CHAPTER 3

HEART RATE VARIABILITY

3.1 INTRODUCTION

Basics of HRV are introduced. Sources of HRV are given. Time domain methods, combined time domain and frequency domain methods and nonlinear methods are discussed in this chapter. In time domain methods, statistical methods and geometrical methods are included. In combined time domain and frequency domain methods, rhythm pattern analysis is included. Recording and analysis of HRV is described.

3.2 BASICS OF HEART RATE VARIABILITY

HRV refers to the beat-to-beat alterations in heart rate. Under resting conditions, the ECG of healthy individuals shows periodic variation in R-R intervals. The rhythmic phenomenon known as respiratory sinus arrhythmia (RSA), changes with the phase of respiration-cardio-acceleration during inspiration and cardio-deceleration during expiration. Atropine abolishes RSA. HR is a nonstationary signal. Its variation may contain indicators of diseases (Acharya et al 2006, RenuMadhavi and Ananth 2012 and Bigger et al 1988).

The HRV analysis has proven useful in diagnosis, treatment and monitoring of various pathologies (Dilbag Singh et al 2008 and Luiz Carlos Marques Vanderlei et al 2009).
Combined with the non-stationary periodic beating of the heart is information on its regulatory environment. (Tarun Chandra et al 1996 and Saif Ahmed et al 2009).

Coexisting technical advances have resulted in methodological techniques capable of performing quantitative analysis of HRV (Hiromitsu Kobayashi et al 1999 and Ripoli and Emdin 2009).

A high degree of HRV is attained in compensated heart with good function, whereas HRV can be decreased with severe coronary artery disease (CAD), congestive heart failure (CHF), aging and diabetic neuropathy (DN). (Kleiger et al 1987 and Kurstacic et al 2008).

Automatic analysis of HRV from Holter recordings may be invalidated by beat recognition errors and recording artifact, resulting in filtering and editing of the computer recognized RR interval sequence. Two new methods for HRV analysis have been developed relied as an estimation of the width of the main peak of the frequency distribution curve of the computer – recognized normal-to-normal beat sequence. These methods are independent of a low level of recognition error and artifact, thus eradicating the requirement for operator-dependent, time-consuming editing (Malik et al 1989).

HRV is sensitive and responsive to acute stress and thus acts as a dynamic marker. Mental load like making complex decisions and public speech tasks lower a person’s HRV. A regular physical activity has been shown to raise HRV (Ichiro Kawachi 1997 and Sugihara et al 1996).

Linear measurers of HRV consist of various time and frequency domain indices. HRV was examined manually from calculation of mean R-R interval and its standard deviation measured on short term (eg. 5 minute)
electrocardiograms. The smaller the standard deviation in R-R intervals, the lower is HRV. To date, over 26 different types of arithmetic manipulations of R-R intervals have been used in the literature to indicate HRV. Examples include the standard deviation of normal RR intervals, SDNN which is square root of variance and the standard deviations of the normal mean R-R interval obtained from successive 5-minute periods over 24-hour Holter recordings (called the SDANN index), the number of instances for hour in which two consecutive R-R intervals differ by more than 50 msec over 24-hours (called the pNN50 index), the root-mean square of the difference of successive R-R intervals (the rMSSD index), the difference between the shortest R-R interval during inspiration and the longest during expiration (called the MAX-MIN, or peak-valley quantification of HRV), and the base of the triangular area under the main peak of the R-R interval frequency distribution diagram obtained from 24-hour recording, and so on. The SDNN is one of the most important and clinically meaningful time domain measure.

The HRV spectrum contains three components: the high frequency (0.16-0.4 Hz) component, which is synchronous with respiration and is identical to RSA. The second is a low frequency (0.04-0.15 Hz) component. The third is a very low frequency (VLF) (<0.04Hz) with physiologic significance (Acharya et al 2006). The power of spectral components is the area below the relevant frequencies present in absolute units (square milliseconds). The total power of a signal, integrated over all frequencies is equal to the variance of the entire signal. Some investigators have used the ratio of the low-to-high frequency spectra as an index of parasympathetic-sympathetic balance.

