Lecture 15, Mar 16, 2023

Electrocardiogram (ECG)

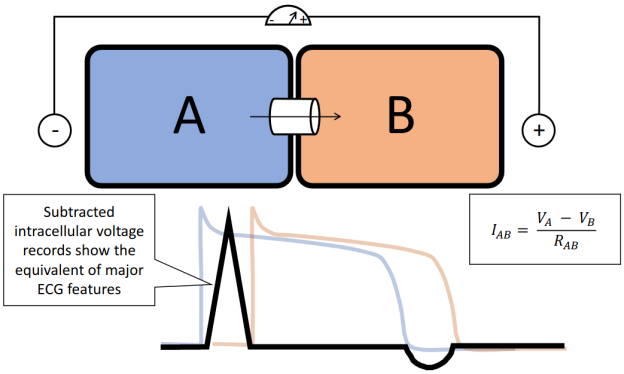

Figure 1: Subtraction of action potentials

- Consider 2 cells attached with a gap junction; what if we measure the potential of the entire unit?
  - Since the action potential has to go through the 2 cells, the second cell's action potential is delayed
  - An electrode outside the cells shows the voltage difference on the two sides
- First the sinoatrial node fires, then the atrial muscle depolarizes; the atrioventricular node depolarizes and then spreads the action potential to the other heart tissue

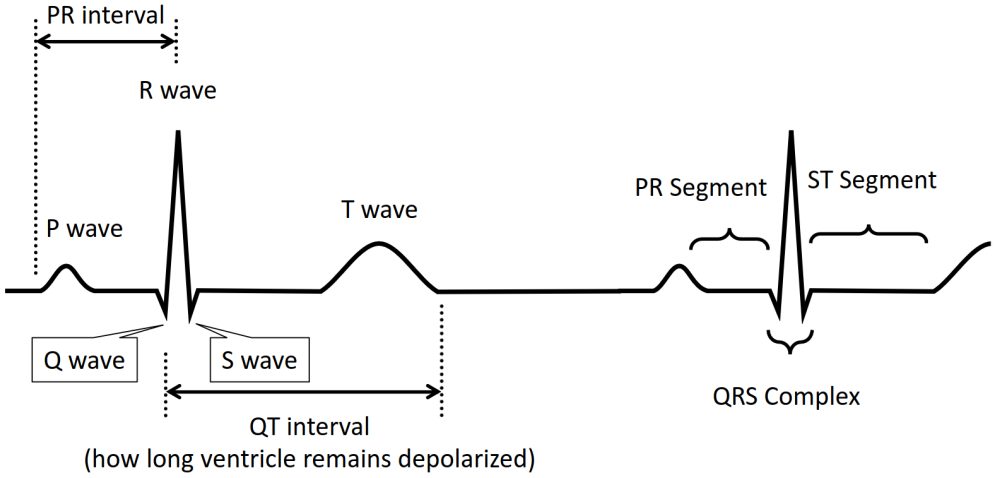

Figure 2: Structure of an ECG wave

- The P wave is caused by the atrial action potential; because there isn't as much atrial muscle mass, the P wave is small
- After a short delay the ventricular action potential fires, and since there is more ventricular muscle, it creates a large spike (the R wave)
  - Since ventricular muscles are synchronized this is a very sharp peak
- Cardiac muscles conduct much slower than neurons and skeletal muscles and have a large range of speeds

Sequence of Depolarization/Repolarization

- Depolarization sequence:

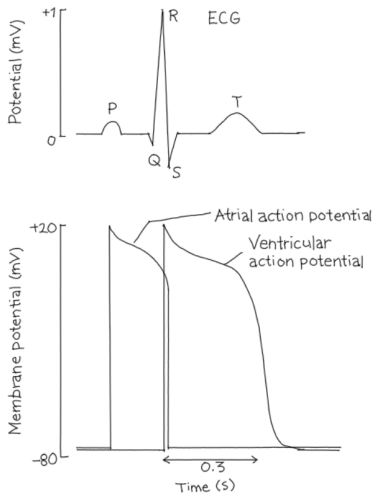

Figure 3: ECG wave forming as a result of depolarization of different parts of the heart

