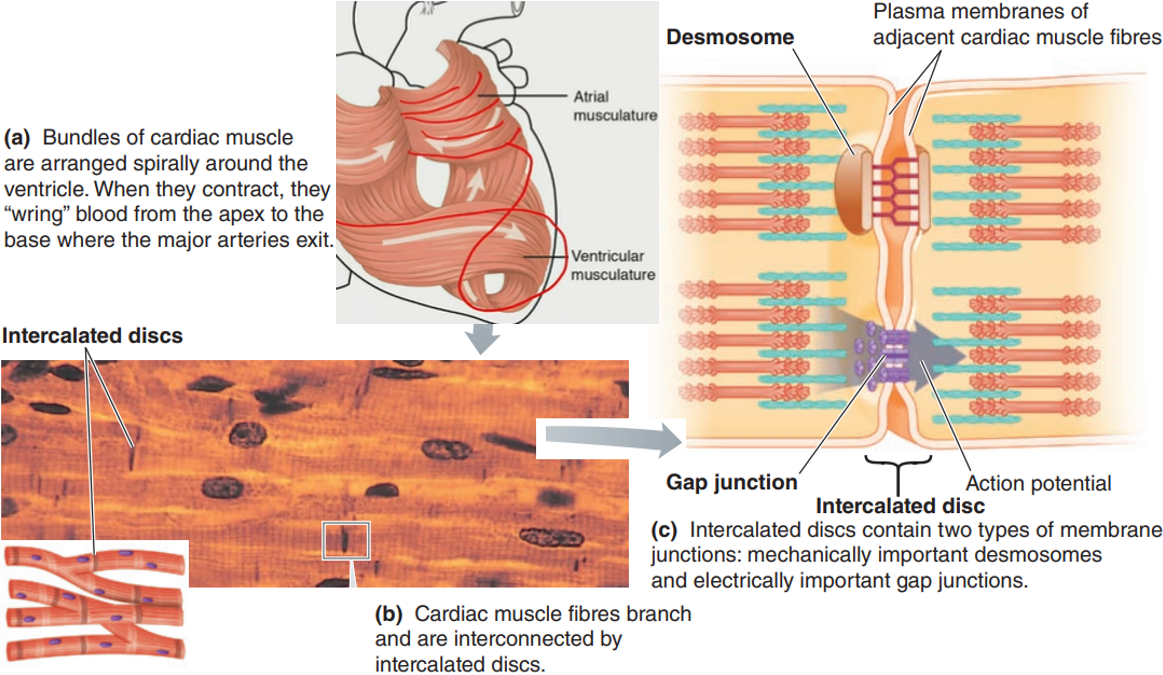
**Circulatory System**

* Heart, blood vessels, and blood
* **Pulmonary** (branch in to 2) & **systemic** (branch into many for many organs) circulation
  + ~ muscular system 25%, nervous 15%, digestive 25%, renal 25%

**Anatomy of the Heart**\* (label parts)

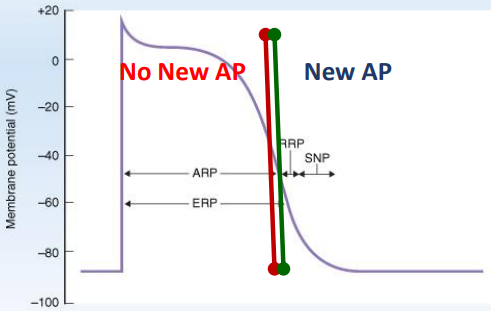
* Located in **thoracic cavity** (chest) in between the **sternum** (breastbone) anteriorly and the **vertebrae** (backbone) posteriorly, press on the bones to do CPR
* Diagram

  Description automatically generatedBase (top) to the right, **apex** (bottom tip) to the left; feels apex (ventricle beats harder)
* Valves:
  + **Atrioventricular** valves: right – **tricuspid** (3 cusps), left – **bicuspid** / mitral
    - Held back by **chordae tendineae** and **papillary muscle**
  + Aortic / pulmonary valves (**semilunar**) – 3 cusps
    - Held back by backwards pressure (not as strong) and anatomical structure
  + No valves between atria and veins
    - atrial pressures not much higher than venous pressures
    - during atrial contraction where vena cava enters atria partially compressed
  + **Fibrous skeleton**: 4 interconnecting rings of dense connective tissue
    - Diagram