Despite the need for electrophysiologic expertise for the assessment of HRV, the equipment is not that expensive requiring only ECG equipment, microprocessors and relevant software for carrying out Fourier analysis.
Several studies have indicated a connection between negative emotions like anxiety, hostility, etc. and decreased HRV. HRV is a measurement of the exchange between sympathetic and parasympathetic activity in autonomic functioning (i.e., the nervous system that controls heart, intestines, and other organs).

HRV is a promising yet difficult measurement that still has many unresolved issues. HRV is dependent on many factors such as age, sex, position breathing, smoking, hour of the day and medications. Inconsistent results in HRV have been found in depressives and have lower HRV than controls (Moser et al 1998).

A primary focus of clinical work and research is in observing or modifying the balance in regulatory impulses from the vagus nerve and sympathetic nervous system. HRV may also vary as per the health condition, and the lifestyle of a person. It is lower among people who have an inactive lifestyle.

HRV can be assessed by time domain or frequency domain indices. The time domain measures are relied on the amount of time, in milliseconds, in the beat-to-beat intervals of the heart or from the differences between the normal beat-to-beat intervals. The beat-to-beat interval is defined as the time in ms between normal R to R waves on an ECG.

The gold standard for time domain measures is to examine a 24 hour assessment of HRV that has been stored with a Holter monitor. A 5 minute assessment of HRV has been found to be clinically valid and meaningful. Frequency domain measures of HRV provide information on the frequency distribution of the components of HRV using power spectral density (PSD) analysis (Penzel Thomas et al 2003).
Many of the Institute Heart Maths’s (IHM’s) research studies have evaluated the influence of emotions on the ANS utilizing the analysis of HRV or heart rhythms, which exists as dynamic window into autonomic function and balance. While the rhythmic beating of heart at rest was once believed to be monotonously regular, it is now known that the rhythm of a healthy heart under resting conditions is irregular (Boaz Tiran et al 2004).

The mathematical transformation of HRV data into power spectral density (PSD) is used to discriminate and quantify sympathetic and parasympathetic activity and total ANS activity. Power spectral analysis lessens the HRV signal into its frequency components and quantifies the relative power of these components.

HRV’s use has become popular owing to it’s ease of derivation. ‘HRV’ has become the conventionally accepted term to describe variations of both instantaneous heart rate and RR intervals.

Recent developments in microprocessor technology has enabled the calculation of frequency measures based on mathematical manipulations performed on the same ECG derived data. Frequency measures involve the spectral analysis of HRV. RR interval data are represented on a tachogram, in which the Y-axis plots the R-R intervals and the X-axis the total number of beats. Spectral analysis of the tachogram transforms the signal from time to frequency on the x-axis by indicating the signal as a combination of sine and cosine waves with diverse amplitudes and frequencies. The method uses Fourier transforms (Ichiro Kawachi 1997).

To characterize HRV nonlinear dynamics, different approaches are chosen. They are: computation of the maximal Lyapunov exponent (MLE), Corrected Conditional Entropy (CCE), Pattern Fractal Dimension (PFD), Correlation dimension, Multiscale entropy, Renormalized entropy, Wavelet

3.3 SOURCES OF HRV

Autonomic nervous system provides impulses which are applied at sinoatrial node which generates beats of heart rate. Sinoatrial node is natural pacemaker. Artificial pacemakers are available to connect to heart. In the absence of impulses from sinoatrial node, ventricles act as generators of impulses and heart rate is at less value of beats per minute. High frequency components of HRV are related to parasympathetic nervous system. Low frequency components of HRV are related to parasympathetic nervous system and sympathetic nervous system. This relation is not proved (Brian Olschnsky et al 2008).

3.4 METHODS OF HRV

3.4.1 Time Domain Methods

The simplest of a number of methods to carry out a linear operation are the time domain methods with these methods the heart rate or the intervals between successive normal complexes are obtained. Simple time domain variables that can be evaluated have something as heart of a whole the mean RR interval, the mean HR, the difference between the longest and shortest RR interval, the disagreement between night and day HR, etc.

