK9
  - ↓ LDL-receptor degradation
  - ↑ LDL receptors on hepatocytes
  - ↓ LDL cholesterol in plasma

The Liver



Wikipedia/Public Domain

# PCSK9 Inhibitors

Alirocumab, Evolocumab

- Given by subcutaneous injection
- Results in significant LDL reductions ( > 60%)
- Major adverse effect is injection site skin reaction
- Used when hyperlipidemia persists despite statins
- Downside: **cost**



# Hypertension

Jason Ryan, MD, MPH



# Hypertension

- Diagnosis of hypertension requires more than one measurement

Stage	SBP		DBP
Normal	<120	and	<80
Prehypertension	120-129	and	<80
Stage I hypertension	130-139	or	80-89
Stage II hypertension	>140	or	>90
Hypertensive Crisis	>180	or	>120

# Etiology

- Most (90%) is primary (“essential”) HTN
  - Cause not clear
- Remainder (10%) secondary
  - Most associated with chronic kidney disease
  - Hyperaldosteronism
  - Renal artery stenosis
  - Pheochromocytoma
- White coat hypertension
  - Elevated BP in clinic only



Public Domain



# Hypertension

## Risk Factors

- Family history
- African-American race
- High salt intake
- Alcohol
- Obesity
- Physical inactivity



Wikipedia/Public Domain

# Hypertension

## Associations

- Stroke
- Heart disease
  - MI
  - Heart failure
- Renal failure
- Aortic aneurysm
- Aortic dissection



[Freestocks.org](https://www.freestocks.org)

# New Onset Hypertension

- Screen for **complications and comorbid conditions**
  - Hemoglobin A1c or fasting glucose
  - Lipid panel
  - EKG
  - Serum creatinine
  - Urinalysis (protein)

# Hypertension

## Treatment

- Lifestyle modification recommended for **all patients**
- Weight loss – most effective intervention
- **DASH diet** – 2<sup>nd</sup> most effective intervention
  - Dietary Approaches to Stop Hypertension
  - Vegetables, fruits
  - Whole grains
  - Poultry, fish
  - Low in sugar and red meats



Wikipedia/Public Domain

# Hypertension

## Treatment

- Exercise
- Sodium restriction
- Alcohol limitation



"Mike" Michael L. Baird/Wikipedia

# Hypertension

## Drug Therapy

- Recommended initial choices:
  - Thiazide diuretics
  - ACE inhibitors/ARBs
  - Dihydropyridine calcium channel blockers



Pixabay

# Hypertension

Compelling indications

Indication	Drug
Prior myocardial infarction	Beta-blocker
Diabetes	ACEi or ARB
Osteoporosis	Thiazide diuretic
Proteinuria	ACEi or ARB



# Hypertensive Urgency

- Severe hypertension without end-organ damage
- No agreed upon BP value
- Usually  $> 180/120$



Flickr



# Hypertensive Emergency

## Hypertensive Crisis

- Also no definite value
- BP usually  $> 180/120$
- Often a patient with longstanding HTN who stops meds
- Neurologic impairment
  - Retinal hemorrhages, encephalopathy
- Renal impairment
  - Acute renal failure
  - Hematuria, proteinuria
- Cardiac ischemia

# Malignant Hypertension

- Sometimes used to refer to hypertensive emergency with **papilledema**



Public Domain

# Hypertensive Emergency

## Treatment

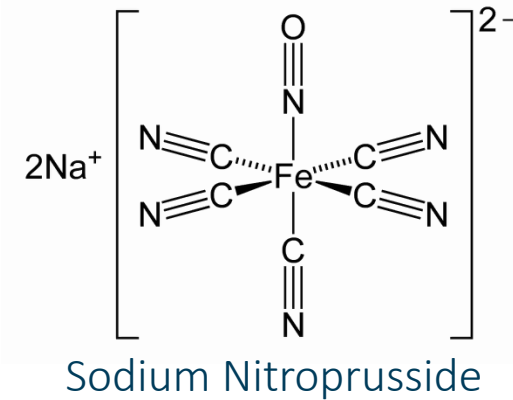
- Gradual reduction in blood pressure
  - ↓ MAP no more than 25 to 30% in first two hours
  - Rapid reduction → ischemia
  - Goal usually < 160/100 mmHg
- Drug choices (all intravenous)
  - Hydralazine
  - Esmolol
  - Nitroprusside
  - Labetalol
  - Clevidipine or nicardipine



Flickr

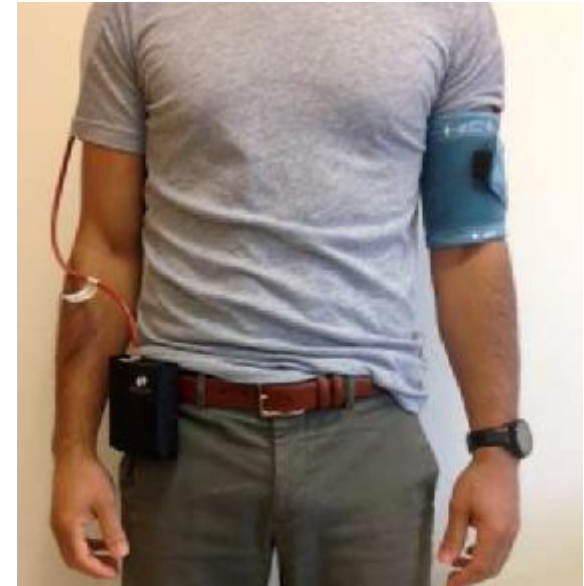
# Nitroprusside

- Short-acting drug
  - Smooth muscle relaxation
  - Venous and arteriolar vasodilation
  - ↓ afterload (arteriolar dilation)
  - ↓ preload (venous dilation)
- **Cyanide toxicity** with prolonged use
  - Multiple cyanide groups per molecule
  - Inhibits electron transport
  - Toxic levels with prolonged infusions
  - Lactic acidosis



# Ambulatory Blood Pressure Monitor

- Used when clinic BP may not represent average BP
- White coat hypertension: elevated BP only in clinic
- Masked hypertension: normal BP in clinic only



Public Domain

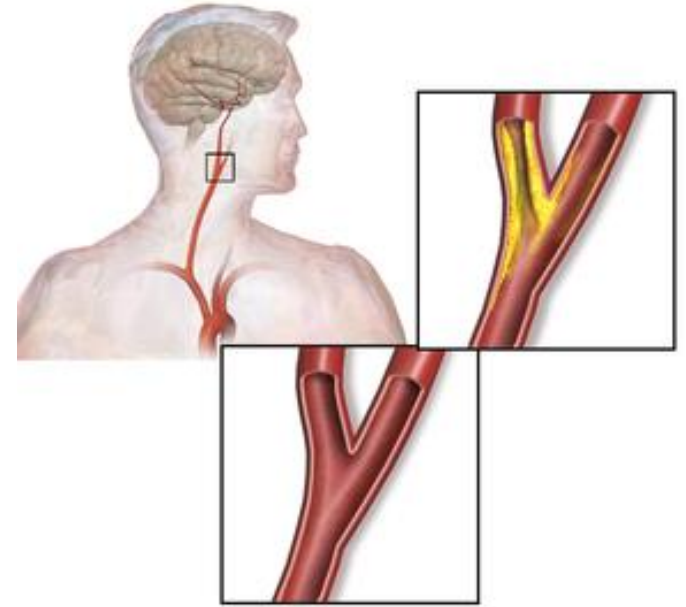
# Peripheral Vascular Disease

Jason Ryan, MD, MPH



# Carotid Artery Disease

- Atherosclerotic narrowing of the carotid artery
- May ulcerate → thrombus → embolization
- Occurs at carotid bifurcation
- Usually asymptomatic
- “Symptomatic” if embolization within past 6 months



# Carotid Artery Disease

## Clinical Features

- Stroke
  - Usually MCA territory
  - Homonymous hemianopsia, hemiparesis, and hemisensory loss
  - Aphasia (left-sided)
  - Spatial neglect (right-sided)
- Amaurosis fugax
  - Transient monocular blindness caused by embolus to ophthalmic artery (branch of ICA)
- Carotid bruit



# Hollenhorst plaques

- Cholesterol embolization to retinal artery
- May also occur with aortic plaque embolization



Larry Halperin, MD/Retinal Image Bank

# Carotid Artery Disease

## Diagnosis

- Carotid duplex ultrasound
- Magnetic resonance angiography
- Computed tomographic angiography
- Angiography

MRA



# Carotid Artery Disease

## Treatment

- Carotid endarterectomy (CEA)
- Carotid artery stenting (CAS)
- Numerous clinical trials comparing CEA to CAS in various groups

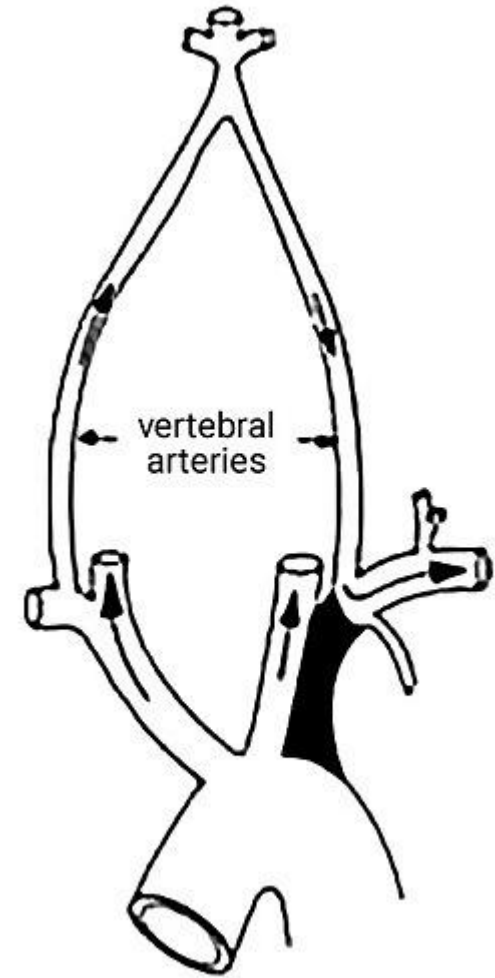
# Carotid Artery Disease

## Management

- All patients: **statin, aspirin**, BP control, lifestyle counseling
- Asymptomatic patients
  - $\geq 80\%$  stenosis: carotid endarterectomy or stenting
  - $< 80\%$  stenosis: medical management
- Symptomatic patients
  - 100% stenosis: medical management
  - 70-99%: carotid endarterectomy or stenting
  - Men 50-69%: carotid endarterectomy or stenting
  - All others: medical management

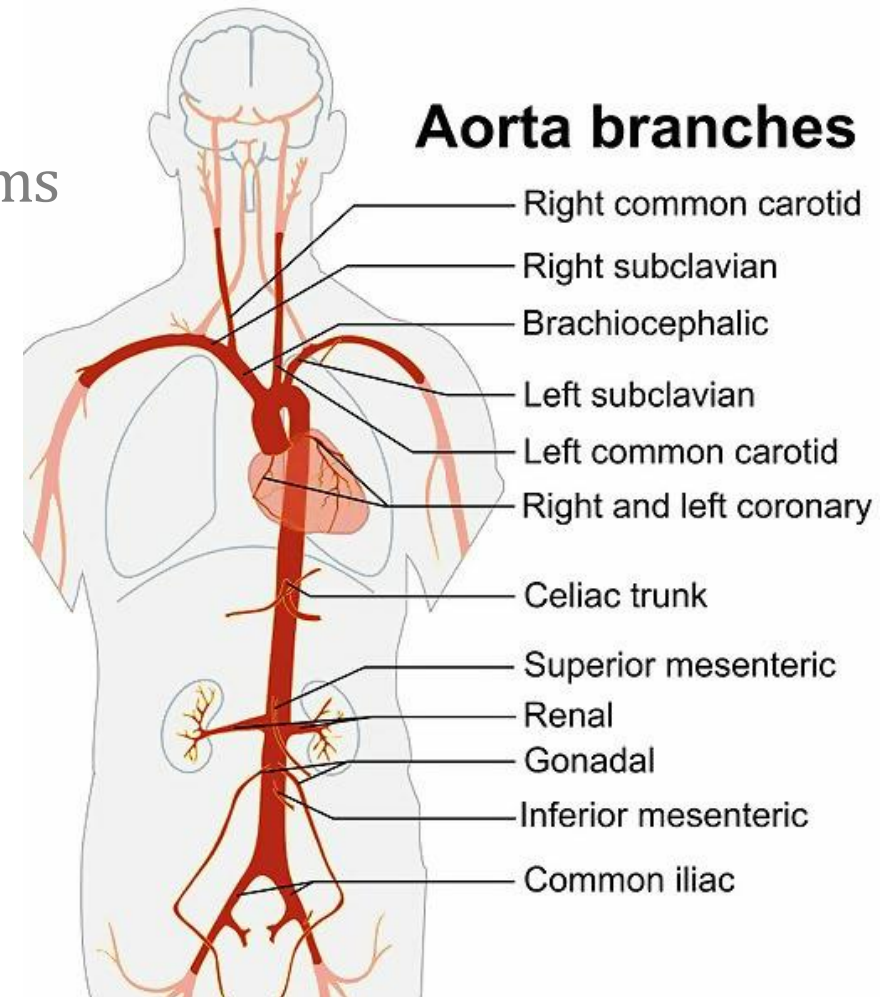
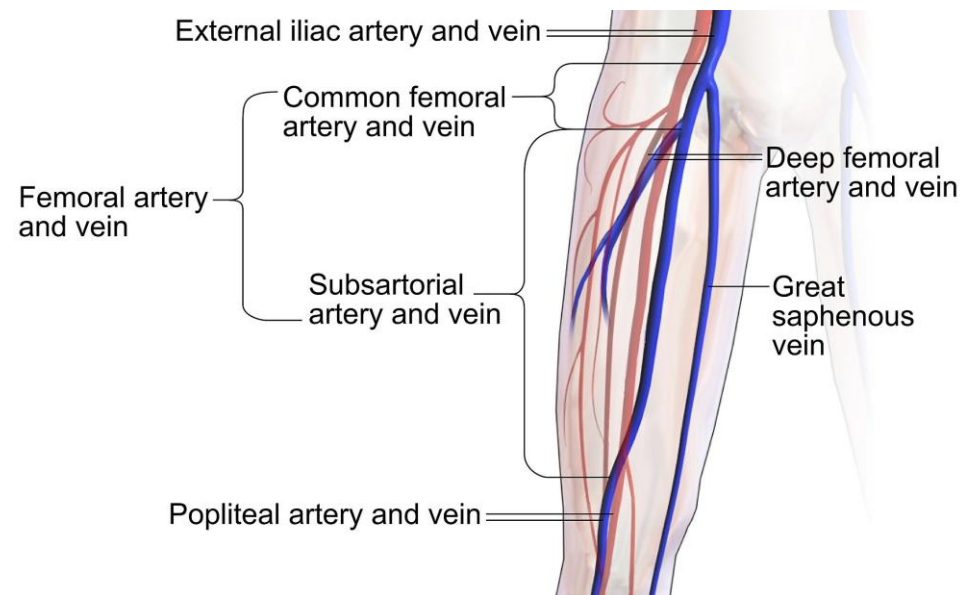
# Subclavian Steal

- Flow reversal in vertebral artery
- Caused by **stenosis of subclavian artery**
- Blood pressure discrepancy ( $>15$  mmHg SBP)
- **Exercise-induced arm ischemia**
  - Pain, fatigue, numbness
- Rarely dizziness or syncope
- Diagnosis: clinical plus subclavian ultrasound
- Treatment: bypass surgery or stenting