      Description automatically generatedSingle plane that separates both atrium from ventricles, provides structure for cardiac muscle and valves (all 4 valves lies on the same plane)
* Wall: 3 layers + muscle
  + **Endothelium**: thin inner layer, special epithelial tissue, circulatory system
  + **Myocardium**: middle layer, composed of cardiac muscle, heart wall
    - Dominates heart contraction – spiral ring like structure, squeeze up
    - **Functional syncytium**: connected by **intercalated discs**, contracts in sync
      * Gap junctions (electrical) and desmosomes (mechanical)
      * Atria and the ventricles each form separate functional syncytium
      * Specialized conduction system between atria & ventricle
    - Entire heart contraction is **all or none**, can only control gradation
  + **Epicardium**: thick external layer, covers the heart
  + **Pericardium** (pericardial sac), double layered membrane, secrete **paracardial fluid** into paracardial cavity (between inner layer and epicardium, protection)

**Electrical Activities of the Heart**

* **Contractile** (99%) vs **Autorhythmic** (pacemakers: SA node, AV node, Bundle of His & Purkinje fibers) cells
* **Autorhythmicity**: heat beats (contracts) at its own, self generated rhythm
* Cardiac Excitation-Contraction Coupling:
  + Calcium enter cytosol through **L-type channels in T tubules**
  + Triggers **ryanodine receptors** (not dihydropyridine receptors in skeletal muscles) on SR to release calcium
  + After contraction, Ca–ATPase pumps calcium back to SR, a secondary pump (Ca out Na in, primary is Na-K pump that pumps Na out) pumps **Ca back to ECF**
* **Cardiac muscle AP**: characterized by long refractory period (plateau), can’t summate
  + Not enough Ca to interact with all troponins (unlike skeletal)
    - ↑ intracellular Ca => ↑ crossbridges => ↑ strength of cardiac contraction
  + **Depolarization**: still by Na influx
  + Chart, line chart

    Description automatically generated**Plateau**: primarily by slow L-type Ca channel (Ca in, maintain depolarized)
  + **Elongated absolute refractory**: Na channel inactivated due to maintained high potential, summation and tetanus impossible
    - AP lengths:
      * Atria: 150 ms
      * Ventricles: 250 ms
      * Purkinje fibers: 300 ms
      * Skeletal: 1-2 ms
    - **ARP** (absolute): Na channel inactive, can’t fire again
    - **ERP** (effective): at the end of ERP Na channels begin to recover but still insufficient to fire
    - **RRP** (relative): need greater stimulus to fire, new AP have shorter plateau
    - **SNP** (**Supranormal** **Period**): more excitable (higher potential)
  + **Repolarization**: still K efflux, slow & fast, slow is what causes repolarization
  + **No hyperpolarization**: K efflux is slow
  + Resting potential: maintained by inward rectifier K channel ( in graph is outward rectifier K), which is unique as it can move K both in and out of the cell
* **Pacemaker AP:** without external stimuli, do not have organized sarcomeres (doesn’t contribute to contractile force, only provide electrical signal to set heart rate)
  + **Pacemaker cells**: sinoatrial node (**SA node**, fastest, set rate) => atrioventricular node (**AV node**) => **bundle of His** (atrioventricular bundle) & **purkinje** fibres
    - Normally driven by SA node, if SA fails AV (latent pacemaker) takes over
    - **Ectopic focus**: region where AP initiates elsewhere that’s faster than SA, often caused by anxiety => premature ventricular contraction (PVC)

|  |  |  |
| --- | --- | --- |
| Location | Duration of Action Potential (msec) | Intrinsic Firing Rate (impulses/min) |
| Sinoatrial node | 150 | 70-80 |
| Atrioventricular node | 150 | 40-60 |
| Bundle of His | 250 | 40 |
| Purkinje fibers | 300 | 15-20 |

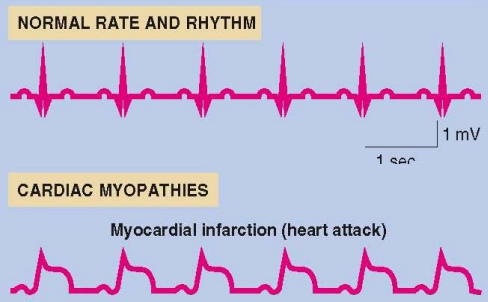
* + **Pacemaker potential**: (funny, Na & K open by hyperpolarization, Na more) => (Ca open by slight depolarization) => (Ca open at threshold instead of Na, close) => (K open by high potential like in normal AP, Ca close)
    - No resting potential, starts at ~ -**60 mV**
    - Diagram

