HIGH RESOLUTION ELECTROCARDIOGRAPHY

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High Resolution Electrocardiography is a very specialized type of surface ECG which involves computerized analysis of small segments of a standard ECG in order to detect abnormalities, termed Ventricular Late Potentials (VLP) that would be otherwise obscured by skeletal muscle and electrical noise. There are various types of these low amplitude signals which can be detected by High Resolution Electrocardiography but the most important are Ventricular Late Potentials and the main clinical use of High Resolution Electrocardiography is to detect these VLPs. Ventricular Late Potentials are present in terminal part of QRS complex and these may extend into ST segment as well; hence the name "late potentials" because they arise late in ventricular activation process.

KEY WORDS: High Resolution Electrocardiography, Late Potentials, Arrhythmias

INTRODUCTION

The history of surface High Resolution Electrocardiography began in 1973 with the attempt of three groups to record His bundle potentials using the signal averaging techanique[1]. High Resolution Electrocardiography is a very specialized type of surface ECG which involves computerized analysis of small segments of a standard ECG in order to detect abnormalities, termed Ventricular Late Potentials (VLP) that would be otherwise obscured by skeletal muscle and electrical noise. The term "Signal Averaged ECG" which is frequently and synonymously used with High Resolution Electrocardiogram, refers to one of the signal processing techniques that enhances the detection of low amplitude Electrocardiographic signals. The "noise" in conventional ECG ranges from 8-10 μv and is generated primarily by skeletal muscle activity. This level of noise masks the temporal and spectral features of ECG that identify patients with ventricular tachycardia. In High Resolution Electrocardiography noise is reduced to less than 1.0μv[2].

LATE POTENTIALS

Major application of High Resolution Electrocardiography is to detect ventricular late potentials (VLPs). These are low amplitude, high frequency signals present in the terminal part of QRS complex, extending into the ST segment. Late potentials cannot be detected by 12 lead standard ECG because they are obscured by background skeletal muscle noise[3]. They correspond to fractionated electrograms recorded on endocardial mapping and represent regions of anisotropic conduction through areas containing bundles of viable myocardium interspersed with fibrosis[4]. These late potentials are now accepted as non-invasive markers for areas of slow conduction, which is substrate for reentrant ventricular tachyarrhythmias[5].

SIGNAL AVERAGING TECHNIQUES

Signal Averaging can be briefly described as "signal processing technique done usually digitally whereby repeated or periodic waveforms which are contaminated by noise can be enhanced. By summating noisy waveforms the random components i.e. the noise will be decreased while the deterministic components i.e. the desired signal will be unchanged. Signals may be averaged by temporal or spatial processes. Spatial averaging has a potential advantage that it eliminates the variation between serial High Resolution Electrocardiography induced by changes in heart rate, voltages, and ventricular activation time[5]. However available commercial systems use temporal averaging which reduces random or uncorrelated noise by the square root of number of waveforms averaged[7]. The following requirements must be met for temporal averaging to work effectively.

- The signal of interest must be repetitive or invariable
- Signal of interest must be time locked to a fiducial point
- Noise must be random with uncorrelated to the fiducial point[1].

TIME DOMAIN ANALYSIS

In time domain analysis the filter output corresponds in time with the input signal. Most of the signal processing systems use time domain analysis to detect late potentials. Detection of late potentials requires high gain amplification and appropriate digital filtering to reject low frequencies associated with the plateau and repolarization phases of action potential ST, segment and T wave. This enhances detection of high frequency signals associated with ventricular depolarization[8].

The passband and characteristics of the filter are crucial to time domain analysis. Most systems use a 40 Hz high pass bidirectional filter derived from a four-pole Butterworth. Orthogonal, bipolar XYZ leads are recorded, averaged, filtered and combined into a vector magnitude called the filtered QRS complex. The accepted characteristics of a late potential using above mentioned 40 HZ bidirectional filter include: -

1.Duration of filtered QRS complex > 114 ms.

2.Duration of signal < 40 µv in terminal QRS complex > 38 ms.

3.Root mean square voltage in last 40 ms of filtered QRS complex < 20 µv[9].

Figure 1 shows a normal High Resolution Electrocardiogram.

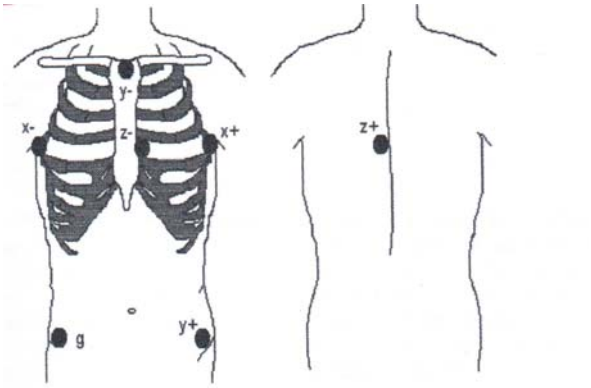
Figure 2 shows presence of late potentials.