# Peripheral Artery Disease

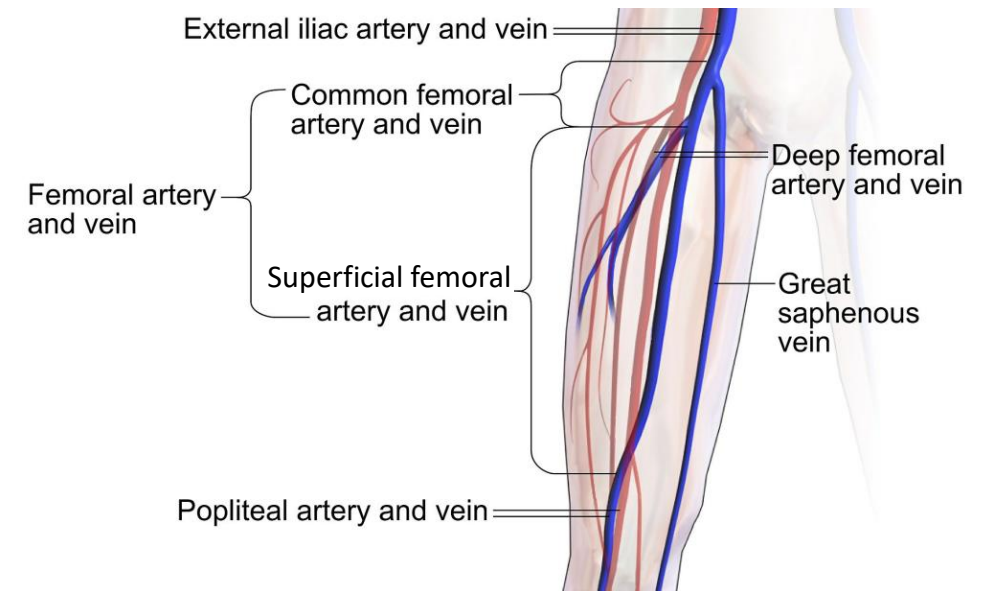
- Atherosclerotic disease of **lower extremity**
- Most commonly aortoiliac or femoral systems



# Peripheral Artery Disease

## Clinical Features

- **Claudication**
  - Pain induced by walking, relieved with rest
  - Quads, calves, and gluteal muscles most commonly involved
- Aortoiliac disease: buttock and hip claudication
- Common femoral: thigh or calf claudication
- Superficial femoral or popliteal: calf pain



# Peripheral Artery Disease

## Clinical Features

- Hairless legs/feet
- Shiny skin
- Ulcers
- Buerger's Sign: elevation turns foot pale, dangling turns bright red



# Peripheral Artery Disease

## Clinical Features

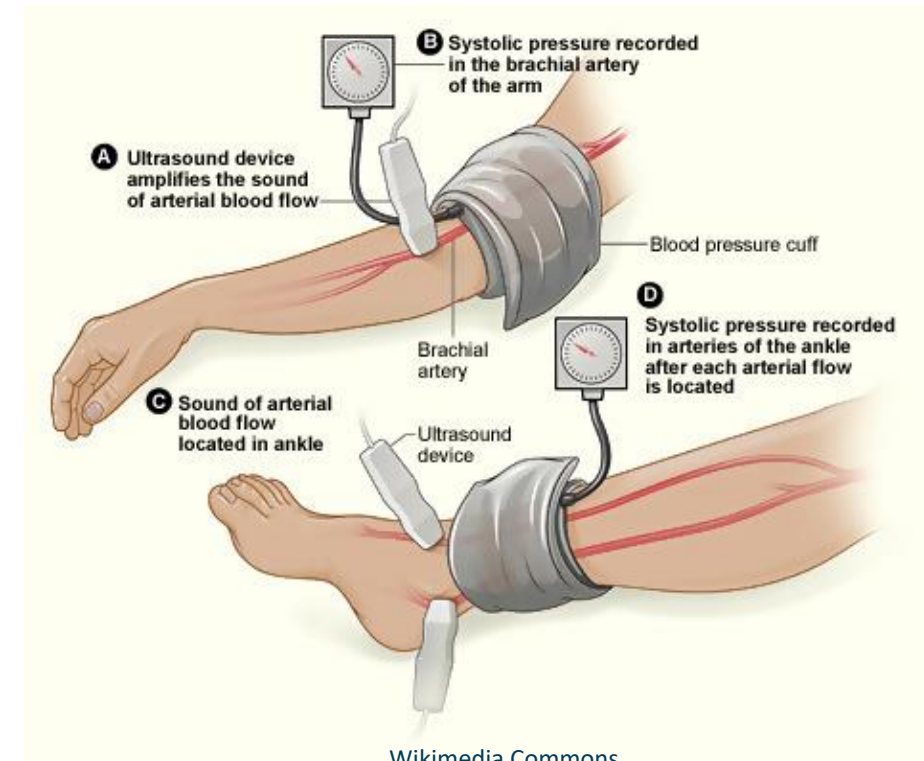
- Rutherford Symptom Scale

Category	Symptoms
0	Asymptomatic
1	Mild claudication
2	Moderate claudication
3	Severe Claudication
4	Rest pain
5	Minor tissue loss
6	Major tissue loss

# Peripheral Artery Disease

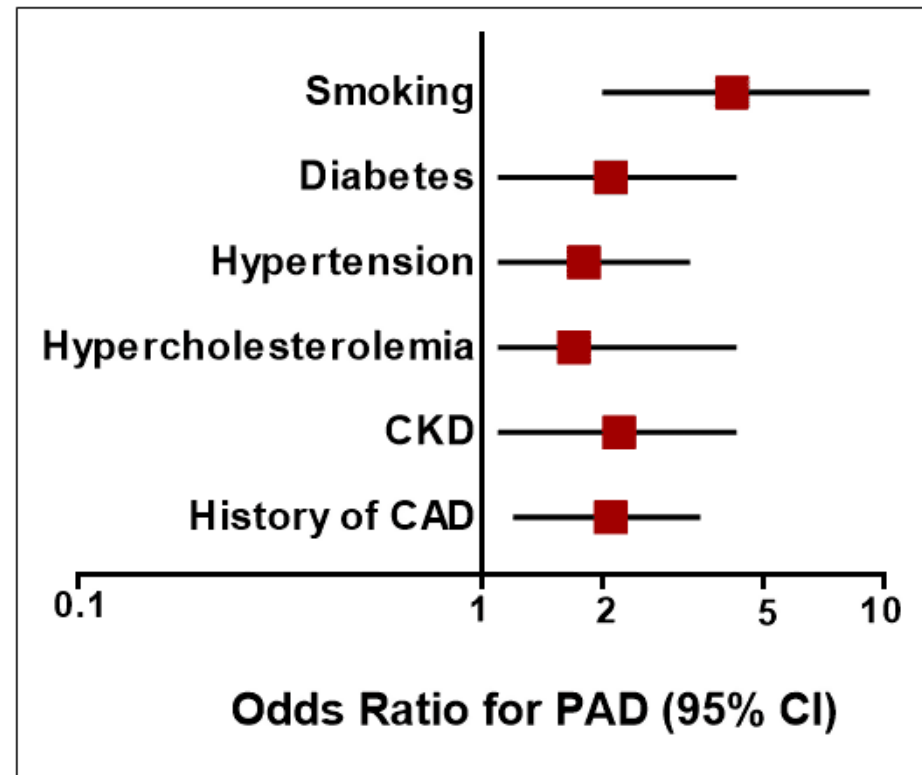
## Diagnosis

- Ankle-brachial index
  - Normal: 1.0
  - Abnormal  $\leq 0.9$
  - At rest and with exercise
- Imaging
  - Ultrasound
  - CT/MRI



# Peripheral Artery Disease

## Risk Factors



Selvin E, Erlinger TP. Prevalence of and risk factors for peripheral arterial disease in the United States: results from the National Health and Nutrition Examination Survey, 1999-2000. *Circulation*. 2004 Aug 10;110(6):738-43.

# Peripheral Artery Disease

## Treatment

- Highest risk among PAD patients: **cardiovascular disease** (stroke, MI)
  - Aspirin or clopidogrel
  - Statin
  - Smoking cessation
  - Treatment of diabetes and hypertension

# Peripheral Artery Disease

## Treatment

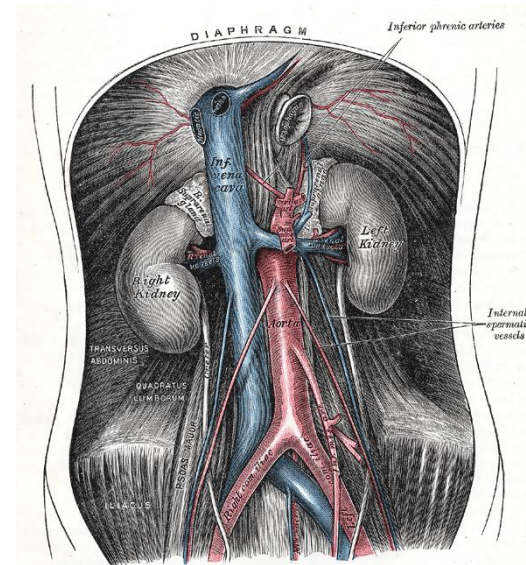
- Initial treatment for claudication: **exercise program**
- Cilostazol: phosphodiesterase inhibitor
  - Some evidence it decreases claudication symptoms
- Surgical revascularization or stenting



Public Domain

# Leriche Syndrome

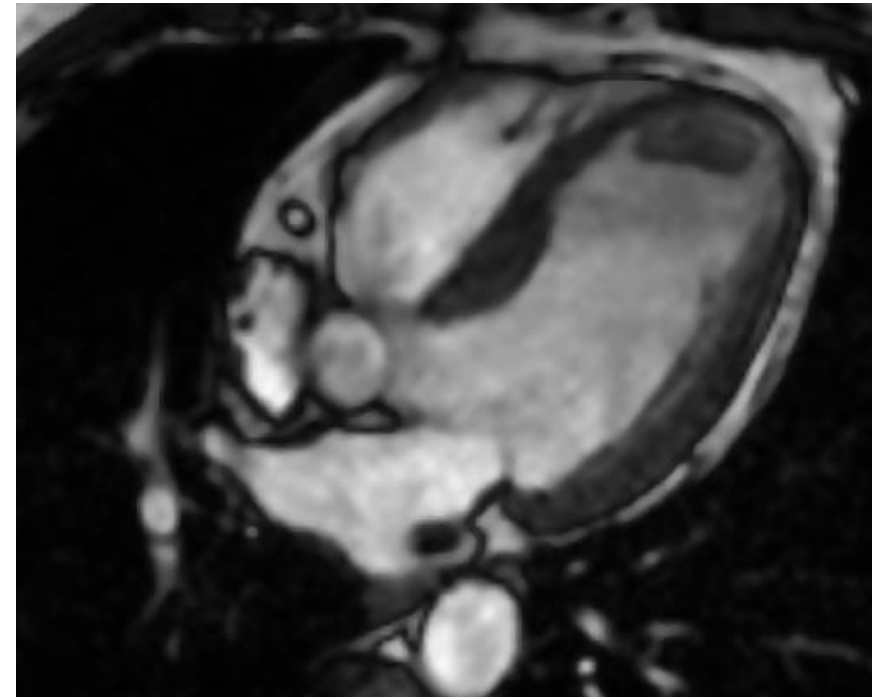
- Narrowing of aorta above iliac bifurcation
- Bilateral thigh/hip claudication
- Impotence
- Absent or diminished femoral pulses



Wikipedia/Public Domain

# Acute Limb Ischemia

- Sudden decrease in limb perfusion
- High risk of amputation
- **Thrombosis**
  - At site of atherosclerotic plaque
  - At aneurysm
  - Hypercoagulable state
- **Cardiac embolism**
  - Left atrial appendage in atrial fibrillation
  - Left ventricle in patients with anterior infarction



# Acute Limb Ischemia

## Clinical Features

- **P**ain
- **P**allor: Pale or mottled (livedo reticularis)
- **P**ulselessness
- **P**oikilothermia (cool skin)
- **P**aresthesia: numbness, tingling
- **P**aralysis

### **Mottled Skin**

Blotchy, red, marbled



Public Domain



# Acute Limb Ischemia

## Clinical Features

- Claudication or known PAD prior to acute limb ischemia
  - Suggests thrombosis
  - Can have slower onset of symptoms: hours to days
- No prior PAD
  - Suggests embolism
  - No time for recruitment of collateral blood vessels
  - Severe signs of limb ischemia develop quickly
  - Rapid onset of symptoms: minutes

# Acute Limb Ischemia

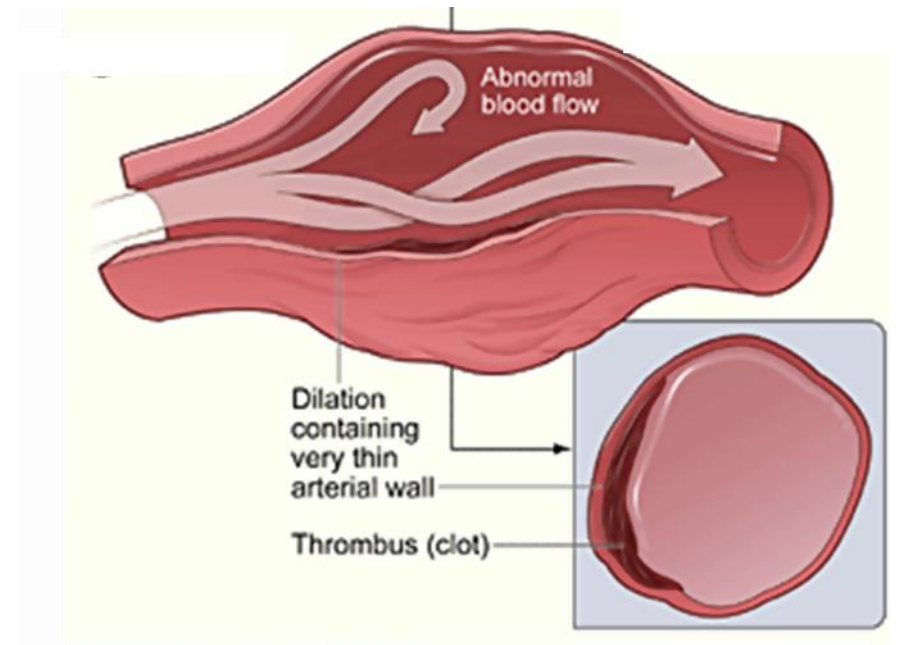
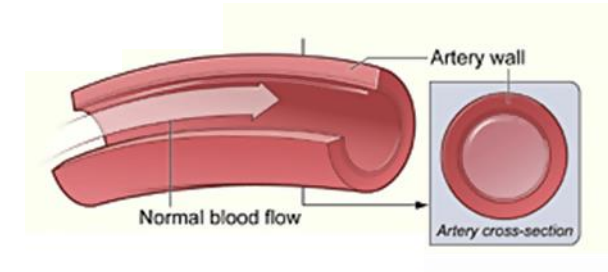
## Diagnosis and treatment

- Diagnosis: CT angiogram
- Treatment:
  - IV fluids
  - Leg in dependent position
  - Heparin
  - Thrombolysis
  - Surgical revascularization
  - Amputation

Class	Definition	Intervention
Viable (I)	- Mild pain, but intact capillary refill, peripheral pulses	None
Marginally threatened (IIa)	- Moderate pain, diminished pulses, possible sensory deficit	Urgent revascularization
Immediately threatened (IIb)	- Severe pain, sensory/motor deficits, no pulses	Emergent revascularization
Irreversible ischemia (III)	- Complete paralysis/no sensation - Signs of dead tissue	Amputation

# Aneurysms

- Focal dilation more than 50% above vessel diameter
- May develop thrombosis → limb ischemia
- Popliteal artery: most common
- Femoral artery: 2<sup>nd</sup> most common
- Diagnosis by ultrasound, CT, or MRI