      Description automatically generatedDiagram

      Description automatically generatedUses lots of **Ca channels** for depolarization (instead of Na), slower
* Impulse conduction:
  1. Atrial contraction:
     + rapid transmission of AP through the **interatrial pathway**, so
     + **2 atria contract about simultaneously**
     + ~160 ms **before ventricles** (blocked by fibrous tissue) to ensure complete filling of the ventricles (~80% auto, ~20% from atrial contraction)
  2. **Internodal pathway**: delay from SA through AV (so atrial finishes contraction)
     + Only pathway from atrial to ventricle
  3. Ventricle contraction:
     + rapid transmission of AP through bundle of His and purkinje fibres, so
     + **all ventricle muscles contract about simultaneously** (the 2 ventricles also contract together)
* **Fibrillation**: muscles didn’t contract at same time, deadly in ventricles (not as deadly in atria); electrical defibrillation can depolarize all to correct it

**Electrocardiogram (ECG/EKG)**

* **Small amplitude** (1 mV vs 110 mV for AP): only records part of the electrical activity that reaches the body surface
* **Sum** of electrical activity in all cardiac cells, temporal & spatial summation
* Records **DIFFERENCE** in voltage detected by electrodes at two different points
  + Not a direct recording of actual electrical activity
  + No recording if ventricular muscle is completely depolarized or completely repolarized
  + Signals are translated by ECG machine
* Depends on the **ORIENTATION** of the recording electrodes (leads)
  + 3 Standard Bipolar Limb Leads (**Einthoven triangle**): 2 arms and left leg, triangle with center over heart, 3 leads
  + 12 conventional electrode system: 6 leads from the limbs and 6 leads from chest (around the heart)
* A picture containing chart

  Description automatically generatedReading ECG record:
  + **Records trigger** of contract/relax, (all muscles contract/relax no difference - flat)
    - Pacemaker signals (SA, AV) not recorded, too small to reach body surface
  + Common abnormalities:
    - Rate: heart rate measured from distance between QRS complexes
      * >100: **tachycardia** (tachy means “fast”)
      * < 60: **bradycardia** (brady means “slow”).
    - Rhythm: spacing/sequence of events; **arrhythmia** is abnormal rhythm, some examples are
      * **Extrasystoles**: PVC from ectopic focus, extra peak/wave
      * **Atrial flutter** (atrial too fast) & **heart block** (problematic conduction between A and V): more P than QRS (2:1 or 3:1)
      * **Fibrillation**: no definite P (atria) or QRS (ventricle, deadly)
    - Cardiac myopathies: damage/death (**necrosis**) of heart muscles
      * **Myocardial ischemia** (inadequate oxygen) / inadequate blood supply => heart attack (**acute myocardial infarction**)
        + Likely cause is vessel blocked or ruptured
      * Abnormal QRS complex + characteristic enzymes in blood

**Artificial Pacemakers**

* If the SA node is not fast enough, or there is a block in the heart’s electrical conduction system, an artificial pacemaker will maintain an adequate HR
* **Hopps’ First External Pacemaker**
  + vacuum tube technology, crude and painful
  + potential hazard of electrocution by ventricular fibrillation
* **Modern pacemaker**: implanted into the body
  + May be a combination of a pacemaker and defibrillator
  + May have multiple electrodes stimulating multiple sites within the heart to improve synchronization of the ventricles
  + Externally programmable: pacing modes must be optimized/individual

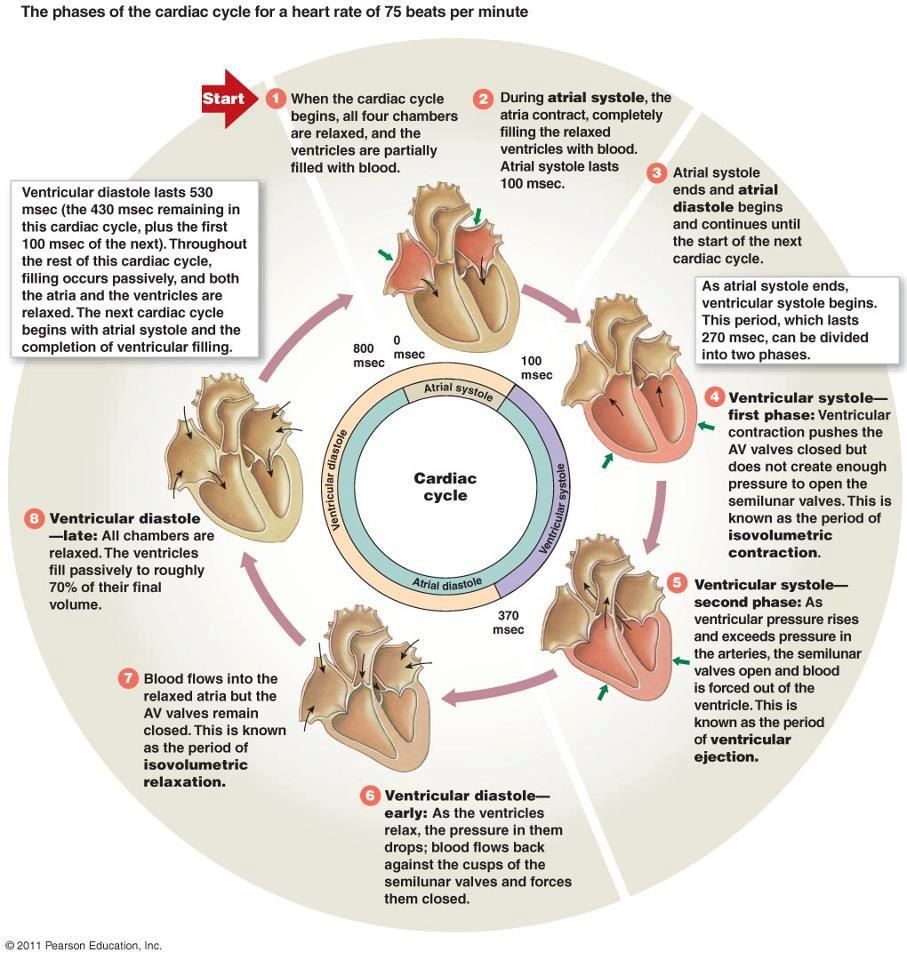
**Cardiac Muscle Mechanical Properties**

