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A Survey on the Cardiology Ontology and Its Analytical Procedures

Priyanka Mayapur[1]

B.E. Student, Dept. of Electronics and Communications Engineering, Agnel Institute of Technology and Design, Assagao, Goa, India[1]

ABSTRACT: Heart is an organ whose electrical activity is responsible in generating a trace that contains important information about the heart. This general article focuses on the various details and basics related of the heart and the techniques used to analyse an ECG.

KEYWORDS: Heart, ECG, Heart Rate, HRV, Defects, Techniques, Computer Processing, Arrhythmia

I. INTRODUCTION AND THE HUMAN HEART

The human heart is a muscular organ that acts like an electro-mechanical pump supplying blood through blood vessels via the network of cardiovascular system. It is located just behind and slightly left of the breastbone. It has three sections of circulatory system: pulmonary (lungs and heart), systemic (body systems) and the coronary (vessels that serve heart). It consists of three layers; Myocardium, Epicardium, Endocardium. It is divided into four chambers. The upper two chambers are called as the atria and the lower two chambers are called as the ventricles. To be specific, it consists of left atrium, left ventricle, right atrium and right ventricle [1].
The cardiac cycle is split into two phases:

- Systole: During systole, the ventricles contract and push blood into the arteries.
- Diastole: During diastole, the ventricles relax and receive blood from the atria.

The sounds of a normal heartbeat are known as lubb and dupp and are caused by blood pushing on the valves of the heart.

II. THE ELECTROPHYSIOLOGY OF THE HEART AND THE CARDIAC PATTERN ORIGIN

In the heart, the impulse required to produce cardiac contraction during each cardiac cycle is normally generated by the Sino-auricular node (S.A. Node) situated in the right atrium which travels to excite both the atria. The process of excitement or stimulation of a biological tissue is electrically termed as depolarization. After auricular excitation, the impulse converges on to the A-V node. It then passes down the bundle of His (H) and its branches to reach and excite both the ventricles simultaneously.

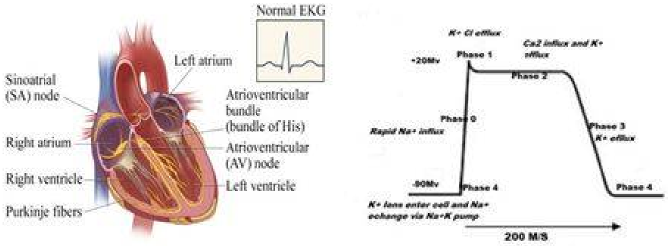

Fig 1: The Electrophysiological View of the Heart and the Cardiac Potential (Left to Right)

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The bundle of His transmits impulses from the atrioventricular node, located at the inferior end of the interatrial septum, to the ventricles of the heart. A bundle branch of His consists of the left bundle branch and the right bundle branch. Their distal and smaller twigs or ramifications are known as Purkinje fibers.

In the ventricles, the interventricular septum which is quite muscular and thick is the first to get simulated (deposited). It is immediately followed by simultaneous activation (depolarization) of both the left and the right ventricular myocardium. After ventricular excitement there follows a period of restitution of recovery to a state called as the resting state. The process of recovery back to resting state is due to ionic reflux at the cellular and the intercellular level. The restitution towards coming back to resting state is known as repolarization. In the auricles, the restitution or repolarization forces are too minute to be distinctly recordable. They get submerged with other intervals or segments of the tracing [2].

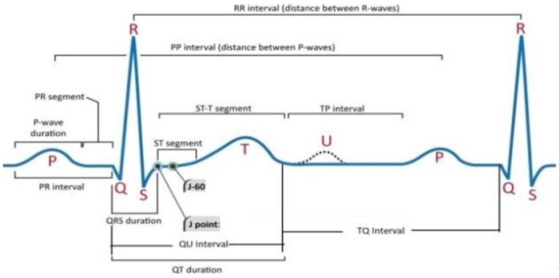

Fig 2: An ECG Waveform

This complete tracing of the electrical activity of the heart in exquisite detail is measured in terms of a graphical and diagnostic tool called as the Electrocardiogram (ECG) which was invented by Willem Einthoven in 1903 in Netherlands.

