1.1: Anatomy and Physiology of the Heart

This segment is a prerequisite lecture in preparation for the EKG interpretation primer. A strong foundation in the anatomy and physiology of the heart is essential in understanding and interpreting EKGs. This segment will review that anatomy and physiology.

The above is a visual reminder of the structures of the heart. Of note, the tricuspid valve is also known as the right atrioventricular valve. The mitral valve is also known as the bicuspid valve or the left atrioventricular valve. Both terminology is correct. The tricuspid valve is *tricuspid* because it has 3 flaps that seal together to form the valve, anchored along the wall of the adjacent ventricle wall. The *bicuspid* valve only has 2 flaps.

The pulmonary and aortic valves are called semilunar valves. These valves are funnel-shaped and, while morphologically different from the cuspid valves, fulfill a similar function (preventing blood backflow). When you auscultate heart sounds with a stethoscope, the sounds you are hearing are the valves opening and closing.
Coronary Arteries

The coronary arteries provide the heart with its own dedicated blood supply. While the left ventricles do pump oxygen-rich blood to the rest of the body, the entire heart does still require their own blood supply. The coronary arteries are the first arteries that branch off the aorta.

For the time being, just be aware that there are coronary arteries, their job is to supply blood to the heart tissue, and make a mental note of where they are located. They will be revisited in a later segment.

What is Electricity and Polarization?

It is first necessary to understand what electricity is. Electricity is defined as the presence and the flow of electrical charge. All forms of electricity (including the kind that is used to power devices like lights in a home) involves a flow of positively and/or negatively charged atoms from one point to another. Atoms that have a non-zero charge are called ions.

To understand what an ion is, it is helpful to understand atomic theory as it relates to the position of electrons. An atom contains a nucleus (center) made of protons and neutrons. Protons are positively charged particles, neutrons are particles that have mass but are not charged (neutral = neutron). Electrons orbit around the nucleus of the atom, much like a planet orbits around a sun. While protons and neutrons are fairly stable in their position in the atom, electrons are constantly in motion around the outside of the atom. We can predict where they are at a given time using Bohr’s theory, and use that prediction to determine how that atom is electrically charged.

In short: Each electron inhabits an area called an “energy level.” Energy levels can be compared to levels in an apartment. Each level of the apartment complex has a set number of rooms, and those rooms must be filled in order to start filling the next level. The first level can contain up to 2 electrons. The second level up to 8, the third up to 18, and so on. One electron can only occupy one space, so an electron in the first energy level only counts for the first energy level; it does not get counted toward the number needed for the second energy level. We will use a sodium atom as an example:
A sodium atom contains 11 protons, 11 neutrons, and 11 electrons. According to Bohr’s theory, an atom wants to have all of its energy levels completely full, and can accept electrons from other atoms or give them away so that its top-most energy level is completely full. Sodium has 2 completely full levels - the first level with 2 electrons and the second level with 8 electrons, so a total of 10 of the atom’s 11 electrons have filled energy levels such that they are full. Sodium has a total of 11 electrons, so the 11th will start filling the third energy level.

Each atom wants to have completely filled energy levels with no extra and no vacancies. The third energy level contains 18 slots, and only 1 is being occupied by electrons in the sodium atom. This electron can be “given away” and used by another atom that has an almost-filled energy level (for example, hydrogen has only 1 electron and needs 1 more to fill its first energy level). Since it is much easier for the atom to give one electron away than it is to find 17 electrons to fill its third energy level, the electron is usually given away to another atom.

Atoms normally have 0 net charge, which means the number of protons and electrons are the same. However once an electron is either given away or accepted by another atom, the balance of 11 protons to 11 electrons has changed. Now the atom only has 10 electrons. The number of protons has not changed, so that means there are 11 positive charges and only 10 negative, leading to a net positive charge of 1.

A net positive charge is written as either 1+ or just +, so a sodium ion can be written as Na+. If we examined another atom that accepts 2 electrons to fill its outer-most energy level, like sulfur, would be written as 2-, meaning it has a negative charge of 2 (because it accepted 2 electrons instead of 1). Ions that have a positive charge like sodium are called cations; ions with a negative charge like sulfur are called anions.

### Polarization and Ion Shifts in Cardiac Muscle

When ions flow from one point to another point, it transfers energy in that direction. That transfer of energy is measurable and is referred to as electricity. Polarization refers to a concentration of positive or negative charges that are higher than other surrounding areas.
Both muscle cells and the interstitial fluid surrounding muscle cells contain cations and anions. At rest, a muscle cell is typically in a polarized state at about -75 mV. That means: there are anions whose collective charge is -75 mV within the cell, where the area outside the cell is closer to neutral or is somewhat positively charged.