* **Contractile activity**: overlap between actin and myosin fibres & [ECF Ca2+ ]
* Diagram

  Description automatically generatedActin & myosin similar to skeletal muscle
* **Nebulette** is the myocardial form of **nebulin** (anchor for thin filaments)
* **Synchronized conduction**: gap junctions & desmosomes through intercalated disks
* **Nourishment**: coronary circulation: varying amount, receives mainly during diastole

**Mechanical Events of the Cardiac Cycle**

* **Systole** (contraction and emptying) vs **diastole** (relaxation and filling): different for atria and ventricle, conventionally refers to ventricle activity
* **Stroke volume** (SV, ~70 ml): end-diastolic volume (EDV, ~135 ml) – end-systolic volume (ESV, ~65 ml)



Diagram

Description automatically generated

\* Isovolumetric contraction is similar to isometric contraction of muscles

\* Both valves are closed when aortic > V > A pressure

S (systole)

A (atrial) (empty)

IC

IR

E (empty)

This is where stroke volume is measured

\*Valves controlled by pressure!

This is where blood pressure is measured

**Heart sounds**

* 2 sounds, first is “lub” as AV close (QRS peak), second is “dub” at semilunar close (T wave peak)
* **Murmur**: heart sound from turbulent flow (vibration sounds), valve malfunctions
  + **Stenotic valve**: narrowed valve, does not open completely (whistle sound)
  + **Insufficient valve**: cannot close completely (swishing or gurgling murmur)
    - Regurgitation/leaky valve
  + **Rheumatic fever**: autoimmune disease triggered by bacteria, damage valves
  + Sound, location and timing of the murmur can be used to identify valve   
    (Lub-Whistle-Dup => stenotic semilunar, Lub-Dup-Whistle => stenotic AV,   
    Lub-Swish-Dup => insufficient AV, Lub-Dup-Swish => insufficient semilunar)

**Cardiac Output and its Control**

* **Cardiac output (CO):** HR\*SV**,** volume of blood pumped by each ventricle per minute
  + **Cardiac reserve:** difference between CO at rest and at maximum exercise
* \***Cardiovascular control centre**: brain stem (medulla) => both division of ANS => cyclic AMP second-messenger system => heart rate & stroke volume (sympathetic only)
  + **Parasympathetic**: vagus nerve => acetylcholine => A, SA, AV
    - Increase K permeability of SA, AV (decrease rate)
    - Shortens plateau (contractility) of A
  + **Sympathetic**: norepinephrine & epinephrine (hormone, indirectly) => receptors => A (little), SA, AV, V
    - Increase Ca current (increase rate of SA, AV, contractility of A, V)
    - Increases **venous return** (EDV) by constricting blood vessels
  + Normal HR of 70 is **already under parasympathetic control**
* **Stroke volume** (EDV - ESV): intrinsic (length-tension) vs extrinsic (sympathetic) control
  + \***Frank–Starling law**: intrinsic relationship between EDV and stroke volume
    - diastolic filling, EDV (preload/venous return), stretching of heart, fiber length before contraction, contraction strength, stroke volume
      * Cardiac muscles are always below optimal length (overlaps)
      * Stretching also make thin & think filaments closer (squeezed)
    - **Equalize of output** between the right and left sides of the heart
    - Text

      Description automatically generatedRespond to venous return from sympathetic nervous system