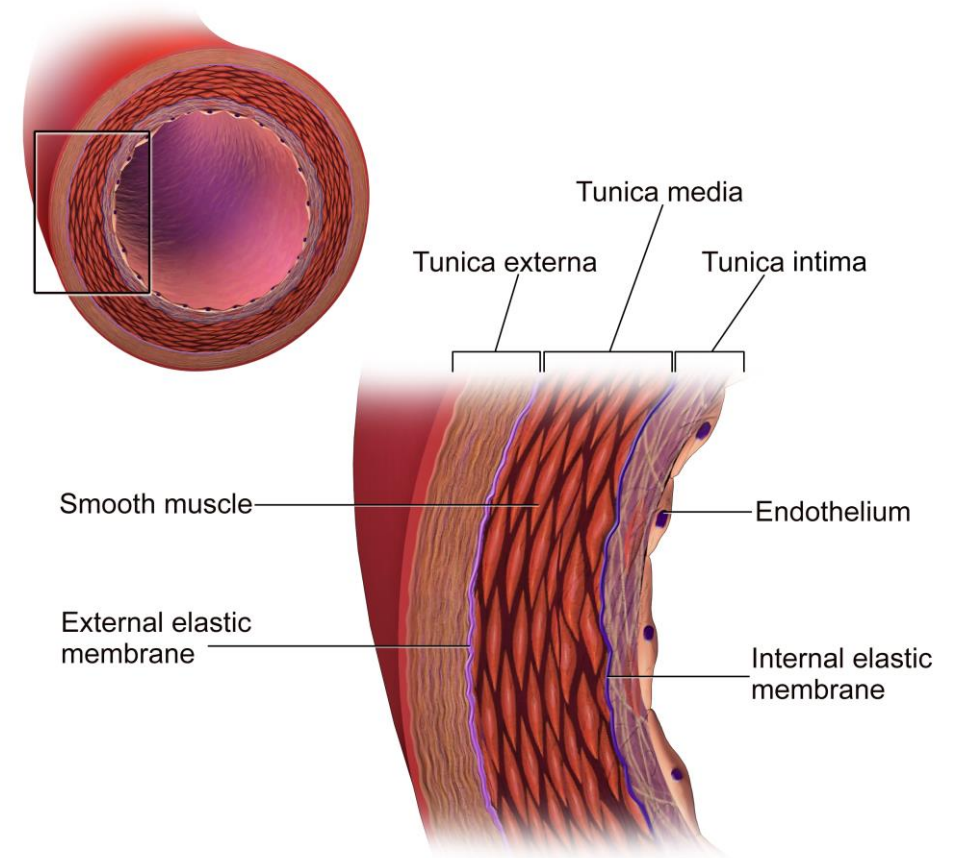


Wikimedia Commons/Public Domain

# Pseudoaneurysms

- Hole through intima/media
- Blood fills space between layers
- Usually traumatic
- Common in **femoral artery**
  - Vessel damage from catheterization

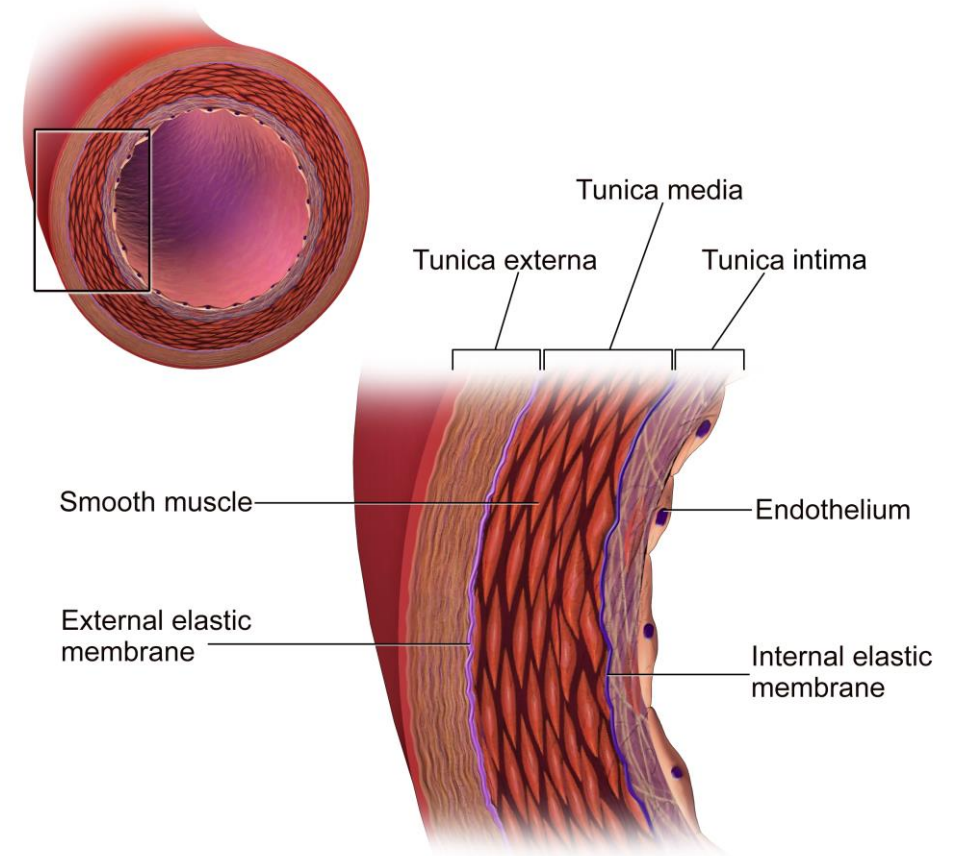
## The Structure of an Artery Wall



# Pseudoaneurysms

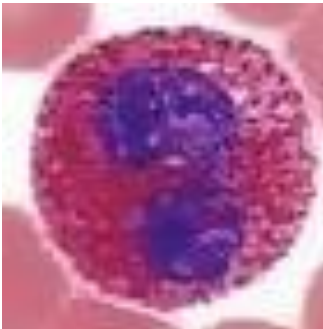
- Diagnosis: ultrasound
- Treatments:
  - Surgery
  - Stenting
  - Ultrasound guided thrombin injection

## The Structure of an Artery Wall

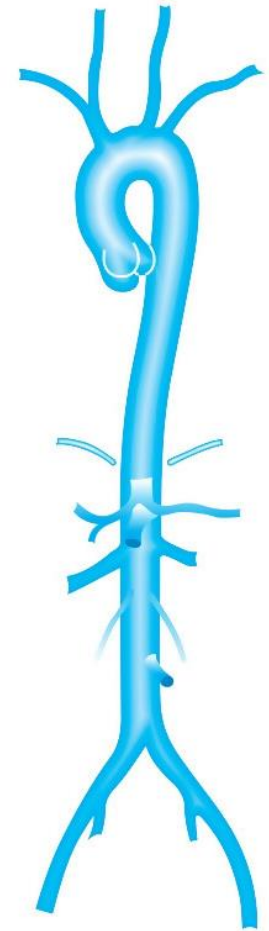


# Atheroembolism

- Cholesterol embolization from aortic plaque
- Commonly occurs after cardiac catheterization or vascular surgery
- Classic cause of livedo reticularis (mottled skin)
- May cause **eosinophilia**
- Treatment: supportive



Public Domain



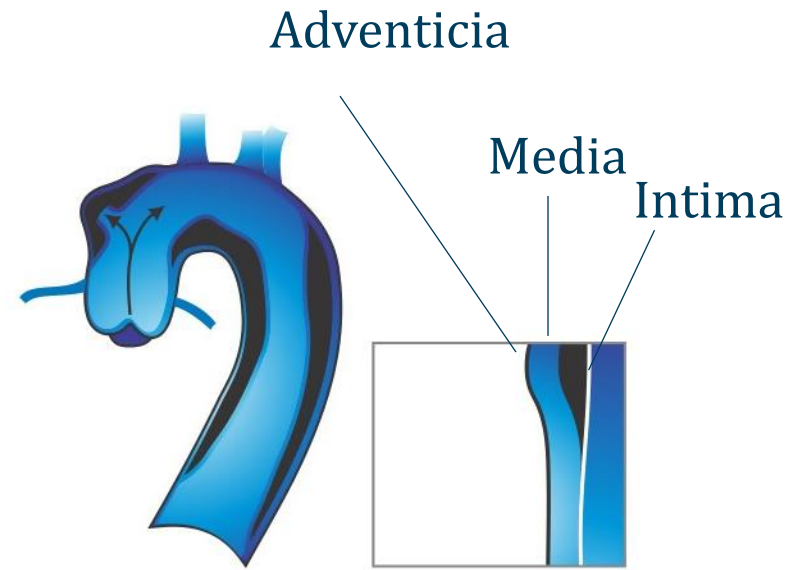
# Aortic Disease

Jason Ryan, MD, MPH



# Aortic Dissection

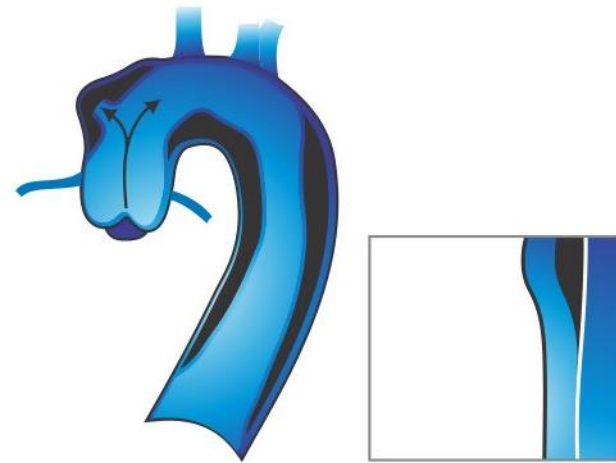
- Three layers to aorta
  - Intima
  - Media
  - Adventicia
- Dissection → **tear in intima**
- Blood “dissects” intima and media





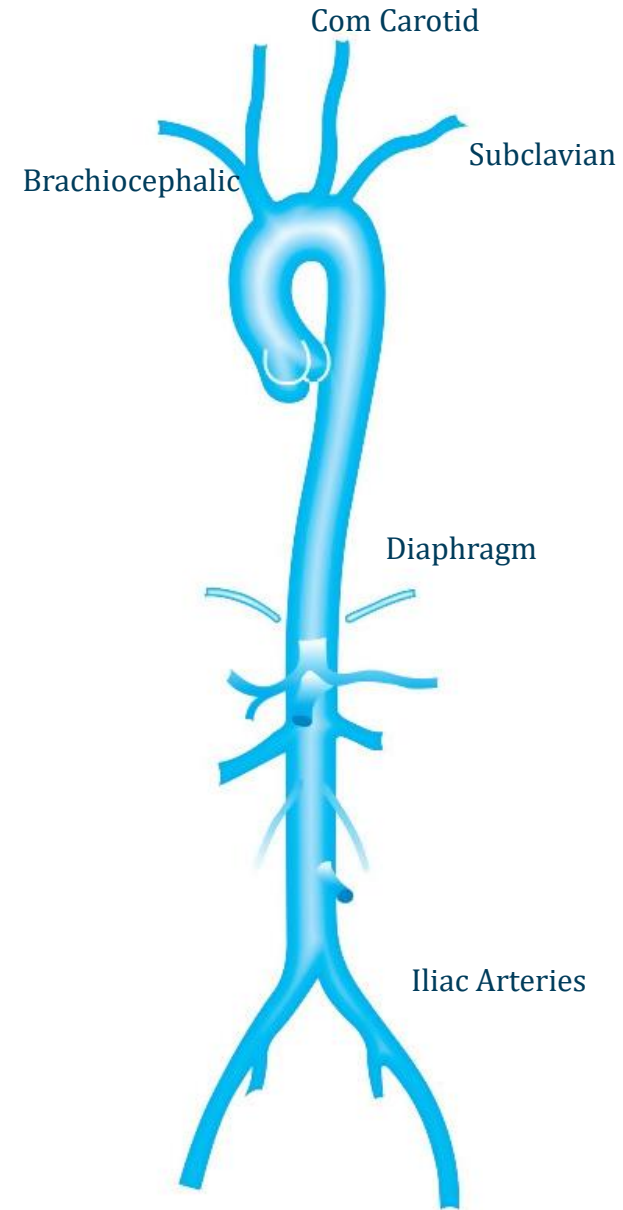
# Types

- Type A
  - Involves ascending aorta and/or arch
  - Treated **surgically**
- Type B
  - Descending aorta
  - Can be treated **medically**
  - Control hypertension/symptoms
  - Surgical mortality high



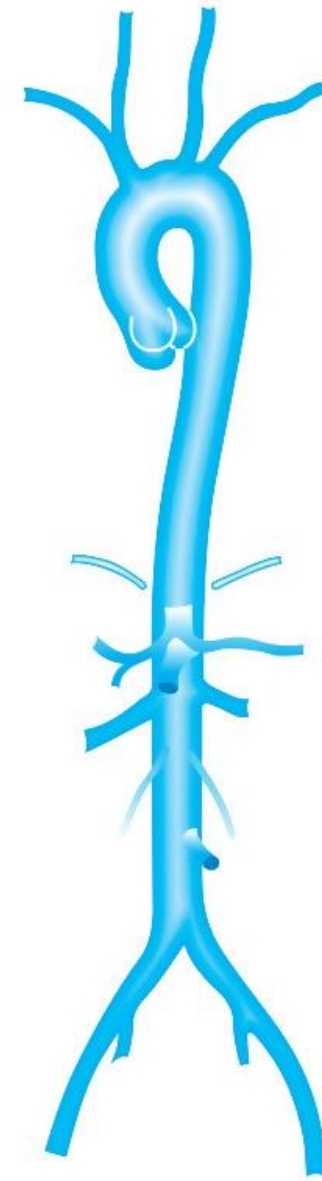
# Propagation

- Blood enters dissection plane
- Spreads proximal, distal
- Can disrupt flow to vessels



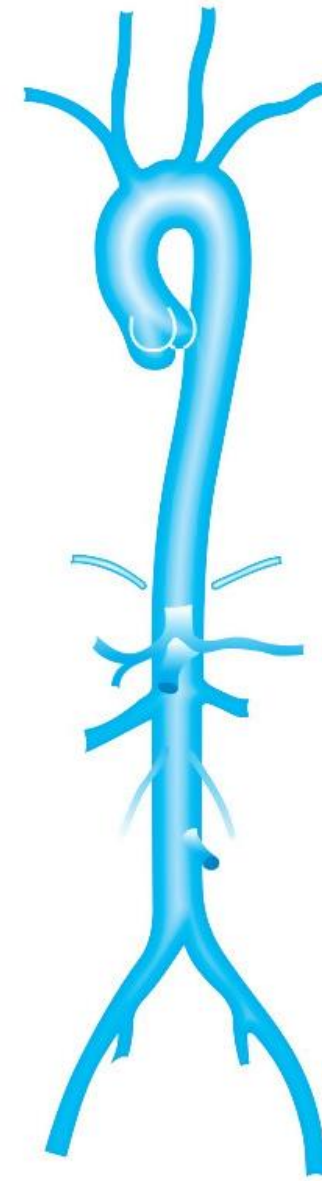
# Propagation

- Propagation to aortic root
  - Aortic regurgitation
  - **Pericardial effusion/tamponade**
  - Myocardial ischemia (obstruction RCA origin)
- Propagation to aortic arch
  - Stroke (carotids)
  - Horner's syndrome
  - Vocal cord paralysis



# Propagation

- Propagation to distal aorta (type B)
  - Limb ischemia
  - Mesenteric ischemia
  - Renal failure