3.4.2 Statistical Methods

From a series of instantaneous heart rates, those recorded over longer periods, 24 h, statistical time-domain measures can be calculated. These may be divided into two classes, (a) those originated from direct
measurements of the RR intervals or instantaneous heart rate, and (b) those got position of from the discrepancies between RR intervals.

The simple variable to calculate is the standard deviation of the NN interval (SDNN), i.e. the square root of variance. SDNN reflects all the cyclic components responsible trusted over a 24-h period and covers both short-term high frequency variations, and the lowest frequency components. SDNN is not a well defined statistical quantity because of its dependents on the length of recording periods. Short-term 5-min recordings and nominal 24 h long-term recordings seem to be suitable options.

3.4.3 Geometrical Methods

The series of RR intervals can also be changed the form into a geometric pattern, such as the sample density distribution of RR interval durations, sample density distribution of differences between side be side RR intervals, Lorenz plot of RR intervals, etc., and a simple formula is utilised which judges the variability based on the geometric and/or graphic properties of the resulting pattern. Three common approaches are utilised in geometric methods: (a) a basic measurement of the geometric pattern (e.g. the width of the distribution histogram at the specified level) is changed the measure of HRV, (b) the geometric pattern is interpolated by a mathematically defined shape (e.g. approximation of the distribution histogram by a triangle, or approximation of the differential histogram by an exponential curve) and then the parameters of this mathematical shape are used, and (c) the geometric shape is organized into many pattern-based categories which show different classes of HRV (e.g. elliptic, linear and triangular shapes of Lorenz plots). Most geometric methods require the RR interval sequence to be measured on or changed to a discrete scale which is not too fine or too coarse and which allows the construction of smoothed histograms (Marek Malik 1996).
The advantage of geometric methods is found in relative insensitivity to the analytical quality of the series of RR intervals. The major disadvantage is the requirement for a reasonable number of RR intervals to construct the geometric pattern. Recordings of at least 20 min (but preferably 24 h) should be utilized to ensure the correct performance of the geometric methods, i.e. the current geometric methods are inappropriate to forecast short-term changes in HRV.

3.4.4 Rhythm Pattern Analysis

The time domain and spectral methods mix limitations posed by the irregularity of the RR series. Diverse profiles analyzed by these techniques may give similar results. Projections of decreasing or enhancing cycle length are not symmetrical as heart rate accelerations are followed by a faster decrease. In spectral results, this continues to lesson the peak at the fundamental frequency and to enhance its basis. This proceeds to the idea of measuring blocks of RR intervals firmly decided by properties of the rhythm and investigating the relationship of such blocks without considering the internal variability. Approaches got from the time domain and the frequency domain have been considered in order to lessen these difficulties. The interval spectrum and spectrum of counts methods proceed to equivalent results and are well suited to investigate the relationship between HRV and the variability of other physiological measures. The interval spectrum is well adapted to link RR intervals to variables defined on a beat-to-beat basis.

3.4.5 Nonlinear Methods

It has been forecasted that methods from nonlinear dynamics may give a powerful tool to deduce more information for better understanding the mechanisms of cardiovascular control. Applications of nonlinear dynamics to the physiological sciences showed that nonlinear models are useful for
understanding complex physiological phenomena such as abrupt transitions, sustained oscillations and chaotic behavior. Nonlinear phenomena are obtained by complex interactions of haemodynamic, electrophysiological and humoral variables, as well as by autonomic and central nervous regulations. It has been forecasted that analysis of HRV based on the methods of nonlinear dynamics might elicit valuable information for the physiological interpretation of HRV and for the assessment of the risk of sudden death. For data representation, low-dimension attractor plots, singular value decomposition, and attractor trajectories have been utilized (Voss et al 2008).

Analysis of HR dynamics by methods relied on nonlinear systems theory has resulted in a novel approach for describing the abnormalities in HR behavior. Studies have shown that these measures, scaling analysis methods of HR dynamics, are changed among various patients populations with cardiovascular diseases and they give prognostic information (Makikallio et al 2002 and Ramirez-Villegas et al 2011).