A complete electrocardiographic cycle consist the following waves, intervals and segments:

Table 1: ECG Features and their Description

FEATURE	DESCRIPTION OF THE FEATURES
P WAVE	P-waves represent atrial depolarization.
Q WAVE	The normal Q wave represents septal depolarization and is any initial downward deflection after the P wave.
R WAVE	The R wave represents early ventricular depolarisation and is normally the easiest waveform to identify on the ECG.
S WAVE	The first negative deflection after the R wave represents the S wave indicating the late ventricular depolarization.
T WAVE	The T-wave represents ventricular repolarization.
U WAVE	U waves represent re-polarization of the Purkinje fibers that indicates the last remnants of the ventricular repolarization.
P-R SEGMENT OR PQ SEGMENT	The PR or PQ segment is the flat, usually isoelectric segment between the end of the P wave and the start of the QRS complex. This segment represents the time the impulse takes to reach the ventricles from the sinus node.
P-R INTERVAL OR PQ INTERVAL	The time taken for electrical activity to move between the atria and ventricles is represented by this interval.
R-R INTERVAL	The RR-interval begins at the peak of one R wave and ends at the peak of the next R wave and represents the time between two QRS complexes.
P-P INTERVAL	It indicates the duration of atrial cycle (atrial rate).
QRS COMPLEX	The depolarization of the ventricles is represented by the QRS Complex.
QT INTERVAL	It represents the time taken for the ventricles to depolarize and then repolarize.
ST SEGMENT	The isoelectric line that represents the time between depolarization and repolarization of the ventricles (i.e. contraction) represents the ST segment.
J-POINT	The J point is the junction between the termination of the QRS complex and the beginning of the ST segment.
T-P INTERVAL	The isoelectric interval on the electrocardiogram (ECG) is TP segment that represents the time when the heart muscle cells are electrically silent.
T-Q INTERVAL	Termed as the diastolic interval through the ECG.
Q-U INTERVAL	The QU interval is a measure of the time between the start of the Q wave and the end of the U wave in the heart's electrical cycle.

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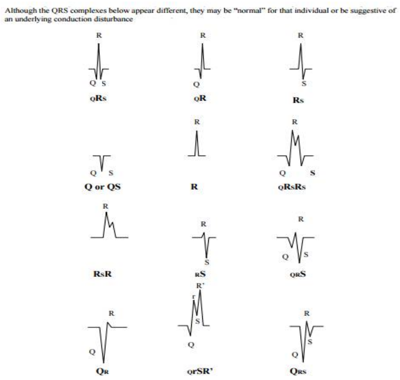

Fig 3: The QRS Morphology

III. USES OF ECG

This noninvasive routine examination of the heart's activity containing prototypical patterns has certainly many uses [7]:

- Heart rate
- Heart rhythm
- Conduction abnormalities
- Heart orientation in the chest cavity
- Evidence of increased thickness of heart muscle (hypertrophy)
- Evidence of damaged heart muscle
- Acutely impaired blood flow to heart muscle
- Warning signs of abnormal cardiac rhythm disturbances
- Damage to heart from certain lung conditions, such as emphysema, blood clots to lung
- Enlarged cardiac chambers (cardiac dilatation)
- Evidence of abnormal blood electrolytes - calcium, magnesium, potassium
- Inflammation of the heart (myocarditis) or its lining (pericarditis)
- Prior heart attacks (myocardial infarction)
- Reduced blood flow during heart attack (unstable angina)

IV. ECG BASICS

A lot of tests have been carried out in order to check the health of the human heart and its functionality but ECG has become an indispensable and effective tool for extracting clinically significant information to know the cardiac peculiarities [4].The ECG is measured by placing a series of electrodes on the patient's skin – so it is known as the surface ECG [3]. An electrode is a conductive pad in contact with the body that makes an electrical circuit with the electrocardiograph. A lead is a slightly more abstract and is the source of measurement of a vector. In ECG lead refers to the voltage between two electrodes.

Generally, ECG is recorded in an image consisting of all 12 channels or lead recordings interlaced 3 second intervals from combinations of leads per row. They often occur in the same order, all occurring aligned in columns:

- First row: I, AVR, V1, V4
- Second row: II, AVL, V2, V5
- Third row: III, AVF, V3, V6

These 12 leads are classified as:

- 3 Standard Limb Leads (Bipolar): I, II III
- 3 Augmented Limb Leads (Unipolar): aVR, aVL aVF
- 6 Precordial Leads: V1- V6

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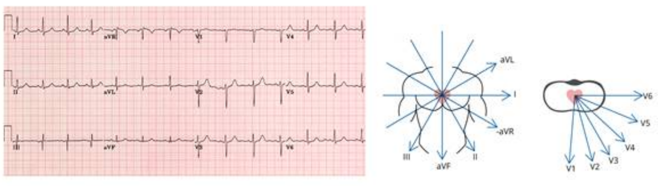
Since distinct diseases manifest differently in each of the leads, it is important to isolate the different leads. Under the expert guidance of the doctorsand after lots of literature review, it was seen that Lead II is the most preferred monitoring lead of choice for continuous ECG monitoring.Most monitors can only show one lead at a time and