# Symptoms and Findings

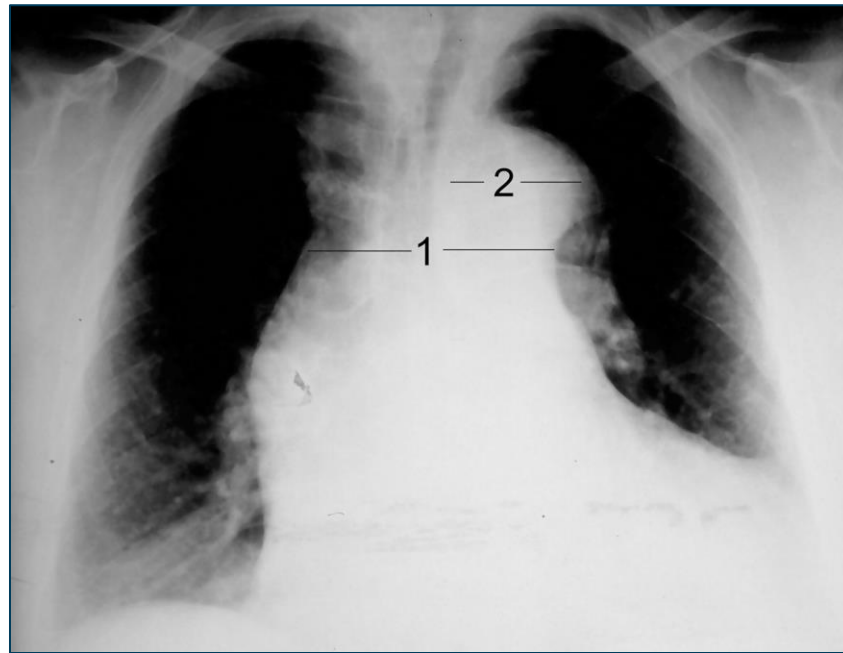
- **“Tearing” chest pain radiating to back**
- Asymmetric blood pressure
  - >20 mmHg difference between right and left



Public Domain

# Other findings

- **Widened mediastinum** on chest x-ray



# Risk Factors

## Aortic Dissection

- Aortic damage
  - **HTN - #1 risk factor**
  - Atherosclerosis
  - Thoracic aneurysm
- Abnormal collagen
  - Marfan Syndrome
  - Ehlers-Danlos
- Others
  - Bicuspid aortic valve
  - Turner Syndrome (bicuspid, coarctation)
  - Tertiary syphilis: Aortitis

# Diagnosis

- Suggested by history, exam, chest x-ray
- Definitive diagnosis
  - **CT scan**
  - MRI
  - Transesophageal echocardiogram (TEE)



Dr. James Heilman/Wikipedia



# Treatment

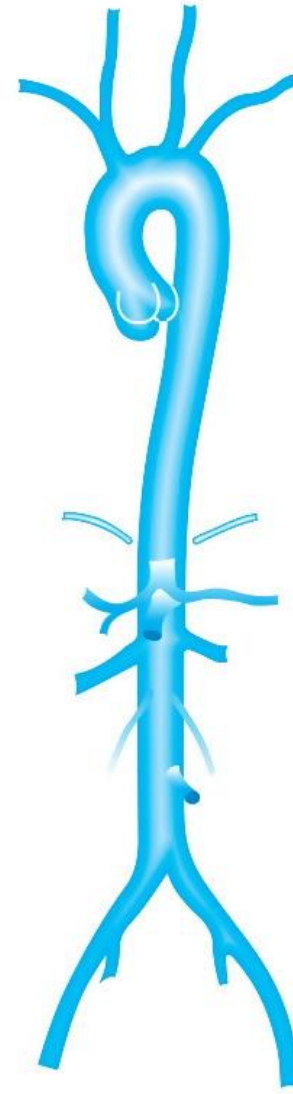
- Type A: **emergent surgery**
- Type B: medical therapy
  - **Blood pressure control**
  - Beta-blockers: IV esmolol or labetalol
  - Nitroprusside



Public Domain

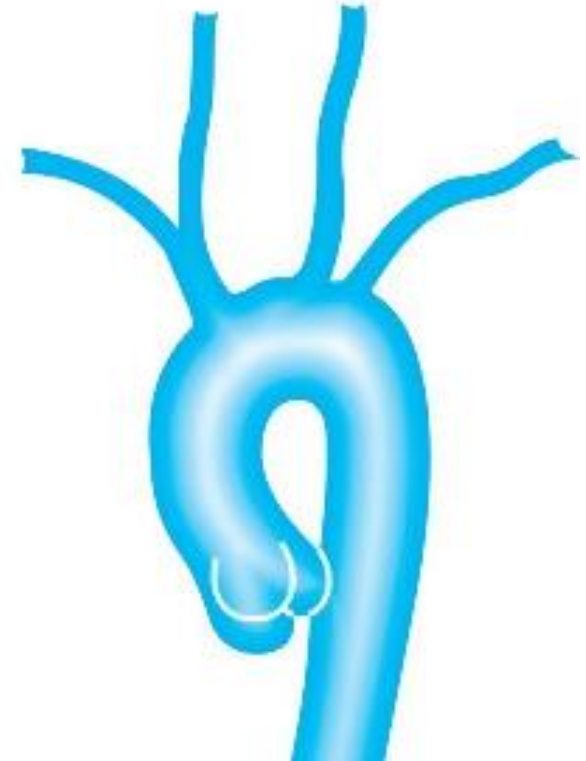
# Aortic Aneurysms

- Dilation/bulge of aorta
- More than 1.5x normal
- Involves all 3 layers
- Thoracic (TAAs)
- Abdominal (AAAs)



# Thoracic Aortic Aneurysms

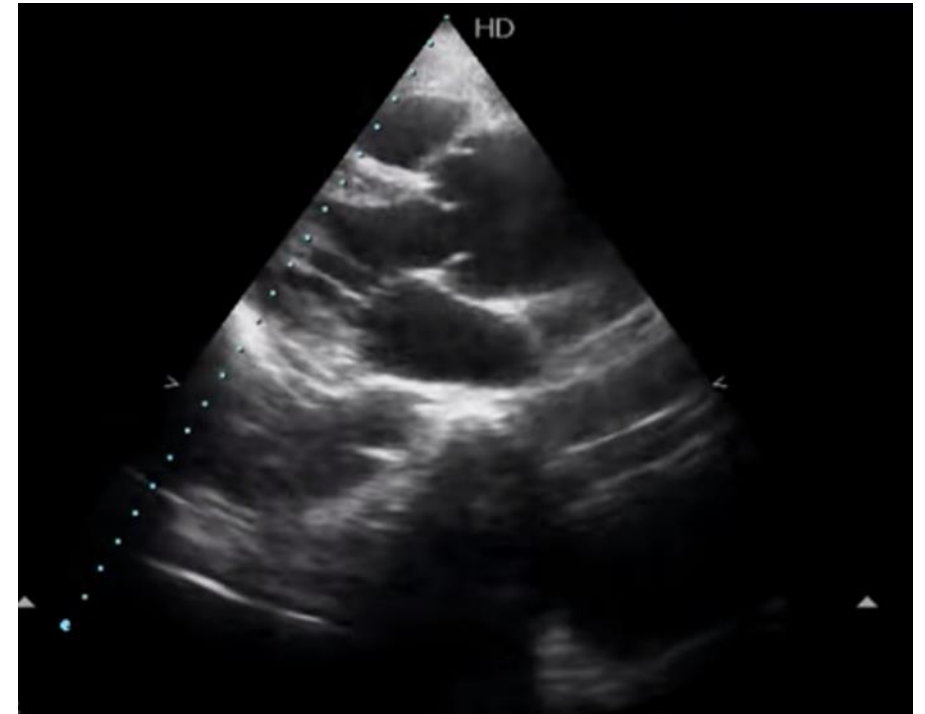
- Important risk factor for dissection
- Usually occur in proximal/ascending aorta
- Major risk factor: **hypertension**
  - Also hyperlipidemia, smoking
- Often seen in association with another disorder
  - Marfan, Turner, bicuspid aortic valve, tertiary syphilis



# Thoracic Aortic Aneurysms

## Diagnosis and treatment

- Most are asymptomatic
- Can cause aortic regurgitation
- Diagnosis:
  - Echocardiography
  - CT
  - MRI
- For most patients, surgery if size  $> 5.5$  cm



# Abdominal Aortic Aneurysms

- More common than thoracic aneurysms
- Associated with **atherosclerosis**
- Most common site: **infrarenal aorta**
  - Most affected by atherosclerosis



# Abdominal Aortic Aneurysms

## Risk Factors

- **Smoking:** strongest association with AAA
- Males: 10x more common
- Age
  - Rare before 55
  - As high as 5% in men > 65
- Hypertension
- Hyperlipidemia



Pixabay/Public Domain

# Abdominal Aortic Aneurysms

- Most are asymptomatic
- Some detected on physical exam
- **Pulsatile mass** from xiphoid to umbilicus
- Natural history is enlargement → rupture
- Followed with **ultrasound** or CT scan
- Surgery if > 5.0 cm



Public Domain

# USPSTF Guidelines

United States Preventative Services Task Force

- **One-time ultrasound** screening recommended
- Men
- Aged 65-75 years old
- Any smoking history (current or former)



# Cardiovascular Pharmacology I

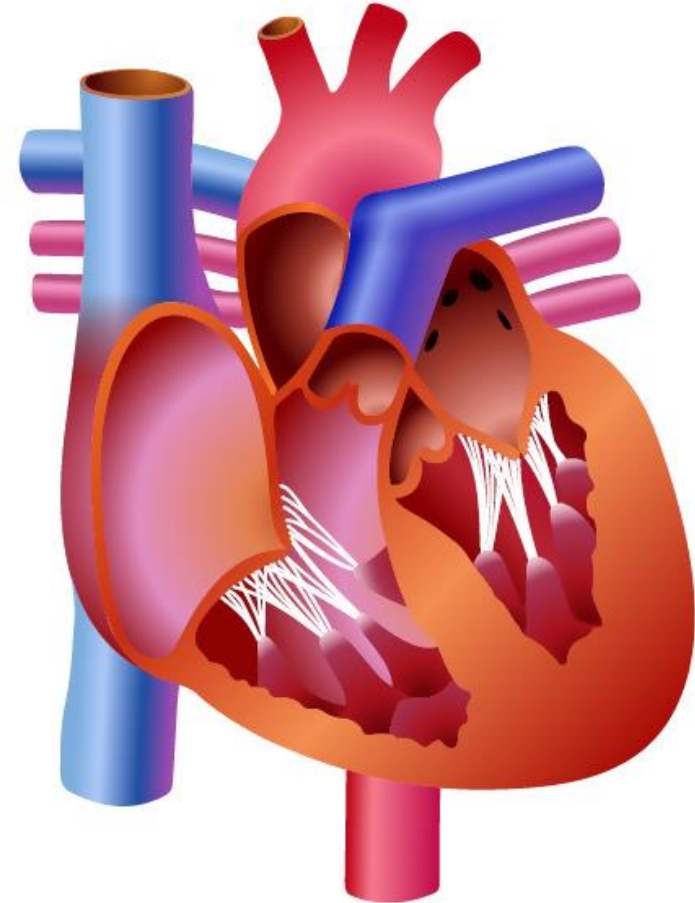
Jason Ryan, MD, MPH



# Beta-blockers

$\beta$ 1-selective antagonists

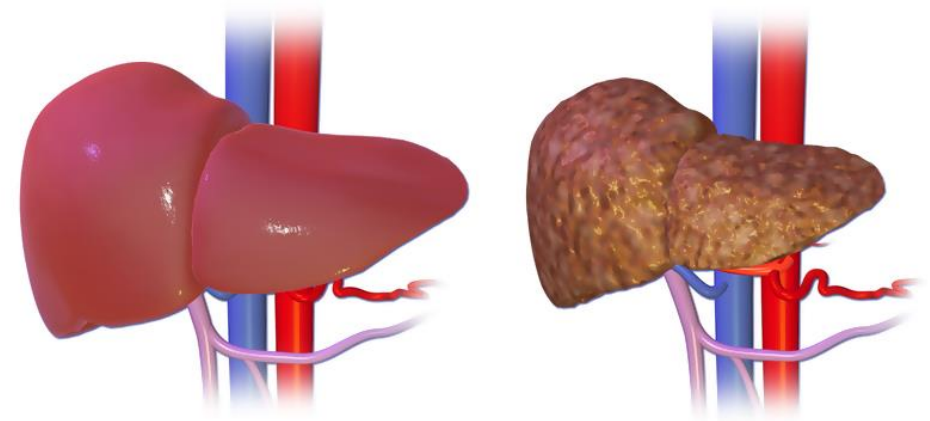
- Atenolol, Metoprolol, Esmolol, Bisoprolol
- Used for **hypertension**
  - Blockade  $\rightarrow$   $\downarrow$  CO  $\rightarrow$   $\downarrow$  BP
- Metoprolol: **systolic heart failure**
  - Blocks sympathetic stimulation of heart
  - Reduces mortality



# Beta-blockers

$\beta_1\beta_2$  (nonselective) antagonists

- Propranolol, Timolol, Nadolol
- Nadolol, Propranolol: Used in **portal hypertension**
  - Beta 1 blockade:  $\downarrow$  CO,  $\downarrow$  ECV  $\rightarrow$   $\downarrow$  BP
  - Beta 2 blockade:  $\downarrow$  portal blood flow
- Timolol: Used in **glaucoma**
  - Beta 1 and Beta 2  $\rightarrow$  aqueous humor production
- Propranolol: **hyperthyroidism**
  - Blocks T4  $\rightarrow$  T3 conversion



Normal Liver

Liver Cirrhosis

# Beta-blockers

$\beta_1\beta_2\alpha_1$

- Labetalol: hypertensive emergency
  - Rapid reduction in blood pressure
- Carvedilol: systolic heart failure
  - Blocks sympathetic stimulation of heart
  - Reduces mortality



Wikimedia Commons/Public Domain

# Beta-blockers

## Side effects

- Fatigue, erectile dysfunction, depression
  - More common with older beta-blockers (propranolol)
- Hyperlipidemia
  - Mild increase in triglycerides
  - Mild decrease in HDL
  - Effect varies with different beta-blockers



Wikimedia Commons/Public Domain

# Beta-blockers

## Side effects

- Caution in **diabetes**
- Blockade of epinephrine effects
  - Epinephrine raises glucose levels
  - Blockade → hypoglycemia
- Blockade of hypoglycemia symptoms
  - ↓ glucose → sweating/tachycardia
  - Symptoms “masked” by beta-blockers

