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Electro-Physiology of Heart with ECG Signal Analysis

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Abstract: This paper presents review of electrical events in human Cardiac Cycle and coordinate mechanical activity like contraction, relaxation and rest of cardiac tissues. The paper illustrate generation and transmission of electrical impulses , direction of propagation of signal from one cell to another, excitation of another cell in respond to incoming electrical signal and automatically discharge of electrical event in one complete cardiac cycle called heart beat. Fundamentally, flow of intracellular-extracellular ions across cell membrane is synchronized and spontaneous process with electrical events of heart, is also discussed. ECG is a pictorial representation of resultant potential difference which develops due to flow of such particular ions in specified location. This paper summarized properties of ECG waveform, different intervals and segments in ECG analysis with associated action potential in response to electrical event of heart.
***Keywords*:**

I. INTRODUCTION

The heart is effectively a dedicated muscle, behave as a pump, who contract sequentially by a preceding phenomena of cellular electrochemical reaction. This mechanical contraction is result of electrical events of the cells which conduct by special cardiac cellsin a well defined manner called Cardiac cycle. It includes sequence of synchronized and coordinated events of all chambers of heart. Systole and Diastole are two defined events in this context. This sequence of events is controlled by the electrical properties of the cells [1] which develop an electrical field in the heart and the body.

The measurement of this electrical field on the body surface is called the electrocardiogram (ECG). The ECG is an important tool for the clinician as it changes characteristically in a number of pathological conditions. A motivation for simulating the electrical activity in the heart is to gain a better understanding of the relationship between the ECG signal and the condition of the heart. These normal ECG signals are very weak and the frequency range is 0.05-100Hz and the mV range. The most of the useful information contained in the range of 0.5-45Hz. Electrocardiography is the primary diagnosis todetect any abnormalities and irregularities found in Cardiac cycle.

II. ELECTRICAL EVENTS OF CARDIAC EXCITATION

Cardiac cycle is contraction and relaxation of atrial- ventricles muscles which take place in 0.8 sec according to 72 beats/min. The human heart contains four chambers i.e., Right Atrium, Left Atrium, Right Ventricle and Left Ventricle. The upper chambers are the two Atria's and the lower chambers are the two Ventricles. Under healthy condition the special group of cells generate electrical signal to the Right Atrium called Sino Atria (SA) node. This signal travels from the Atria to the Atrio-Ventricular (AV) node. The AV node connects to a group of fibers in Ventricles that conducts the electrical signal and transmits the impulse to the lower chamber of heart, the Ventricles. The passage of such electricity culminates in a carefully coordinated contraction of heart muscle that pumps blood through the human body.

The function of the heart muscle is to pump blood to the lungs for oxygenation and then back to the body. The blood enters the heart via the atria and is pumped out by the contraction of the ventricles. The right ventricle supplies blood to the lungs while the left ventricle pumps blood into the rest of the body. The right atrium and the right ventricle together form a pump to circulate blood to the lungs, as shown in figure 1.Pumping is performed with synchronized motion. The time duration in which the ventricles contract is known as "systole" while the time duration during which the ventricles relax to receive blood is called "diastole". [18]

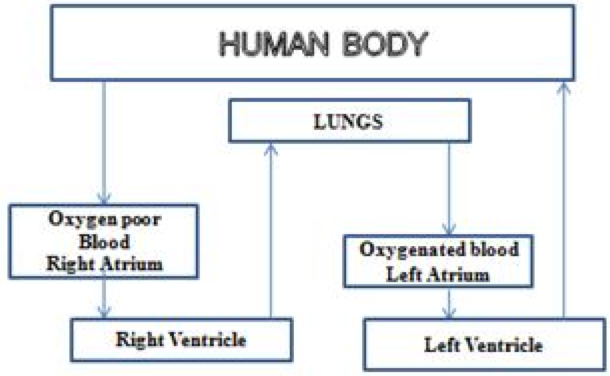

Figure 1: Circulation of Blood

fig 1, shows circulation of blood through lungs into the body. The period of contraction of both atria in heart is atria systole period when blood flows from atria (RA) to ventricle (RV) and make contraction to ventricle, called ventricle systole period. During this systole period, both atria and ventricle contract and empty of blood. The relaxation time when heart chambers are full of blood is diastole period. In healthy human body, systole has 42.05% and diastole has 57.94% fraction of cardiac cycle. Therefore, in one complete cardiac cycle, Cardiac diastole is the event in which 80% of heart part is full of blood.