Quantitative measures of complexity (CD) and predictability (Lyapunov exponent, LE) give prominent information about ANS processes. There is well-organized nonlinear behavior of HRV, which can be predicted with regard to terms such as nonlinear stochastic, regular deterministic, and chaotic (Hoyer 1997 and Cheng LI et al 2008). Although these techniques have been demonstrated to be powerful tools for characterization of various complex systems, no major breakthrough has yet been obtained by their application to bio-medical data including HRV analysis. More encouraging results have been obtained using differential, rather than integral complexity measures, e.g. the scaling index method. No systematic study has been conducted to show large patient populations using these methods. The nonlinear methods represent achievable tools for HRV assessment, but standards are lacking and the full scope of these methods cannot
be anticipated. Advances in technology and the interpretation of the results of non-linear methods are required before these methods are ready for physiological and clinical studies (Marek Malik 1996 and Gley Khader et al 2006).

The normalized entropy detects some abnormalities in the HRV of several patients who have been classified in the low risk group by traditional methods. A combination of these complexity measures with the parameters in the frequency domain seems to be successful to get a more precise definition of the risk.

3.5 RECORDING AND ANALYSIS OF HRV

HRV examination is an effective, completely noninvasive way to measure one’s cardiovascular and overall physical condition. It is relied on the fact that one’s heart does not beat at the same rate all of the time.

The skilled practitioner can use HRV to:

1. assess functional health
2. pinpoint particular medical conditions
3. test the effectiveness of ongoing therapies
4. test fitness levels

HRV has been used to study sympatho-vagal balance. Innumerable methods have been proposed to measure HRV. Two very simple methods for many years, (1) the measurement of sinus rate variability with breathing at a fixed rate of 5 or 6 breaths/min, and (2) the valsala index, which measures the ratio between the shortest RR intervals during phase II and the maximal RR interval during phase IV. Analysis of the 24-h Holter ambulatory ECG has
been utilized to measure HRV. Methods to analyze HRV provide both time and frequency domain measurements that quantify periodicities in data. Information to risk stratify patients for future ventricular arrhythmias or other cardiac events leading to premature death may be possible by quantifying HRV (Acharya et al 2004 and Voss et al 2008).

HRV is measured at a fixed breathing rate of 5-6 breaths/min though normal breathing rate is 12-16 breaths/min.

Phase II : Reduced venous return and compensation

Return of systemic blood to the heart is impeded by the pressure inside the chest. The output of the heart is reduced and stroke volume falls. This occurs from 5 to about 14 seconds in the illustration. The fall in stroke volume reflexively causes blood vessels to constrict with some rise in pressure (15 to 20 secs). This compensation can be quite marked with pressure returning to near or even above normal, but the cardiac output and blood flow to the body remains low. During this time the pulse rate increases (Compensatory tachycardia).

Phase IV : Return of Cardiac output

Blood return to the heart is enhanced by the effect of entry of blood which had been dammed back, causing a rapid increase in cardiac output (24 secs on). The stroke volume usually rises above normal before returning to a normal level. With return of blood pressure, the pulse rate returns towards normal.

Many time and frequency domain variables measured over the 24-h period are correlated with each other. These correlations prevail because of both mathematical and physiological relationships. The physiological
prediction of the spectral components calculated over 24 h is difficult. Unless special investigations are performed which utilize the 24-h HRV signal to get information other than the frequency components (e.g. the log–log slope of spectrogram), the results of frequency–domain analysis are equivalent to those of time–domain analysis.

Time domain methods for measuring HRV are the easiest to perform. Spectral methods have been used to analyze HRV for the past 40 years (Reed et al 2005).

HRV was analysed off-line with the help of software using Burg’s algorithm to find the LF/HF ratio for each sleep stage (Toscani et al 1996).

3.6 CONCLUSIONS

Heart rate variability is explained. Time domain, combined time domain and frequency domain methods and nonlinear methods are mentioned.