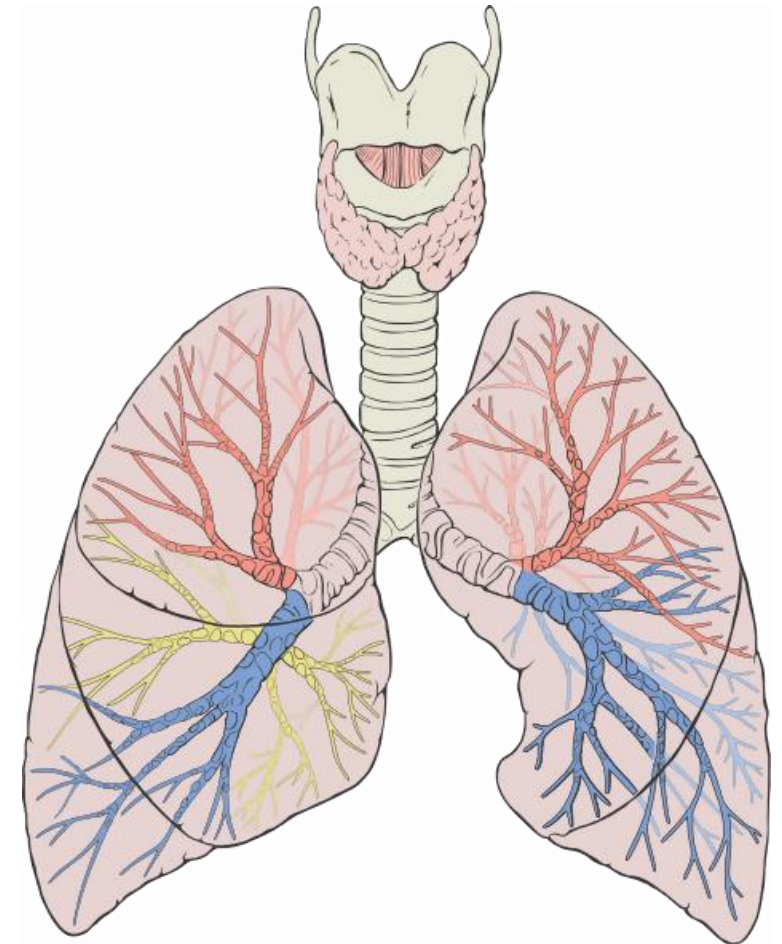


Victor/Flickr

# Beta-blockers

## Side effects

- Caution in **asthma/COPD**
  - B2-receptors: bronchodilators
  - B2-blockade may cause a flare
  - B1-blockers (“cardioselective”) often used
- Decompensated **heart failure**
  - B1-blockers lower cardiac output → worsening of symptoms
  - Commonly used in compensated heart failure
  - Mortality benefit



Wikimedia Commons/Public Domain



# Beta-blockers

## Overdose

- Depression of myocardial contractility → shock
- Bradycardia/AV block
- Treatment: **glucagon**

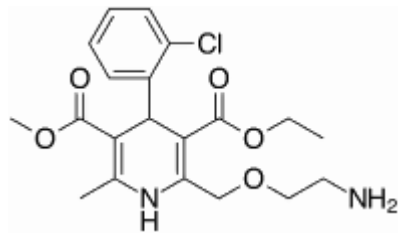


Wikimedia Commons/Public Domain

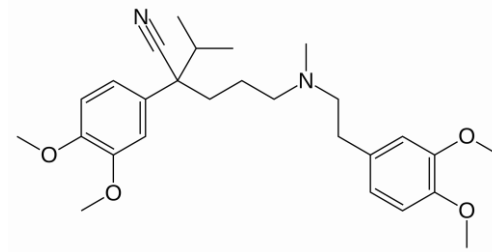


# Calcium Channel Blockers

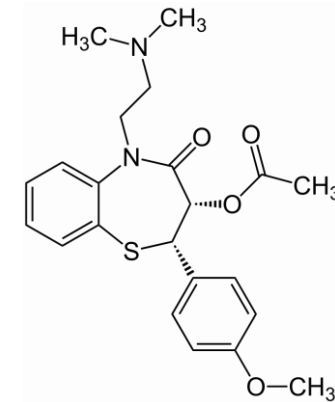
- Three major classes of calcium antagonists
  - dihydropyridines (amlodipine)
  - phenylalkylamines (verapamil)
  - benzothiazepines (diltiazem)
- **Vasodilators** and **negative chronotropes/inotropes**



Amlodipine



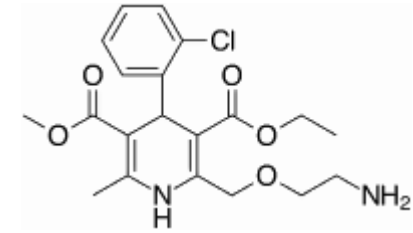
Verapamil



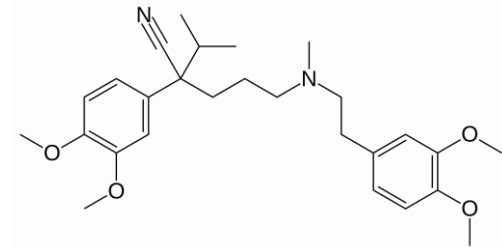
Diltiazem

# Calcium Channel Blockers

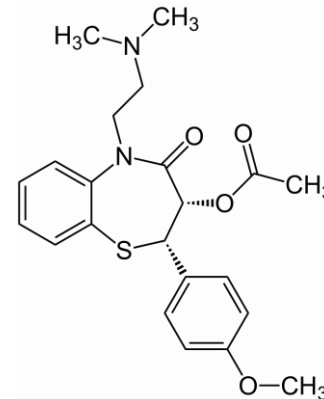
- Dihydropyridines (nifedipine) → vasodilators
  - Main effect: ↓ TPR/BP
- Non-dihydropyridines (verapamil, diltiazem)
  - Similar to  $\beta$ 1-blockers
  - Main effects: ↓HR; ↓ contractility
- Vascular smooth muscle effects
  - Nifedipine > Diltiazem > Verapamil
- Heart rate/contractility effects
  - Verapamil > Diltiazem > Nifedipine



Amlodipine



Verapamil

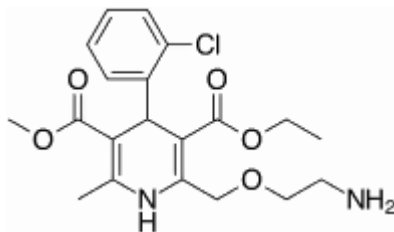


Diltiazem

# Calcium Channel Blockers

## Dihydropyridines (amlodipine)

- Used for **hypertension**
- Flushing, headache, hypotension
  - Peripheral vasodilation
- Key side effect: **edema**
  - Pre-capillary arteriolar vasodilation
  - Flood capillaries with fluid → edema



Amlodipine

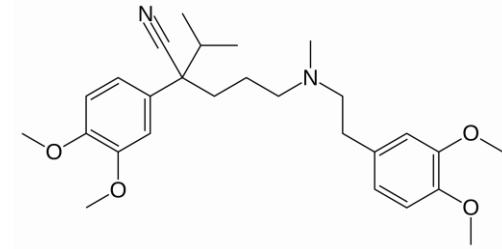


James Heilman, MD/Wikipedia

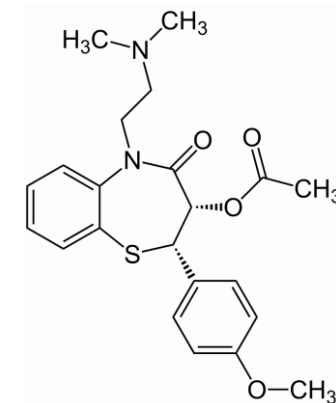
# Calcium Channel Blockers

Verapamil, diltiazem

- Used for **hypertension**
- Also used in heart disease
  - Arrhythmias (atrial fibrillation)
  - Stable angina (lower oxygen demand)
- Potential side effect: **negative inotropes**
  - Contraindicated in heart failure



Verapamil



Diltiazem

# Calcium Channel Blockers

## Other Side Effects

- Constipation
  - Most commonly with **verapamil**
- Hyperprolactinemia
  - Seen with **verapamil**
  - Blocks calcium channels CNS → ↓ dopamine release
  - Galactorrhea
  - Leads to hypogonadism
  - Men: ↓ libido, impotence
  - Pre-menopausal women: irregular menses



Elya/Wikipedia

# Calcium Channel Blockers

## Other Side Effects

- **Gingival hyperplasia**
  - Seen in all types CCB
  - Also with phenytoin, cyclosporine

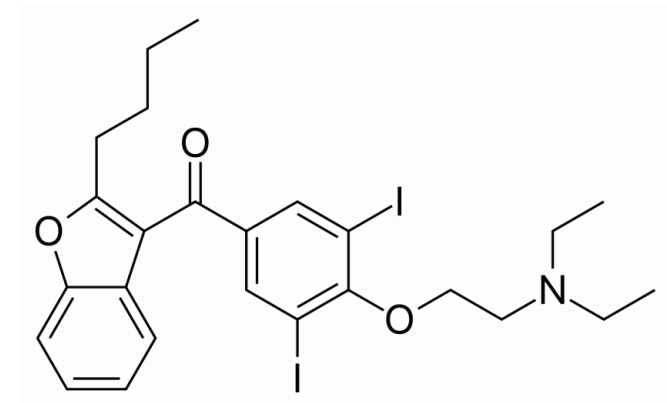
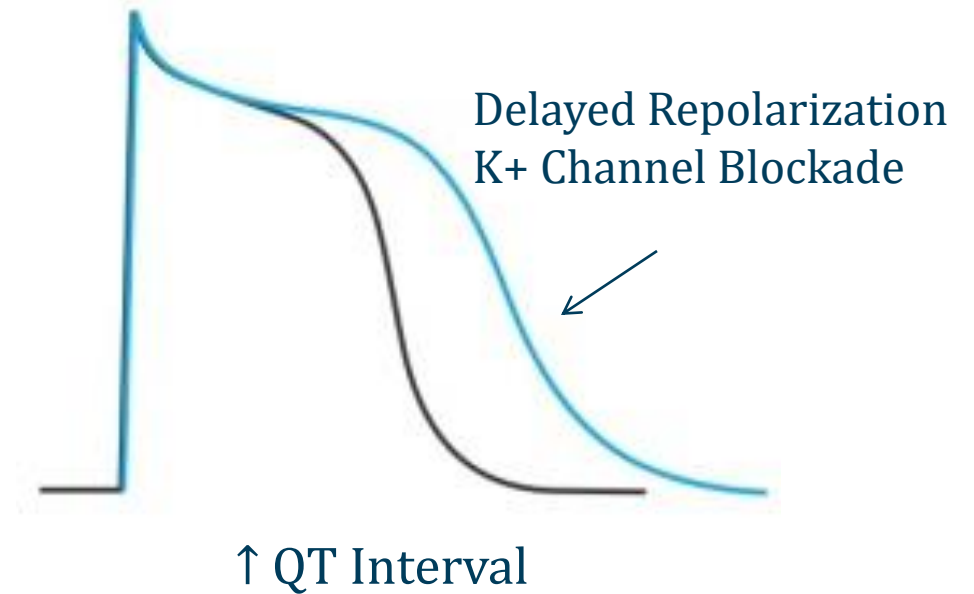


# Vaughan Williams Classification

<u><b>Class I</b></u>	<u><b>Class II</b></u>
<div>Quinidine } Procainamide } Ia</div> <div>Lidocaine } Mexiletine } Ib</div> <div>Flecainide } Propafenone } Ic</div>	Beta-blockers
<u><b>Class III</b></u>	<u><b>Class IV</b></u>
Amiodarone Sotalol Dofetilide Ibutilide	Ca-channel Blockers (Verapamil/Diltiazem)

# Amiodarone

- Class III drug
  - K channel blocker
  - Prolongs Qt interval
- Also has class I, II, and IV effects
  - Class II, IV: Slow HR
- Highly effective drug
- Suppresses atrial fibrillation
- Suppresses ventricular tachycardia

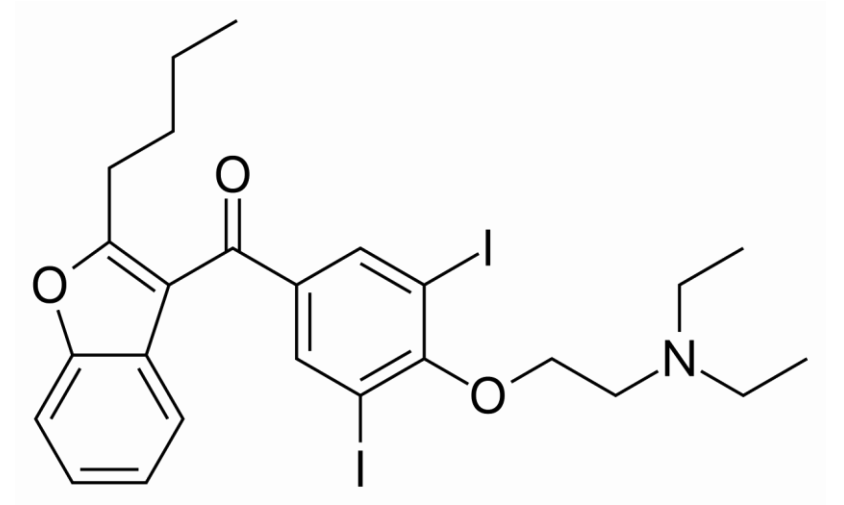


Amiodarone



# Amiodarone

- Highly **lipid soluble**
- Accumulates in liver, lungs, skin, other tissues
- Half-life **about 58 days**
- Once steady state reached, very long washout
- Safe in renal disease (biliary excretion)



Amiodarone

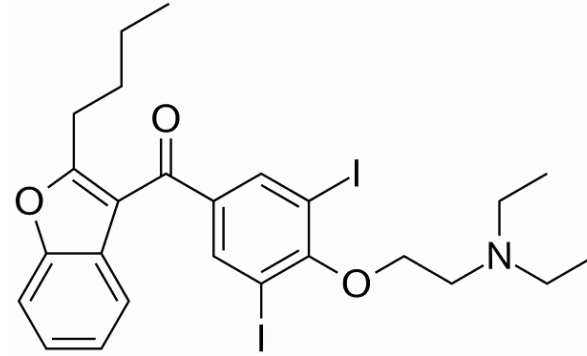
# Amiodarone

- Many potential side effects related to accumulation
- Less likely at lower dosages
- Risk accumulates over time
- Young patients on indefinite therapy at greatest risk
- Often used in older patients

# Amiodarone

## Side Effects

- **Hyper and hypothyroidism**
  - Contains iodine
- **Increased LFTs**
  - Usually asymptomatic and mild
  - Drug stopped if elevation is marked
- **Skin sensitivity to sun**
  - Patients easily sunburn



Wikipedia/Public Domain

# Amiodarone

## Side Effects

- **Blue-gray discoloration**
  - Less common skin reaction
  - “Blue man syndrome”
  - Most prominent on face
- **Corneal deposits**
  - Secretion of amiodarone by lacrimal glands
  - Accumulation on corneal surface
  - Appearance of “cat whiskers” on cornea
  - Does not usually cause vision problems
  - See in many patients on chronic therapy



Abby Crawford/Youtube/Public Domain



# Amiodarone

## Side Effects

- **Pulmonary fibrosis**
- Most common cause of death from amiodarone
- Foamy macrophages seen in air spaces
- Filled with amiodarone and phospholipids
- “Honeycombing” pattern on chest x-ray