III. ELECTRO-CHEMICAL PHENOMENA OF CARDIAC CYCLE

The ionic balancing occur on each side of the cell membrane during the resting part of the heart cycle .The source of electric potentials is the flow of ions, across the cardiac cells, which are enclosed from a plasma membrane. The principal ions involved in this phenomena are Sodium (Na^+), Potassium (K^+) , Calcium (Ca^{++}) and Chloride (Cl^-). The interior of heart is more negative as compared to the exterior. The inner fluid has mainly potassium ions and large organic anions of many species, together with some sodium, chloride, and calcium. The extracellular fluid contains principally sodium and chloride ions with some potassium. The movement of these ions across cell membrane, create electrical signals called cell depolarization/ polarization and it can be measured by potential difference in various specified locations.The transportation of theses ions and generation of electrical signals can be clearly understood by the following phases:-

A. Phase 0, resting of cardiac cells: Called Diastole permits the flow of K^+ than Na^+. It makes, outer part of membrane becomes more positive and develop potential difference -90mV
B. Phase 1,crossing of Na+ ions, at voltage of -60 mV: In respond to electrical stimulus, since the extra-cellular concentration of Na+ ions are more as compared to intra-cellular, it makes Na+ ions allow to flood inside the cell through cell membrane. It results interior part more positive than exterior, resting potential from -60mV to be approximately +20 mV, called de-polarization.
C. Phase 2 (crossing of Ca++2 ions): As the stimulus from the nerve finishes, the Na+ channels close. Although Na+ ions are already in cell, calcium ions (Ca2+) now enter the cell. Potassium ions (K+) move in and this decrease the voltage inside the cell, bringing it back to the resting membrane potential of about 85mV.

The Mathematical description known as the Nernst equationis used to calculate the equilibrium potential(the membrane potential at which the electrical and chemical potentials for a given ion are equal and opposite). At normal body temperature (37°), the Nernst equation is given from the following relation on the log base 10: [6],[7]

$$E_i = \frac{61.5}{Z} \log\frac{[C]o}{[C]i} \text{ mV}$$

Where, E_i is the equilibrium potential of ion , Z Valence of ions, $[C]_0$ is the concentration of ion outside the cell and $[C]_i$ is the ion concentration inside the cell membrane. From this equation, the equilibrium potential for various ions are easily calculated, as shown below for potassium K^+ ion. Table 1, show Ion concentration in human blood with equilibrium potential [1].

$$E_K = (61.5/Z) \log ([K^+]_o / [K^+]_i)$$
$$=61.5 \log \log ([K^+]_o / [K^+]_i)$$

$= 61.5 \log(.01/0.1)$
$=61.5x^{-1}$
$=61.5$ mV

Table 1: Inter-cellular and extra cellular ion concentrations and their resting potentials [1]

Ions	Concentration(mM)		Equilibrium potential
	Intercellular	Extracellular	
Na+	12	120	+61.5 mV
K+	125	5	-86mV
Cl-	5	125	-86mV

IV. ECG SIGNALS AND WAVEFORM ANALYSIS

ECG waveform is the summation of all electrical activities, which can be easily recorded by placing '+' and '-'electrodes placing on the surface of heart in fixed different locations. ECG mainly provides two kinds of information. One is the duration of the electrical wave which is used to show normal or slow or irregular heart beat. Second is the amount of electrical activity passing through the heart muscle, is measured by peak-voltage amplitude of different waves. The abnormalities found in functioning of heart cause various heart diseases, which is reflected in ECG waveform. More tissue depolarizing, increases the amplitude (height) of the complexes [21].