Muscle cells utilize several mechanics to control the flow of cations and anions into and out of the cell which causes an electrical gradient (that is, a gradient in which there is a greater charge on one side of the cell than the other side) to form. The cell membrane contains several types of “gates” that the ions can enter and exit the cell through:

Each type of channel has its own unique purpose and function in polarizing or depolarizing the cell.

### Depolarization

Depolarization is the opposite process of polarization. While polarization creates a gradient in which one area has a higher concentration of cations or anions than the other, depolarization reverses that imbalance. In muscle cells, depolarization also activates other mechanics within the cell that cause the muscle cell to contract (described later).

Depolarization occurs as a result of an action potential. An action potential is the term for a sudden change in polarization in part of the polarized muscle cell, which then spreads to the other parts of the cell. The end of an action potential is the maximum depolarization, or the furthest the cell can get from its polarized state.

In skeletal muscle cells, that outside action is a neurotransmitter opening ligand-gated channels, which increase the voltage trapped within the cell by pumping more ions into the cell. When the cell reaches a certain voltage, voltage-gated channels open in the cell membrane, allowing other ions to flow in and out, depolarizing the cell by allowing ions to flow in more quickly, reaching a near-equilibrium in charge between the outside of the cell and inside. The voltage-gated channels only stay open for a short period of time; when they close, the cell begins to repolarize, using an active transport channel like the sodium-potassium pump to move positively charged ions back out of the cell to allow the cell to return to its baseline polarized state.

Cardiac muscle do not have ligand-gated channels, as they do not respond to neurotransmitters. Instead, cardiac muscle uses hyperpolarization activated cyclic nucleotide gated (HCN) channels, which are unique to cardiac muscle.
They open in response to hyperpolarization, a state in which there is a greater-than-expected charge within the cell. In this case, it responds to negative hyperpolarization, or hyperpolarization that is measured as less than -75 mV (remember -80, for example, is a number less than -75 even though it represents a greater negative charge). They are poorly selective, which means they allow numerous types of ions in and are not very specific for which ones can flood in. Their poor ion selectivity means the depolarization process starts very quickly, as many types of cations are allowed to flood into the cell all at the same time.

Another specific type of channel that is understood to be cardiac-specific is called the fast Na+ channel. This is one type of voltage-gated channel that is selective for sodium and allows very rapid flow of sodium into the cell at a very specific voltage that occurs in the early to mid-phase of depolarization. The fast Na+ channel opens in response to a small amount of positive electrical stimulation but closes again when it exceeds a certain amount of positive electrical stimulation, well before action potential occurs. This allows rapid increase in depolarization, but slows the depolarization process immediately before action potential, allowing adjacent cardiac muscle cells to contract in conjunction. Closing the sodium channel before too much sodium flows in also prevents cell lysis: water tends to follow sodium, and too much sodium can pull too much water into the cell, stretching it and causing it to burst.

**Unique Attributes of Cardiac Muscle**

Cardiac muscle tissue has several unique attributes that allow it to function effectively specifically in the heart. The first unique attribute cardiac muscle has is its ability to excite and stimulate its own depolarization without outside intervention. Additionally, voltage that stimulates depolarization in one cell can spread to other adjacent cardiac muscle cells. Cardiac muscle can do this because it contains a physical conductor between its adjacent cells in a space called an intercalated disc:

The intercalated discs are special connections between the cardiac muscle tissue that allows it to have branch-like connections to multiple other muscle fibers. Within the intercalated discs are areas called gap junctions, which allow electrical currents to be transferred to other cells. One cardiac muscle cell can stimulate the voltage-gated channels in adjacent cells connected by intercalated discs, commencing the depolarization process of the other cells in synchrony with the originator. This allows multiple muscle fibers to go through depolarization and reach action potential together as
The branch-like pattern that almost weaves cardiac muscle cells together is important as well because it allows the muscle cells to contract together in a net-like pattern, rather than in a strictly linear pattern. This net-like network of muscle tissue is more effective at pumping and pushing blood.

Desmosomes are units that anchor the cardiac muscle tissue to one another. This prevents them from pulling apart and tearing at the junction site as they contract all at the same time.

![Cell nucleus and Intercalated discs](https://med.libretexts.org/Bookshelves/Nursing/An_EKG_Interpretation_Primer_(Christianson_et_al.)/01%3A_Chapters/1.01...

**Figure \(\PageIndex{8}\): Image 8, Intercalated discs**