Public Domain

# Amiodarone

## Side Effects

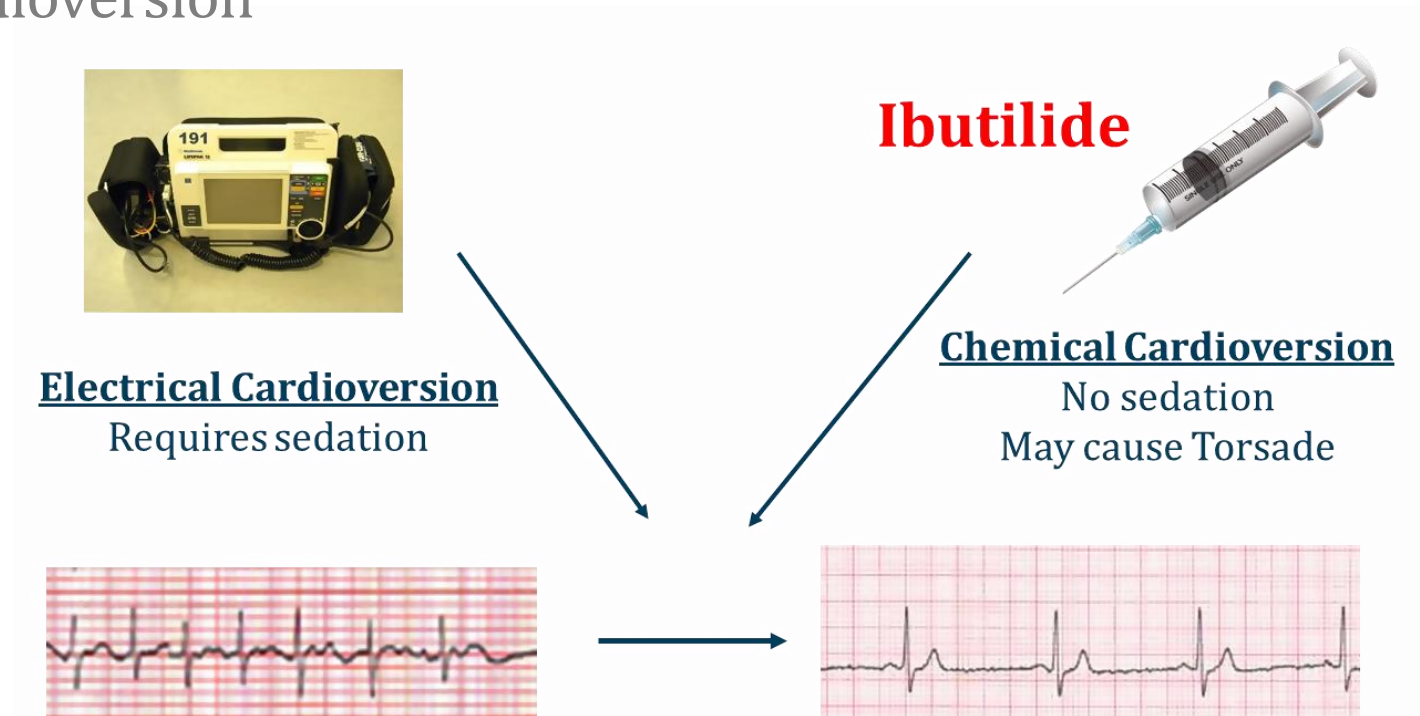
- When starting amiodarone
  - Chest X-ray
  - Pulmonary function tests (PFTs)
  - Thyroid function tests (TFTs)
  - Liver function tests (LFTs)

# Sotalol and Dofetilide

- Commonly used in patients with **atrial fibrillation**
- Typical case
  - Recurrent episodes symptomatic atrial fibrillation
  - Sotalol/Dofetilide started
  - Cardioversion to restore sinus rhythm
  - Sinus rhythm persists on therapy
- Other antiarrhythmics also used in this manner
  - Amiodarone
  - Propafenone
  - Flecainide

# Ibutilide

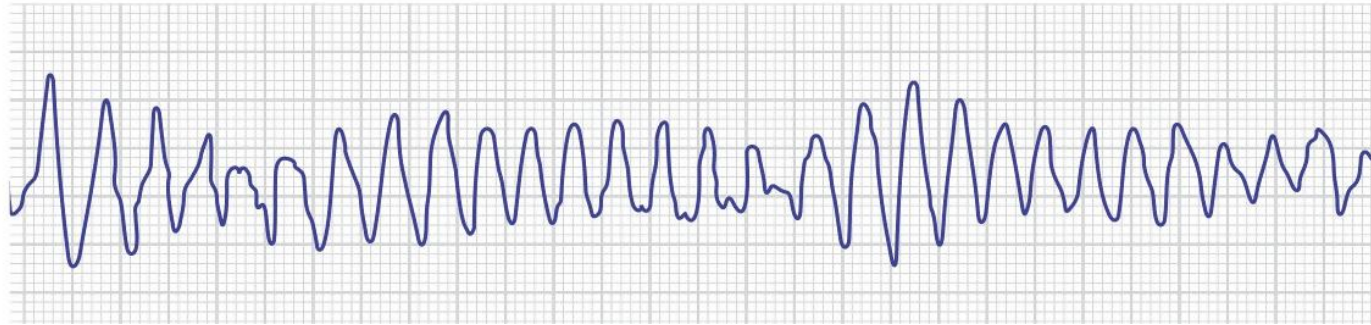
- Intravenous drug
- Half life of 2 to 12 hours
- Used for “chemical cardioversion”





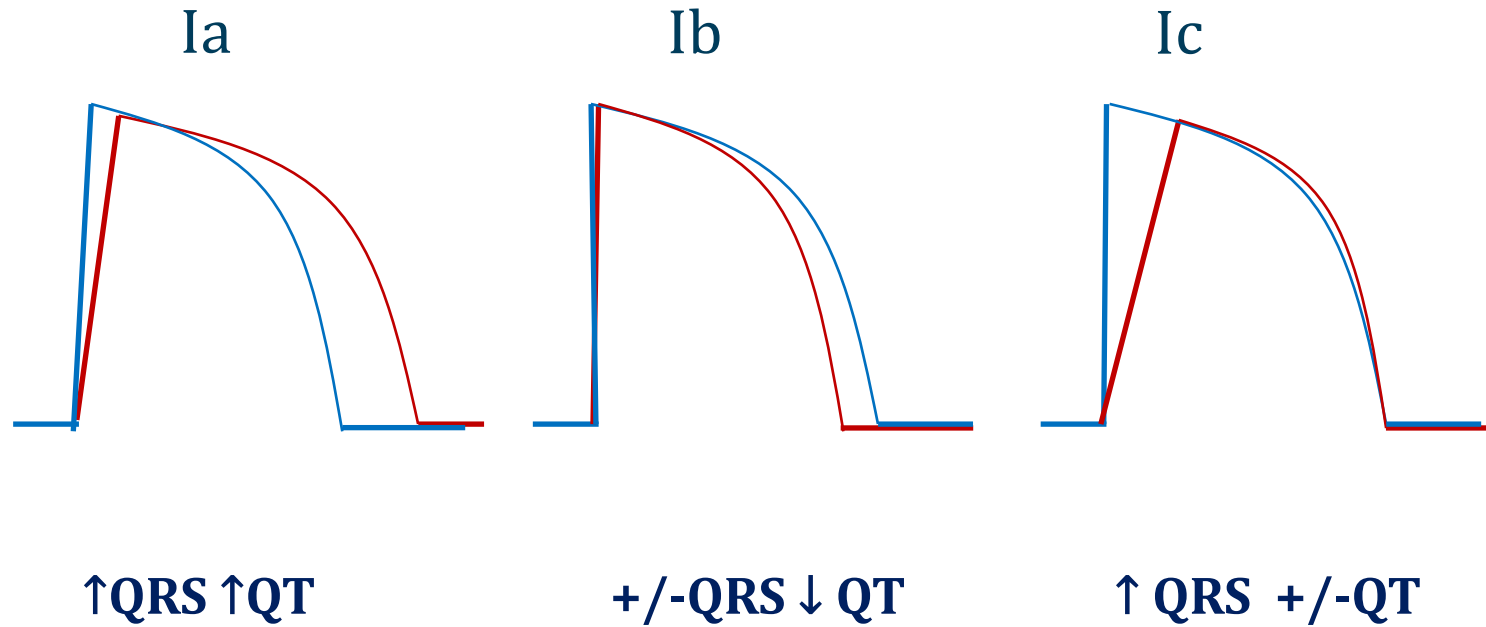
# Class III Antiarrhythmic Drugs

- Amiodarone, sotalol, dofetilide, ibutilide
- Major adverse effect: prolongation of Qt interval
- Increased risk of **torsades de pointes**



# Class I drugs

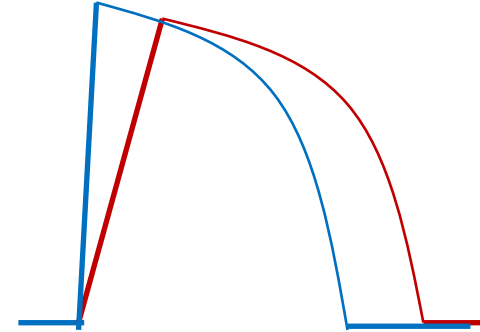
## Effects on Resting Action Potential



# Class Ia Drugs

Quinidine, procainamide

- **Prolong QRS**
- **Can also prolong Qt** ( $\downarrow K^+$  outflow)
- Quinidine
  - Oral drug
  - Can decrease recurrence rate of atrial fibrillation
  - Associated with increased mortality
- Procainamide
  - Intravenous drug
  - Slows conduction in accessory pathways (WPW)
  - Used in arrhythmias associated with bypass tracts



# Procainamide

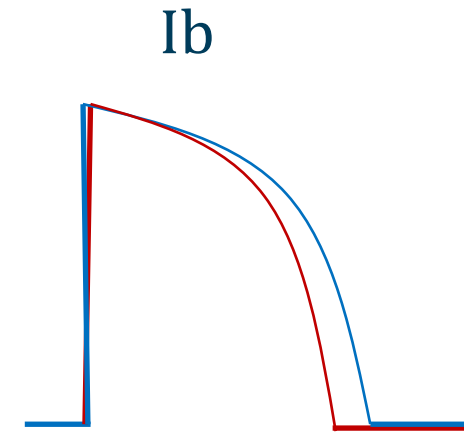
- Associated with **drug-induced lupus**
  - Classic drugs: **INH, hydralazine, procainamide**
- Often rash, arthritis, anemia
- Antinuclear antibody (ANA) can be positive
- Key features: **anti-histone antibodies**
- Resolves on stopping the drug



# Class Ib Drugs

Lidocaine, Mexiletine

- Na channel blockers
- Most Na channel binding in **depolarized state**
- Ischemia → more depolarized myocytes
- Effective drugs in ischemic arrhythmias
- More effective at fast heart rates
- Less time to unbind before Na channels open again
- Main use: ischemic ventricular tachycardia
  - Fast heart rates
  - Depolarized Na channels



**+/-QRS ↓ QT**

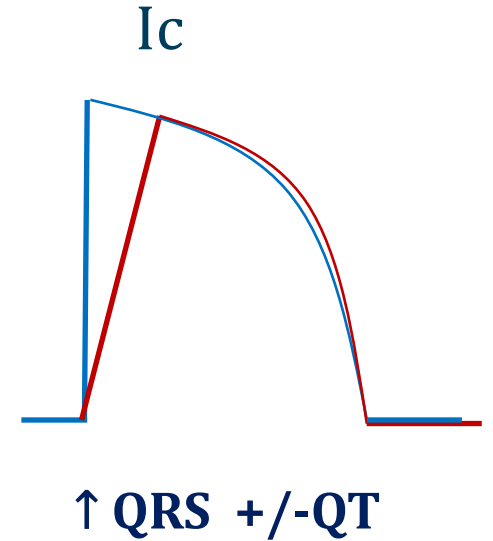
# Class Ib Drugs

Lidocaine, Mexiletine

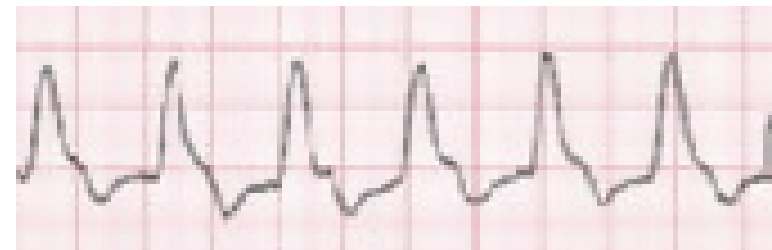
- Lidocaine also a local anesthetic
  - Na channel nerve block
- May cause **CNS stimulation**
  - Tremor, agitation
  - Tremor in patient on Mexiletine = toxicity
- Cardiovascular side effects
  - From excessive block of Na channels
  - Bradycardia, heart block, hypotension

# Class Ic Antiarrhythmic Drugs

- Flecainide, propafenone
- Used for suppression of atrial fibrillation
- Only used in patients with “structurally normal hearts”
  - Normal LV function
  - No significant valvular disease
- Major adverse effect: **prolongation of QRS interval with exercise**



**Baseline**

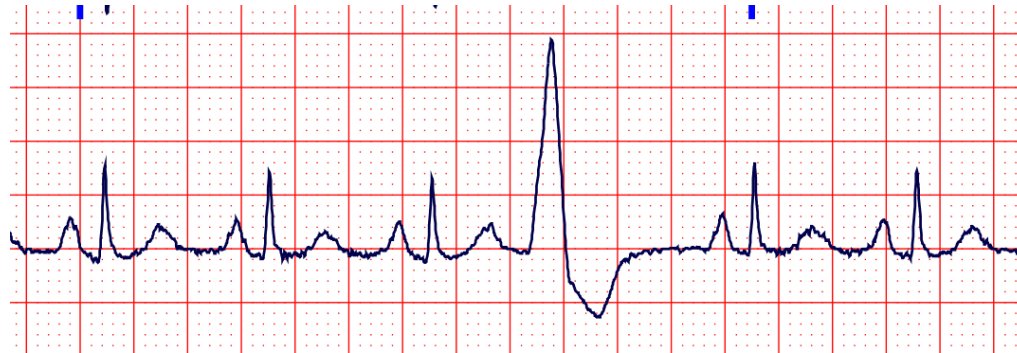


**Exercise**

# Antiarrhythmic Drugs

- Class I and class III agents associated with **increased mortality**
- Only used when absolutely necessary
  - Recurrent ventricular tachycardia
  - Highly symptomatic atrial fibrillation
- Not used for PACs or PVCs

Premature Ventricular Contraction





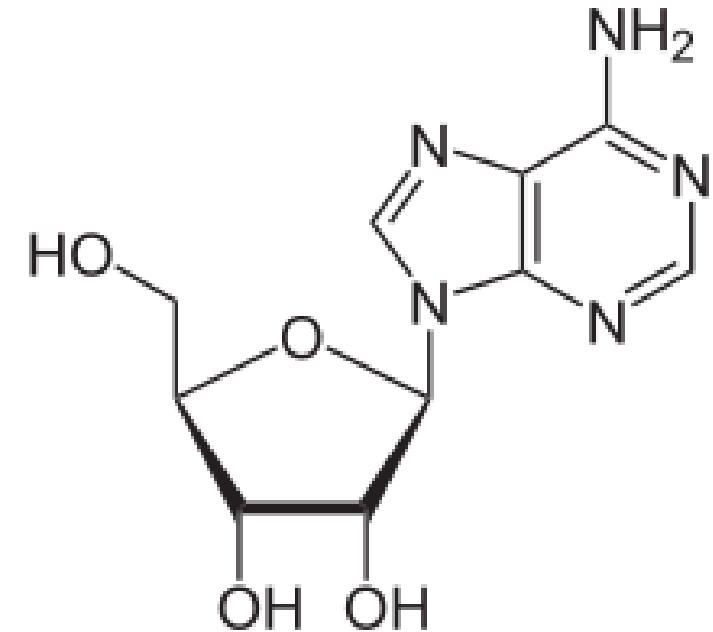
# Cardiovascular Pharmacology II

Jason Ryan, MD, MPH



# Adenosine

- AV nodal cells:
  - **Activates K<sup>+</sup> channels**
  - Drives K<sup>+</sup> out of cells
  - Hyperpolarizes cells: Takes longer to depolarize
- Result: **Slowing** of conduction through AV node



# Adenosine

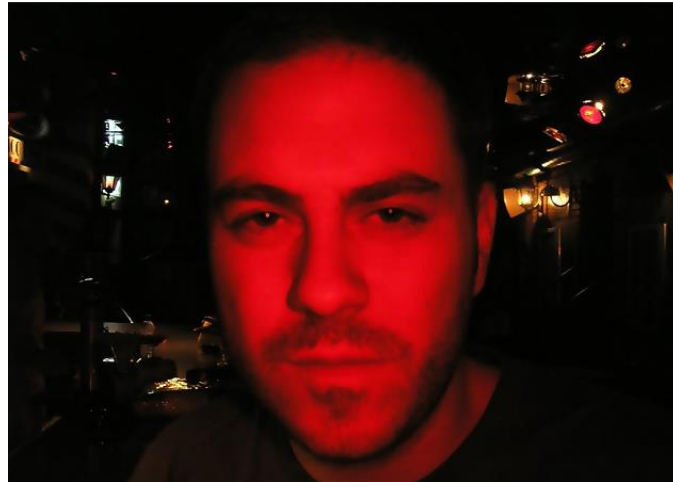
- Short half life – given IV
- Used to treat supraventricular tachycardias
- Most common SVT: **AV node reentrant tachycardia (AVNRT)**
- Slow and fast circuits in AV node → arrhythmia
- Adenosine slows AV node conduction → arrhythmia with terminate

