The Cardiac Conduction System

Generation and Conduction of the Cardiac Impulse

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KEYWORDS

• Action potential • Cardiac conduction system • Electrocardiogram • Automaticity • Cardiac impulse

KEY POINTS

- Contraction of the heart is initiated by the generation and conduction of the cardiac impulse.
- Pacemaker cells generate a cardiac impulse without any external stimulation because of changes in electrolyte concentration inside and outside the cell.
- A cardiac impulse is conducted from the sinoatrial node to the atrioventricular node via internodal pathways and passes through the atrioventricular node to depolarize the ventricular myocardium through the Purkinje network.
- Changes in the ionic potential during the heartbeat can be recorded from the surface of the skin, yielding electronic data known as the electrocardiogram.

INTRODUCTION

Cardiac disease is the most common cause of mortality in the developed world, and the number of patient deaths from cardiovascular-related disease increased by a third between 1990 and 2010.[1] This increase, coupled with a further projected increase in the prevalence of cardiovascular disease,[2] has led to the electrocardiogram (ECG)

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becoming one of the most used tools in clinical practice. To fully understand the ECG and interpret its results, an understanding of the normal conduction system of the heart is necessary.

The human heart contracts approximately 2.5 billion times during the average person's life span; this is accomplished by the cardiac conduction system.[3] The cardiac conduction system is a physiologic system whereby the myocardium (heart muscle) is stimulated to contract without the requirement of any external stimulation. Contraction of a cardiac myocyte (heart cell) is initiated by an electrical impulse (the cardiac impulse), which propagates freely through the atrial and ventricular myocardium. This phenomenon occurs because cardiac myocytes are electrically coupled via, so-called, gap junctions.[4] All of the myocytes within the heart have the capacity to conduct cardiac impulse; this means that a single stimulation of an atrial or ventricular myocyte can produce contraction of the entire myocardium. During normal activation of the heart, the cardiac impulse originates from pacemaker cells within the sinoatrial (SA) node and uniformly spreads through the atria. The cardiac impulse is then conducted to the atrioventricular (AV) node, via internodal pathways, where it spreads throughout the conduction system of the ventricles and the ventricular myocardium. Irregularities in the normal cardiac conduction system can cause cardiac arrhythmias and, therefore, an abnormal ECG. This article outlines the key principles behind a normal cardiac conduction system, including the generation of the cardiac impulse and propagation of this impulse from the atria through a normal conduction system to the ventricular myocardium.

THE UNDERLYING PRINCIPLES BEHIND THE HEARTBEAT

Electrolytes and Concentration Gradients

To understand the cardiac conduction system, it is important to understand the way in which cells, in particular pacemaker and normal cardiac cells, function. The human body is composed of millions of cells, each cell enclosed by a fatty membrane and surrounded by extracellular fluid.[5,6] All components of the cell contain electrolytes. The electrolytic concentration gradient, along with the ability of the electrolytes to cross the cell membrane, allows the generation of an electrical current.[7]

For contraction of a cardiac myocyte, the most important electrolytes are sodium, potassium, and calcium. The electrolytes are moved in and out of the cell through 2 main pathways: (1) pumps embedded in the cell membrane and (2) ion channels in the cell membrane (**Fig. 1**).[8] The sodium potassium pump plays an important role in this process as it moves sodium out of the cell and pumps potassium in. A concentration gradient is created because the pump is continuously pumping potassium into the cell leading to a greater concentration of potassium inside of the cell than outside, resulting in a change in intracellular potential. In this process, the opposite is true for sodium as a greater sodium concentration is created on the outside of the cell with a lesser sodium concentration inside. The other method by which electrolytes move in and out of a cardiac myocyte is through ion channels.[9] Unlike the sodium potassium pump, which allows multiple electrolytes to pass, ion channels are specific to a single electrolyte. Ion channels are voltage gated and allow for each specific electrolyte to move either in or out of the cell depending on the concentration gradient of that particular ion.[10] When potassium channels are opened, potassium leaves the cell; when sodium channels are opened, sodium enters the cell. It is these opposing reactions that result in an electrical charge across the cell membrane. This is, therefore, the underlying principle behind generation of the cardiac impulse.