One normal heart beat is represented by a set of three recognizable waveforms that start from *P*-wave, followed by the *QRS* complex and ends with *T*-wave. A normal ECG signal have P, QRS,T and U wave, is shown in Figure 2, with their relative amplitude, duration and occurrence.

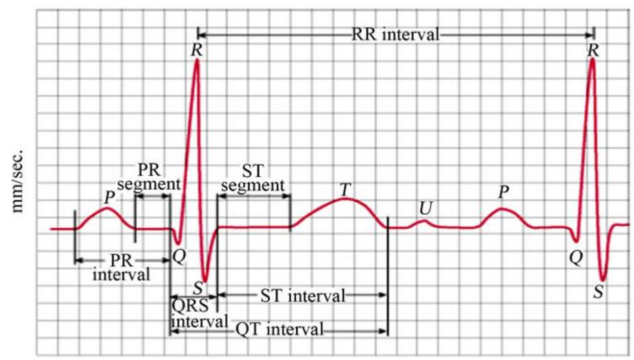

Figure 2: Schematic representation of Normal ECG waveform [A]

[A] Sridhathan Chandramouleeswaran et.al,"Wavelet diagnosis of ECG signals with kaiser based noise diminution" Journal of Biomedical Science and Engineering Vol. 5 No. 12 (2012)

Table 2: Characteristics of ECG Signal with associated electrical activity of heart

Signals	Amplitude (mV)	Duration of Interval ms	Electrical activity
P	0.25	60-80	Atrial de-polarization. An upward deflection in ECG shows atrial contraction.
P-R interval (from beginning of P-wave to the beginning of QRS complex)	-	120-200	Duration of atrial de-polarization and beginning of ventricular de-polarization
P-R segment	-	50-120	Hold up of the electrical signal at the AV Node
Q	0.4	-	-

P-Q interval (the beginning of the P wave to the beginning of the QRS complex, being a Q wave or an R wave)	-	0.13-0.20	A PQ interval of more than 0.20 sec is defined as AV block 1°
Q-T interval (beginning of Q wave and end of T wave)	0.35-0.44	Males: 0.45 sec Females : 0.46 sec	Total time duration of electrical activity take place in Ventricles during de-polarization and re-polarization. Prolongation of QT interval cause sudden cardiac death
R	1.6	-	Ventricular de-polarization
R-R interval	-	40-120	Completion of one cardiac cycle and starting of another one
S-T segment (end of S wave and beginning of T-wave)		100-120	Ventricular re-polarization.
QRS complex (from the start of Q wave to the end of S wave)		80-120	Ventricular de-polarization / Contraction Change in QRS shape show ventricular abnormality, Size of Ventricular Chambers,Myocardial infarction (heart attack).
S-wave			Last stage of ventricular de-polarization
T (A normal T wave is asymmetric, with a slow upstroke and a more rapid downstroke.)	0.1-0.3	120-160	Ventricular re-polarization before the cycle repeats, is ventricular relaxation. Asymmetric, negative T waves shows ventricular overload.
TP segment	-	-	This is the time between the end of one heart beat and the start of the next.
U (positive flat deflection after T wave)	-	-	Re-polarization of the Purkinje fibers. The fusion of the T wave with the U wave,leading to a TU wave, is typical for hypokalemia.

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From the above table, PR segment is there which followed the P wave, the heart muscle does not do anything causing the flat line signal. depolarization of the left ventricle would give positive R waves, whereas re-polarization of the left ventricle gives T waves that are also positive. The recovery of atriums cannot be seen from an ECG signal. Normally, it has a low amplitude and the recovery happens during the QRS complex. The ECG signal level from the end of the T wave to the beginning of the next P wave is defined to be the baseline of the signal.

V.CONCLUSIONS

Depolarization is followed by contraction. The pattern of contraction-relaxation develop polarization-de-polarization and re-polarization of cells.Their sequence is used to detect the condition of heart and its activity. If, their pattern will be predict, then the technique is used to deduce the time of measuring mechanical deformation.

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