SVT Break with Adenosine



# Adenosine

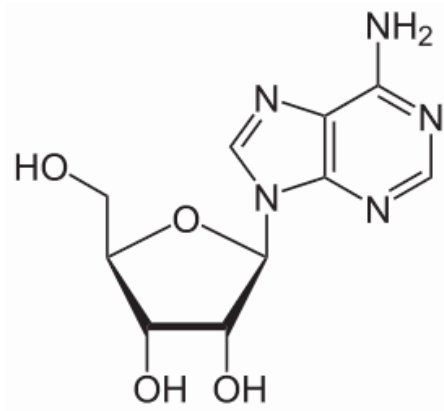
- Also a vasodilator
- Causes skin flushing, hypotension
- Some patients also develop dyspnea, chest pain
- Effects quickly resolve
- Must warn patients before administration for SVT



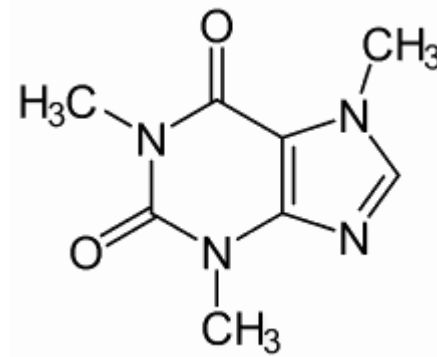
Jorge González/Flickr

# Adenosine

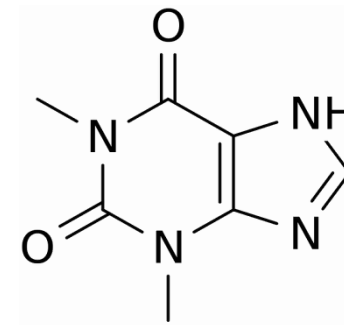
- Effects blocked by **theophylline** and **caffeine**
- Block adenosine receptors



Adenosine



Caffeine



Theophylline

# Atropine

- Muscarinic receptor antagonist
  - Parasympathetic block → ↑ HR and AV conduction
- Used in bradycardia → **↑ heart rate**
- Also speeds conduction through AV node
- Useful for bradycardia from AV block



Before Atropine



After Atropine

# Atropine

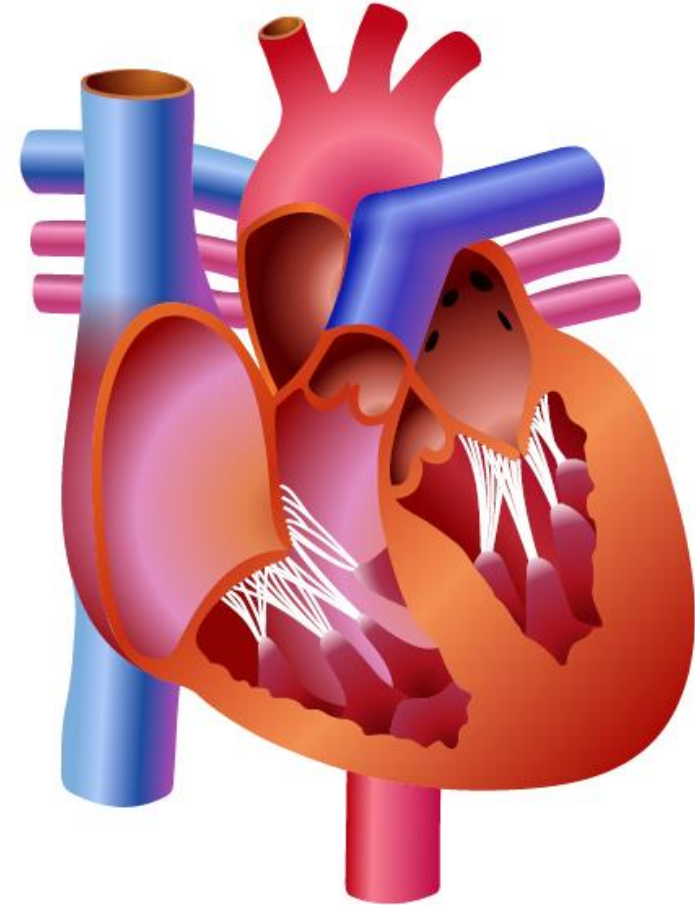
- Many **side effects** related to muscarinic block
- Toxicity:
  - Dry mouth
  - Constipation
  - **Urinary retention**
  - Confusion (elderly)



Wikipedia/Public Domain

# Digoxin

- Two cardiac effects
- **#1: Increases contractility**
  - Used in systolic heart failure with ↓ LVEF
- **#2: Slows AV node conduction**
  - Used in atrial fibrillation to slow ventricular rate

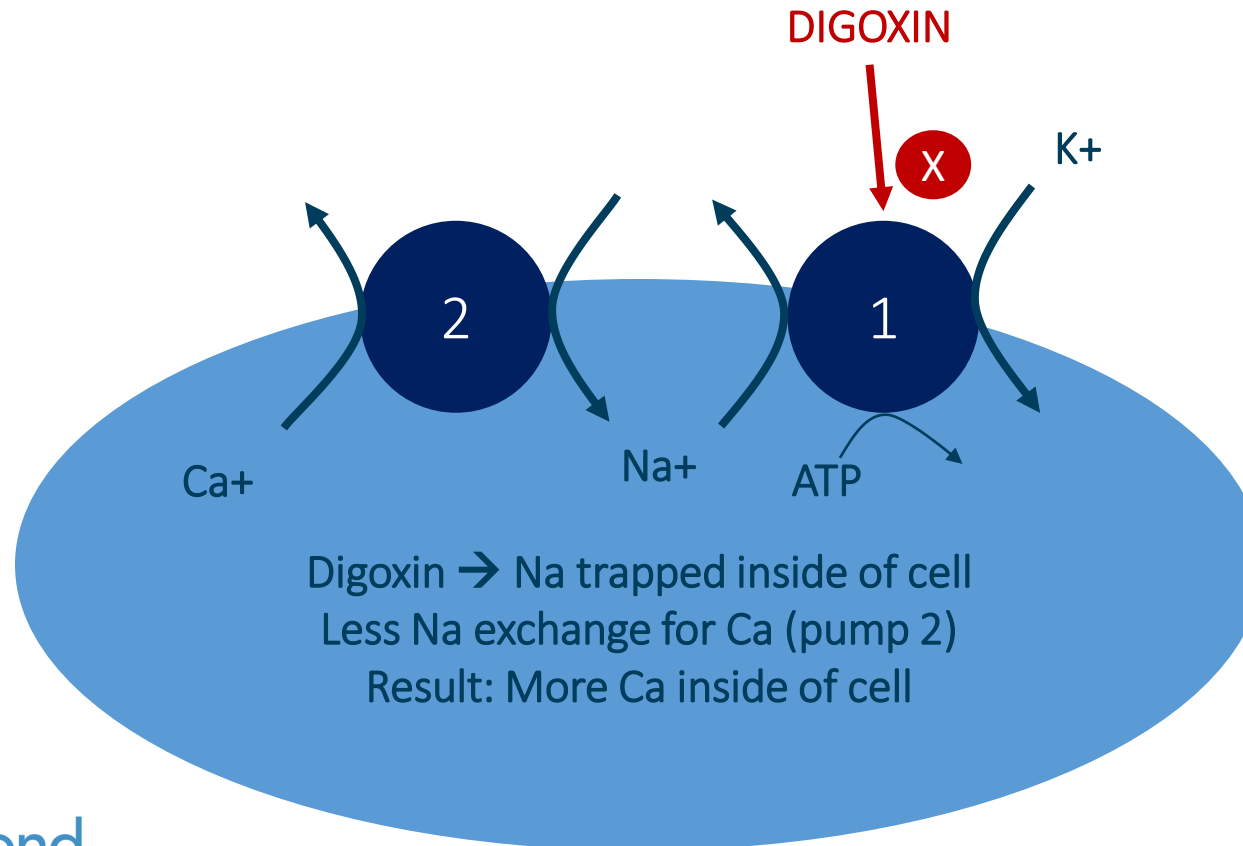




# Digoxin

## Increased Contractility

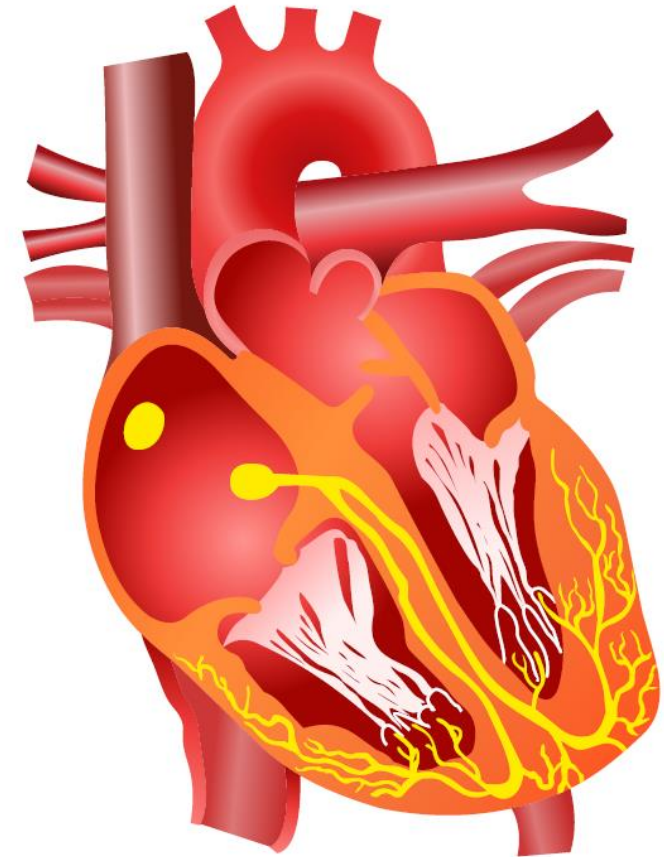
- Inhibits Na-K-ATPase



# Digoxin

## AV Nodal Slowing

- Suppresses **AV node conduction**
  - Increased vagal (parasympathetic) tone
  - Separate effect from blockade of Na-K-ATPase
- Can be used to ↓ heart rate in rapid atrial fibrillation
  - Continued atrial fibrillation
  - Fewer impulses to ventricle → slower heart rate
- Effects similar to BB and CCB in AV node



# Digoxin Toxicity

- **Renal clearance**
  - Risk of toxicity in patients with chronic kidney disease
- **Hypokalemia** promotes toxicity
  - Caused by many diuretics, especially loop diuretics
  - Digoxin patient on furosemide → toxicity
- Levels often need to be monitored

# Digoxin Toxicity

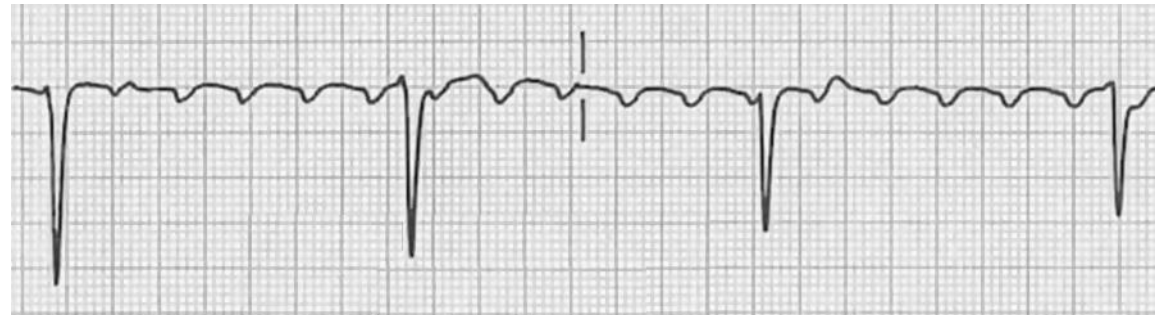
- Gastrointestinal
  - Anorexia, nausea, vomiting, abdominal pain
- Hyperkalemia
- Neurologic
  - Lethargy, fatigue
  - Delirium, confusion, disorientation
  - Weakness
- Visual changes
  - Alterations in color vision, scotomas, blindness
- Cardiac arrhythmias

# Digoxin Toxicity

## Cardiac Toxicity

- More Na inside of cell
- ↑ resting potential atrial/ventricular cells
- Increased automaticity
- **Extra beats:** PACs, PVCs
- Evidence of **AV node block**

### Atrial Tachycardia with AV block



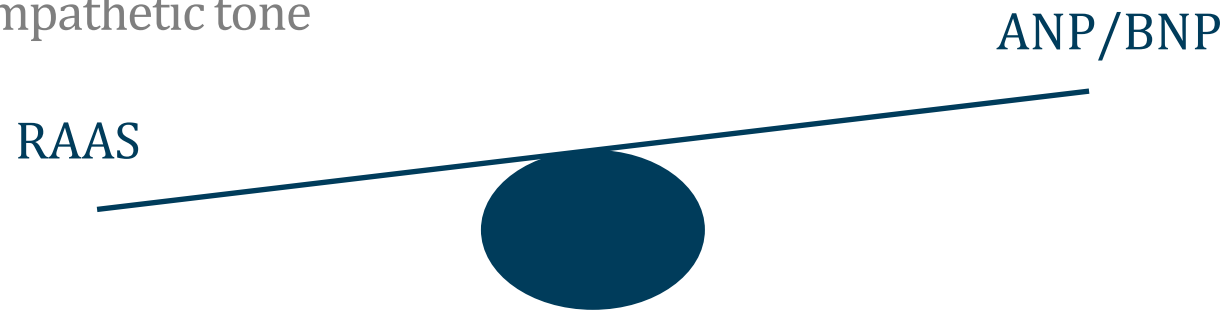
# Digoxin Toxicity

## Treatment

- **Digibind**
  - Antibody binds digoxin
- Correct **hyperkalemia**

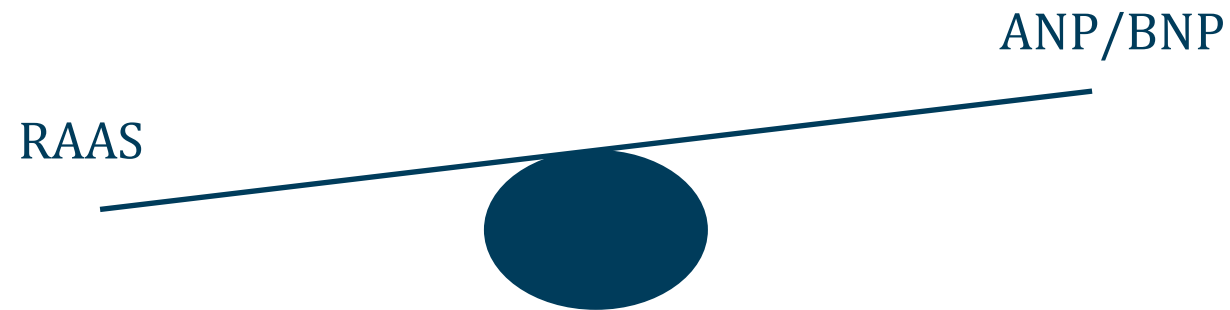
# Sacubitril

- Neprilysin inhibitor
- Neprilysin: Degrades atrial/brain natriuretic peptide
- Inhibition → **↑ANP/BNP**
  - Antagonists to RAAS system
  - Vasodilatation
  - Natriuresis (sodium excretion)
  - Diuresis (water excretion)
  - Reduced sympathetic tone