(a) (b)

Fig 4: ECG image portraying a 12 channel recording along with the 12 Lead Configuration (a and b)

therefore the lead that gives as much information as possible should be chosen. The most commonly used lead is Lead II which measures the potential difference between the right arm and left leg electrode.Since the placement of electrodes for Lead-II configuration is located near the apex of the heart. As a result, the apex of the heart is best viewed by lead II.Nowadays, there are also various configurations in which ECG are measured like the 15-Lead ECG Configuration and the 80-Lead 3D ECG Configuration.The ECG noises due to interferences like electrode contact, motion artifacts, base-line drift and instrumentation noise generated by electronic devices, electrosurgical noise, and muscle contraction sometimes hamper the signal [5].

V. FACTORS RELATED TO THE HEART

- **Rhythm:** It could be defined as a specific order or pattern that an entity, in this case, ECG, is expected to follow in order to match a particular criteria.
- **Heart Rate (HR):** is the speed of the heartbeat measured by the number of contractions of the heart per minute (bpm). The heart rate can vary according to the body's physical needs, including the need to absorb oxygen and excrete carbon dioxide. There are three ways of calculating the heart rate.
  One is the square counting method which would be discussed below.
  Second is the formula method which is:

$$Rate = \frac{60}{R\text{−}R\ Interval\ (Avg)} \qquad (1)$$

  Where R-R interval is the duration between two R peaks successively, also known as inter-beat interval (IBI).
  The third method is the marker method where non-regular rhythms are best determined with the 3 second marker method. The numbers of QRS complexes are counted that fit into 3 seconds and multiplied this number by 20 to find the number of beats/minute [13].
- **Heart Rate Variability (HRV):** is the physiological phenomenon of variation in the time interval between heartbeats. It is measured by the variation in the beat-to-beat interval. It is also known as cycle length variability, RR variability and heart period variability. HRV analysis reflects the interplay of the sympathetic and vagal components of the autonomic nervous system (ANS) on the sinus node of the heart. It is also known to predict myocardial infarction, hypertension, stress, diabetes, chronic obstructive pulmonary disease, apnea, cancer, arrhythmias, blood pressure regulation, renal failure, humoral cardiac factors and sinus node characteristics.
- **Cardiac Efficiency:**is the ratio of work done by the heart to the energy used to perform the work. It is normally about 20-25 percent; the remainder of the oxygen used is converted to heat [8].
- **The Cardiac Output:** Cardiac output (CO) is the volume of blood being pumped by the heart in one minute.
- **Stroke Volume:** is the amount of blood pumped into the aorta during each ventricular systole, usually measured in milliliters. The average heart can push around 5 to 5.5 liters per minute at rest.

The equation used to find cardiac output is:

$$CO = Stroke\ Volume\ x\ Heart\ Rate \qquad (2)$$

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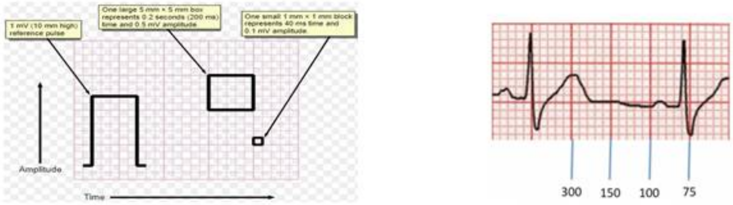
VI. READING OF AN ECG

The ECG waveform has 3 chief characteristics:

- **Duration:** The length of an ECG Tracing measured in fractions of a second.
- **Amplitude:** The height of an ECG wave is called its amplitude measured in millivolts. The isoelectric line is considered to have amplitude of zero. Anything above the isoelectric line is positive; below the line is negative.
- **Configuration:** A more subjective criterion referring to the shape and appearance of a wave.



(c) (d)

Fig 5: Reading an ECG and the Sequence Method (c and d)

The ECG waves are recorded on special graph paper that is divided into 1 mm2 grid-like boxes. The ECG paper speed is ordinarily 25 mm/sec. As a result, each 1 mm (small) horizontal box corresponds to 0.04 second (40 ms), with heavier lines forming larger boxes that include five small boxes and hence represent 0.20 sec (200 ms) intervals. Vertically, the ECG graph measures the height (amplitude) of a given wave or deflection, as 10 mm (10 small boxes) equals 1 mV with standard calibration. On occasion, particularly when the waveforms are small, double standard is used (20 mm equals 1 mv). When the wave forms are very large, half standard may be used (5 mm equals 1 mv). Paper speed and voltage are usually printed on the bottom of the ECG. The distance along one small square represents 0.1mV and along one large square is 0.5mV.
There are five specific rules called as the square counting method used to calculate the Heart Rate manually by just looking at the ECG as discussed below [6]:

- **The Cardiac Ruler or Sequence Method:** Here the numbers of big boxes between R waves are counted using the following numbers: 300-150-100-75-60-50. This can only be used on regular rhythms and not on irregular rhythms as shown in Fig (d).
- **The Six Second Method:** An ECG tracing of six seconds is obtained (i.e. 30 big boxes) and the numbers of R waves are counted that appear within that 6 second period and multiplied by 10.
- **The10 second Method:** An ECG tracing of ten seconds is obtained (i.e. 50 big boxes) and the number of R waves that appear within that 10 second period are counted and multiplied by 6. This is a great method for slow or irregular rhythms.
- **The 300 Method:** The number of large boxes between 2 successive R waves are counted and divided by 300 to obtain the heart rate.
- **The 1500 Method:** Count the number of small boxes between two successive R waves and divide this number into 1500 to obtain heart rate. This works well for faster heart rates.

VII. SOURCES OF ECG

There are many places from where an ECG can be obtained and collected and the stored ECG is obtained in different formats.

- **Electrocardiograph**

An electrocardiograph is a machine that is used to perform electrocardiography by placing electrodes on the skin and produces the electrocardiogram.The fundamental component to electrocardiograph is the Instrumentation amplifier, which is responsible for taking the voltage difference between leads and amplifying the signal.The ECG databases collected from the ECG machine were available in two different formats which were .xml or pdf.

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- **ECG Simulator**

The aim of the ECG simulator is to produce the typical ECG waveforms of different leads and as many arrhythmias as possible. This ECG simulator is a MATLAB based simulator and is able to produce normal lead II ECG waveform. Usually the ECG obtained is in the .csv format.

- **Online ECG Bank Databases**

There are many online databases where recorded ECG are stored and uploaded for the research community in order to process it for further research. Some of the databases which contain the digital recording of physiological signals, time series and related data are PhysioNet Bank and UCI dataset. PhysioNet is a data dictionary which offers free web access to large collections of recorded signals saved in specific formats specifically the .mat format and is involved in the ECG database. UCI is basically a machine learning repository where the data is stored in the form of .dat or .txt format.

VIII. THE CARDIAC PECULARITIES

The term NSR or the normal sinus rhythm is sometimes used to denote a specific type of sinus rhythm where all other measurements on the ECG also fall within designated normal limits, giving rise to the characteristic appearance of the ECG producing a prototypical pattern of the all attributes when the electrical conduction system of the heart is functioning normally. Resting heart arte would be heart rate at rest with no physical exertion. Resting heart rates vary per individual but for a normal heart at rest, the NSR is considered to be from 60-100 BPM. People who are very physically fit often have slightly lower resting heart rates. Also, heart rate, much like weight, tends to increase with age. Athletes may have a rate as low as 40 bpmbecause their hearts are trained to efficiently pump blood which is again considered to be normal. It is seen that values falling within the specified limit as defined in the table could be considered as a normal ECG.If the heart rate is consistently below 60 or above 100 at rest, there might be a heart condition which needs to be considered [9]. During an activity like running or jumping or climbing, the heart rate is expected to increase due to the extra amount of load and the maximum heart rate in these conditions could be calculated using this equation [10]:

Maximum workout heart rate, adjusted for resting heart rate=(220 - age - resting heart rate) X percent of maximum heart rate + resting heart rate (3)

Any deviation from the normal sinus rhythm is considered to be a cardiac peculiarity, irregularity or a defect.
Cardiac irregularities could be of many types with respect to a lot of factors and reasons. Few of it to name would include: myocardial infarction, cardiovascular defects, congenital defects, coronary defects, angina, valvular defects, aortic and pulmonary defects, heart attacks, heart blocks, artheroma, hypertrophy and many more. Among of all the possible defects, cardiac arrhythmia is one of the reasons that contribute to the major causes of death in the world.Cardiac Arrhythmia could be defined as a disorder or disturbance or any abnormality resulting in the normal activation sequence of the myocardium giving rise to irregular heartbeat or abnormal rhythm of the heart that may cause permanent injury to the heart.
Arrhythmia could be of many types and can be classified with respect to three factors:

- **Regularity**

It is a step of analyzing an ECG rhythm.
A rhythm would be termed as Regularly, Irregular, if it has some form or regularity to the pattern of the irregular complex. An Irregularly, Irregular rhythm could be defined as a rhythm that has no pattern at all and whose all intervals are haphazard and do not repeat with an occasional accidental exception.