Cell	Velocity (m/s)
Neuron: Large and myelinated	100
Muscle: Skeletal	3 – 5
Muscle: Cardiac	0.05 - 4
Muscle: Smooth	0.015 – 0.15

Figure 4: Comparison of conduction velocity

1. The sinoatrial node depolarizes
   - The SA node has a very slow conduction velocity (0.05 m/s), since only calcium is used to depolarize
2. The depolarization spreads through atrial pathways (1 m/s)
3. The action potential reaches the atrialventricular node
   - This also spreads very slowly (0.05 m/s)
   - Passing through this node is the only way to depolarize the ventricular muscles
4. Action potential goes through bundle of his (muscle in the middle of the cell) (1 m/s)
5. Purkinje system (septum, the muscle separating the 2 sides of the heart, is depolarized) (4 m/s)
6. The bulk of the ventricular muscles are depolarized (anteroseptal region, near the side of the chest) (1 m/s)
   - This goes down and spreads back up
7. The posterior portion of the base of the left ventricle is depolarized

- Repolarization sequence starts with the ventricular muscles, starting at the epicardial side (i.e. outside in, opposite to the direction of depolarization)

ECG Waveform

- Positive electrode below the heart, negative electrode above the heart defines the direction
  - The depolarization moves from the negative electrode to the positive electrode
- Sequence of the waveform:
  1. The atrial muscle depolarizes, creating the small P wave
  2. After a short delay through the atrialventricular node
  3. The septum is depolarizes from left to right, which is away from the positive electrode, creating the negative deflection of the Q node
  4. The ventricular muscles all depolarize towards the positive electrode, causing the large R wave
  5. The depolarization goes through the rest of the ventricular muscles, moving away from the positive electrode and causing the S node
  6. After a delay, the ventricular muscles repolarize, moving away from the positive electrode and creating the T wave; this isn't as coordinated, so the T wave is spread out
- Disturbances during the T wave could lead to ventricular fibrillation
  - Depolarization during the 20 ms upstroke of the T wave causes an action potential going in the wrong direction, messing up the heart rhythm
  - This could happen due to being hit by a ball, fist, etc

Cardiac Cycle

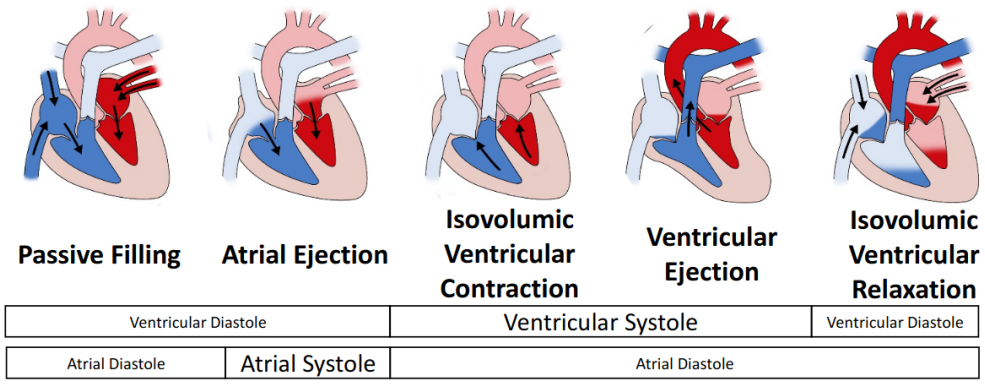

Figure 5: The cardiac cycle

- Ventricular diastole happens in 2 phases, first a passive filling and then an active atrial ejection

  - This is where the P wave happens
- At the end of diastole the mitral valve (valve between the left atrium and left ventricle) closes
  - This happens because the ventricle starts to squeeze (mitral valves are one way and are not muscles)
  - The start of this phase is the isovolumic ventricular contraction phase, when the contraction is enough to close the mitral valve but not enough to open the atrial valve
  - The contraction leads to a build up in pressure
- The pressure becomes enough that the aortic valve opens, leading to ventricular ejection
- At the end, the aortic valve closes as the muscles relax; the mitral valve opens after this
  - This is the isovolumic ventricular relaxation phase
- The mitral and aortic valves closing create audible sounds