# Sacubitril

- Entresto: oral combination sacubitril/valsartan
  - Valsartan: angiotensin receptor blocker (ARB)
- ↓ **mortality**
- ↓ **hospitalizations**



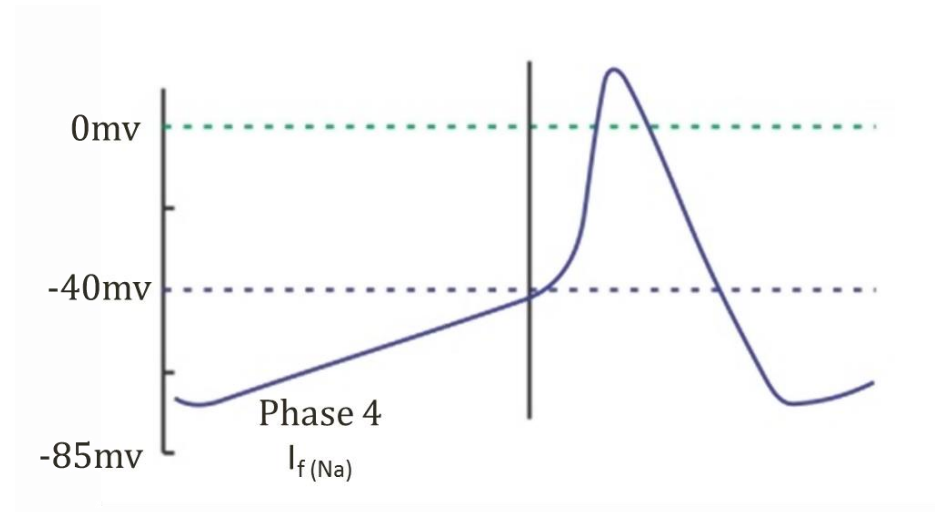


# Sacubitril

- Studied in combination with valsartan
- Many side effects similar to ARBs
- Hypotension
- Hyperkalemia
- Angioedema
  - Tissue swelling
  - Rare, feared adverse effect
  - Caused by elevated bradykinin levels
  - Neprilysin degrades bradykinin
  - **Cannot be given together with ACE inhibitors**

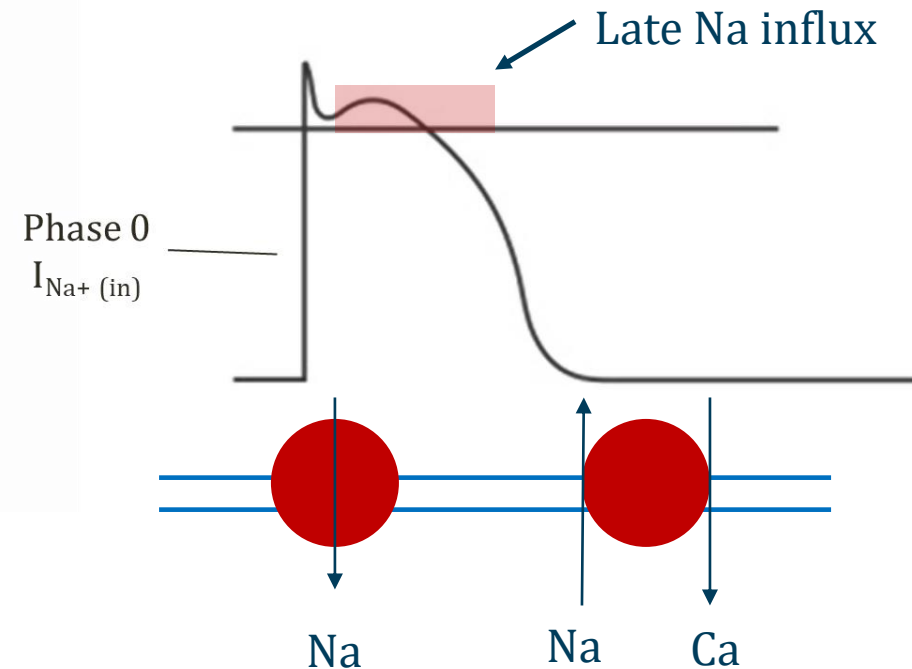
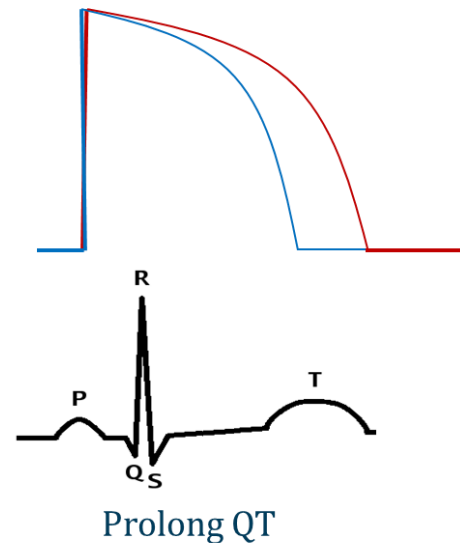
# Ivabradine

- Selective sinus node inhibitor
- Elevated HR → worse prognosis
- Slows heart rate without ↓ contractility
- Inhibits SA pacemaker **“funny current” ( $I_f$ )**
- Used in patients on max-dose beta-blocker with ↑HR
- Limited evidence of ↓ mortality and hospitalizations
- About 15% of patients experience **phosphenes**
  - Visual disturbance
  - Rings or spots of bright light



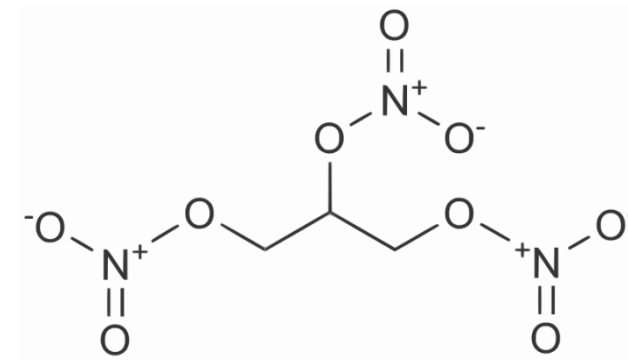
# Ranolazine

- Used for refractory angina
- Inhibits **late sodium current**
- Reduces **calcium overload** → high wall tension
- Reduces **wall tension** and O<sub>2</sub> demand
- QT prolongation



# Nitrates

- Used to treat stable angina
- Converted to nitric oxide → vasodilation
- Predominant mechanism is **venous dilation**
  - Bigger veins hold more blood
  - Takes blood away from left ventricle
  - **Lowers preload**
- Also arterial vasodilation (art << veins)
  - Increase coronary perfusion
  - Some peripheral vasodilation



Nitroglycerine

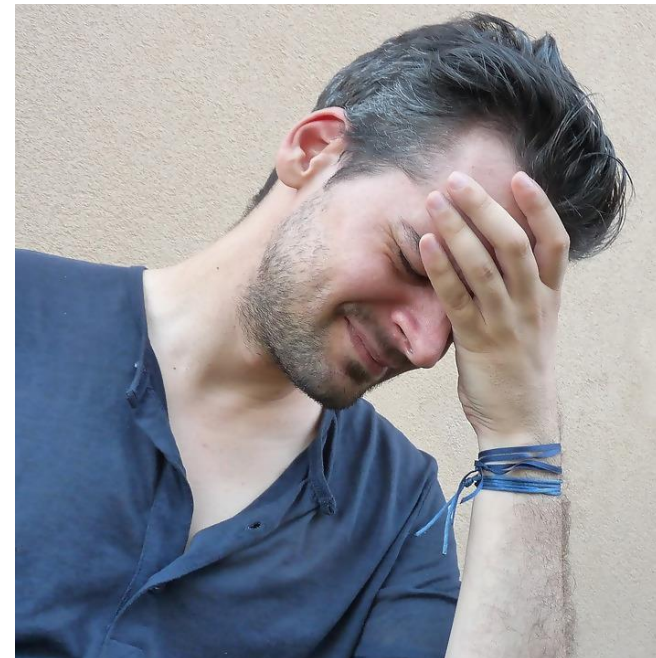
# Nitrates

- ↓ preload → ↓ cardiac output
- **Sympathetic nervous system activation**
- Increased heart rate/contractility
  - Increases O<sub>2</sub> demand
  - Opposite of what we want to do for angina
- **Co-administer beta-blocker or Ca channel blocker**
  - Blunts “reflex” effect

# Nitrates

## Adverse Effects

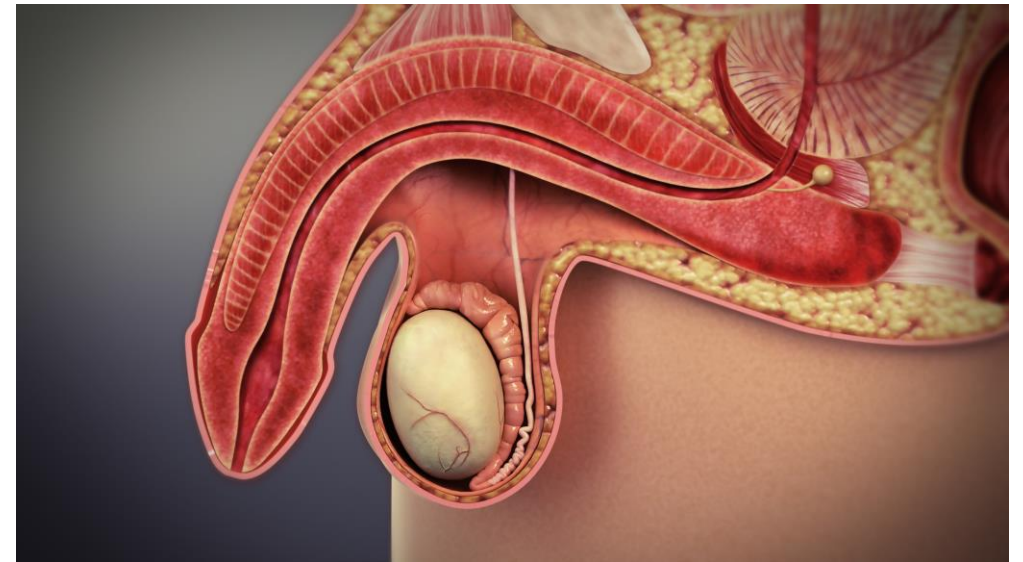
- Headache (meningeal vasodilation)
- Flushing
- Hypotension



phee/Pixabay/Public Domain

# Nitrates and Erectile Dysfunction

- ED common among men with coronary artery disease
- Sildenafil **contraindicated** in men taking nitrates
  - Life-threatening hypotension may occur



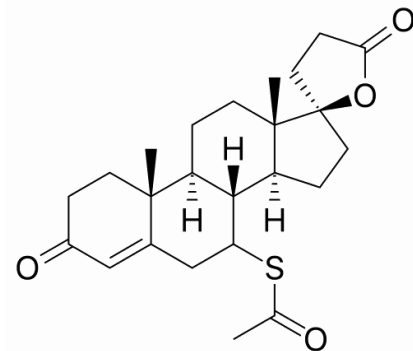
Wikimedia Commons/Public Domain

# Spirolactone, Eplerenone

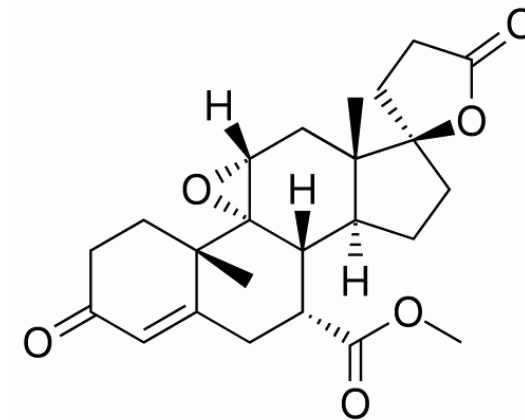
## Potassium-sparing diuretics

- Diuretics:  $\uparrow$ Na/H<sub>2</sub>O excretion
- “Spare” potassium
  - Unlike other diuretics, do not increase K<sup>+</sup> excretion
- **HYPERkalemia is side effect**
- Reduced mortality
- Reduced hospitalization rate

Check BUN/Cr and K<sup>+</sup> before starting drug  
Monitor BUN/Cr and K<sup>+</sup> after starting drug



Spirolactone



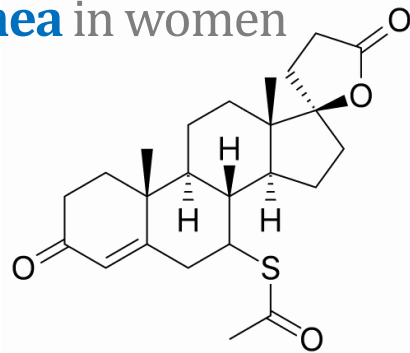
Eplerenone



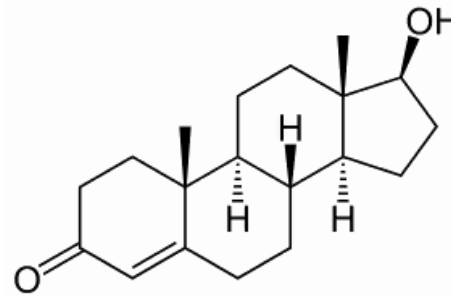
# Spirolactone, Eplerenone

## Potassium-sparing diuretics

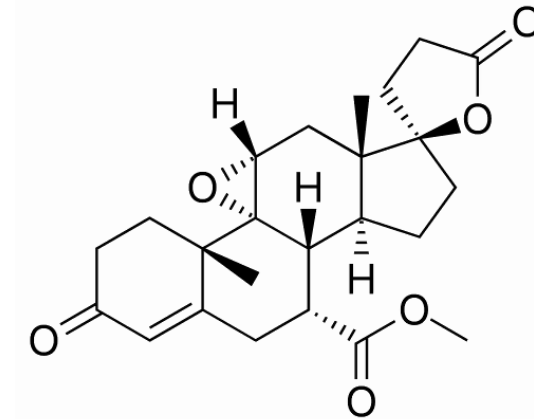
- Similar structure to testosterone
  - Blocks testosterone effects
  - **Gynecomastia** in men
  - Eplerenone: No gynecomastia
- Derivative of progesterone
  - Activates progesterone receptors
  - **Amenorrhea** in women



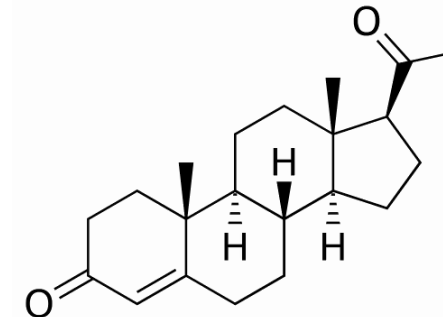
Spirolactone



Testosterone



Eplerenone



Progesterone

# ACE Inhibitors and ARBs

- **ACE Inhibitors**
  - Captopril, Enalapril, Lisinopril, Ramipril
  - Block conversion AI → AII
- **Angiotensin Receptor Blockers (ARBs)**
  - Candesartan, Irbesartan, Valsartan
  - Directly block AII receptor
- Both classes: **↓ mortality and hospitalizations**
- Side effects
  - Hyperkalemia (↓aldosterone)
  - Renal failure (↓GFR)

# ACE Inhibitors

## Unique Side Effects

- Due to increased **bradykinin**
- Dry Cough
  - Occurs in ~10% of patients
- Angioedema
  - Swelling of face, tongue
  - Can be life-threatening