- **Rate**

Rate is the number of times the heart beats per minute.
If a resting heart beats at a rate of 100 or more beats per minute in an average adult, this would represent abnormal rapid beating of the heart defined as Tachycardia resulting in a drop of pumping efficiency, adversely affecting perfusion. Bradycardia is defined as a resting heart rate below 60 beats per minute and can adversely affect vital organs.

- **Origin**

Basically it tells us from where the impulse has been originated from in the heart.
Supraventricular Arrhythmias: Supraventricular arrhythmias are the ones that start in the atria or atrioventricular (AV) node (a group of cells located between the atria and the ventricles). Several types to be mentioned would be atrial

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fibrillation (AF), atrial flutter, paroxysmal supraventricular tachycardia (PSVT), WolffParkinson-White (WPW) syndrome and atrioventricular nodal reentrant tachycardia (AVNRT) [14].

Ventricular Arrhythmias: These arrhythmias start in the heart's lower chambers, the ventricles and can be very dangerous and usually require medical care right away. They include ventricular tachycardia and ventricular fibrillation (v-fib) and premature ventricular contraction (PVC) [14].

IX. COMPUTER PROCESSING

Biomedical signals are non-stationary signals whose analysis requires better time and frequency resolution. Improvements in diagnosis and treatment tools are welcome by the medical community. Traditional technique of visual analysis of ECG is complicated for doctors, time consuming and requires expertise. Therefore, computer based classification of signals and its respective diseases can be immensely useful in diagnostics. The processing is faster, easier and accurate. Modification of enhancement can be done using more evolved techniques.

X. PROCESSING TECHNIQUES

Processing and detecting various characteristics of an ECG can be done using various techniques and algorithms. Also calculation and classification of the respective peculiarities and diseases use different procedures to distinguish the features.

To mention a few methods for detection, calculation, classification and processing of an ECG would include the Pan Tompkins Algorithm, R Spike Detection, Multiscale morphological derivative (MMD) transform-based singularity detector, Adaptive filter structures, Genetic programming, Data mining techniques, PCA (Principal Component Analysis), Clustered utilizing FCM (Fuzzy C_Means) algorithm, SVM (Support Vector Machine), Wavelet transform, Independent Component analysis (ICA), Time Domain, Wavelet Transform, Power Spectral Density, Fuzzy logic, Daubechies six coefficient wavelet, Hidden markov models,Linear Predictive coefficients (LPC), Linear predictive cepstral coefficients (LPCC) and MelFrequency Cepstral Co-efficients (MFCC), Computational Intelligence techniques, Base Line Correction (BLC), Feature Extraction by using GLCM method, Spectral entropy, Poincaré plot geometry, Largest Lyapunov exponent and Detrended fluctuation analysis, Linguistic variables (fuzzy sets), OneR, J48, Naïve Bayes, Error back propagation, Generalized Discriminant Analysis (GDA) feature reduction technique, Multilayer Perceptron (MLP) neural network classifier, Probabilistic neural network (PNN) and Artificial neural networks (ANN), Discrete cosine transform (DCT), Nearest Neighbors, Decision Tree classifier, Linear discriminant analysis (LDA), Partially Collapsed Gibbs Sampler (PCGS), Local Map A Posteriori (MAP) method, Sequential Bayesian detection-estimation algorithm, Elgendi’s algorithm, Hamilton-Tompkins algorithm, Hilbert transform-based method, Calipers, Gaussian probability distribution, Kalman filter, Fourier Transformation, Burg method, Mann-Whitney U test, Software tools like Kubios, GHRV, KARDIA, VARVI, RHRV, ARTiiFACT, Lab View, POLYAN, aHRV were used to analyze the HRV, Somnological 3 software (Embla), H scaling exponent, and Coarse Graining Spectral Analysis (CGSA), Biopac System, Nevrokard software, Kubios HRV Analysis Software 2.0, time domain methods, statistical methods, geometrical methods, frequency domain methods and many more.

The methods mentioned above gave results with accuracy and achieved the respective purposes.

XI. CONCLUSION

Heart being a pump always besting at an ever- changing rate gives rise to a pattern due to electrical activity which is ECG. This ECG carries vital information about the heart and is an important tool for diagnosing heart diseases. This article described about the human heart and its electrophysiological concept in order to get an ECG tracing along with its feature description. It also talked about the basics, methods of reading, sources, the factors related, normal values and the various processing techniques with respect to ECG.The detailed parameters of such signals can be studied for the purpose of further research.

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