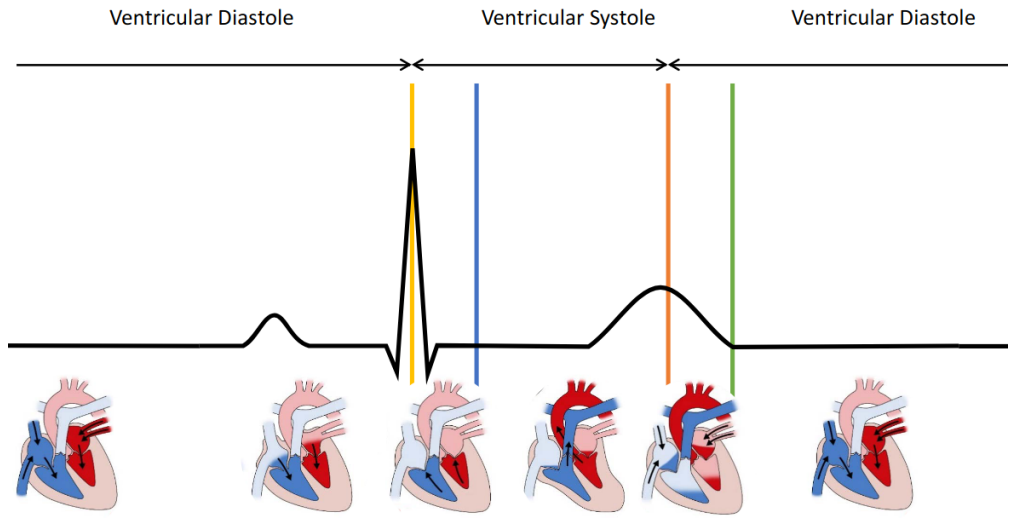

Figure 6: Mapping cardiac cycle events to the ECG waveform

- Where the left ventricular pressure exceeds the left atrial pressure, the mitral valves close; then after the left ventricular pressure comes back down, the mitral vales open as the pressure flips
  - This is why blood pressure has a high value and a low value

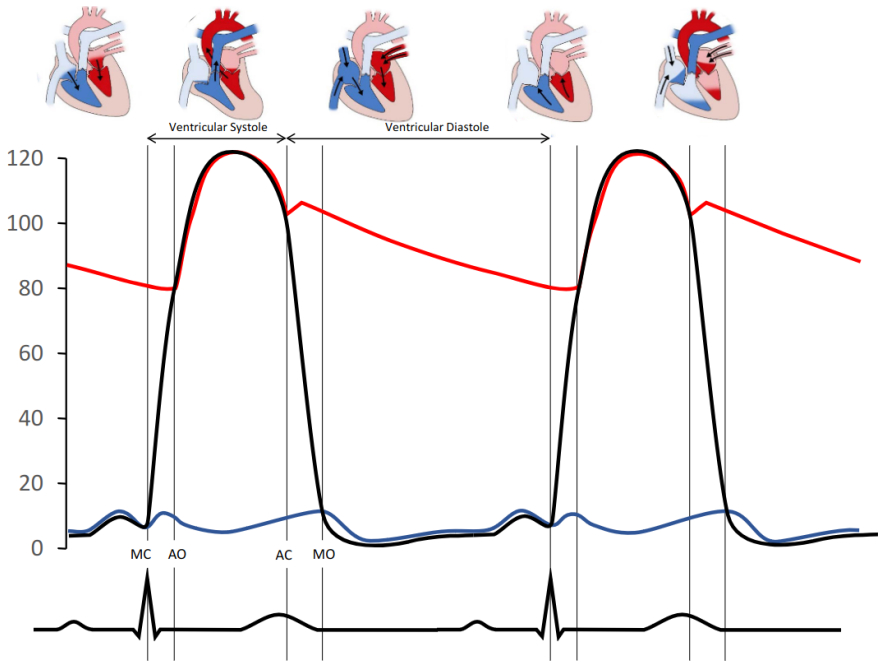

Figure 7: Blood pressure variations in the heart; blue shows the left atrial pressure, black shows the left ventricular pressure, red shows the pressure in the arteries