Lead placement

Three bipolar leads X, Y and Z were used to record High Resolution Electrocardiography as described by Micheal Simson, MD. These are three orthogonal leads at right angles to each other and they cover the heart from all the three dimensions.

Lead placement for a Signal Averaged ECG is much different then for 12 lead ECG. It is as under:

- Positive X (+X) electrode is placed at left fourth intercostal space, midaxillary line.
- Negative X (-X) electrode is placed at right fourth intercostal space, midaxillary line.
- Positive Y (+Y) electrode is placed at the left iliac crest.
- Negative Y (-Y) electrode is placed at superior aspect of the manubrium of sternum.
- Positive Z (+Z) electrode is placed at fourth intercostal space just left of the sternum (V2 position).
- Negative Z (-Z) electrode is placed on back of the patients directly posterior to positive Z electrode. This was done by repositioning the patient on his side making him sit forward.
- A ground electrode (G) is placed on right eighth rib.



This lead placement optimizes the capture of signal regardless of its vector orientation and avoids the cardiac impulse which would introduce a repetitive electrode artifact that would not be eliminated by the signal averaging process.

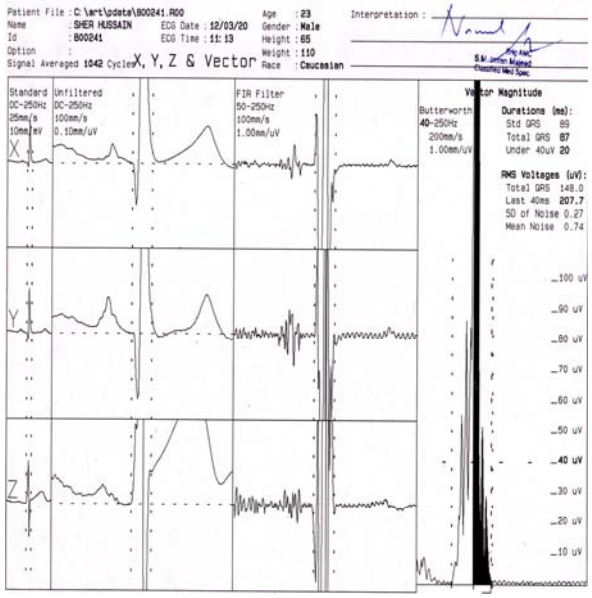


Figure -1: A normal SAECG (fQRS = 87 ms, LAS 40 = 20 ms, RMS 40 = 207.7 µv)

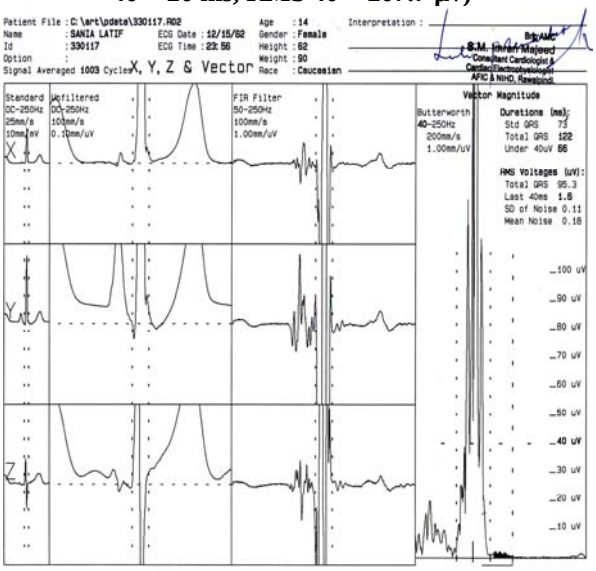


Figure - 2 : SAECG showing ventricular late potentials (fQRS = 122 ms, LAS 40 = 66 ms, RMS 40 = 1.6 µv)

FREQUENCY DOMAIN ANALYSIS

Since late potentials are high frequency signals, Fourier Transform can be applied to extract high frequency content from the High Resolution Electrocardiography, called frequency domain analysis. The Fast Fourier Transform is suitable if

identification of only frequency bands of a particular signal is required; it cannot relate the frequency peaks with time scale[10]. Wavelet Transform is a very recent technique, which is considered an alternative to the Fourier Transform in many fields that require frequency analysis, signal processing or image processing. Unlike Fourier Transform, the Wavelet Transform is two-dimensional in time and frequency, and allows data in both domains to be analyzed at the same time[11].

Current ECG research has no scientific method for determining the start points and end points of P wave, QRS complex and T wave. Frequency domain analysis appears to be the only technique, so far, which can determine start and end points of all these waves mathematically[11].

CLINICAL APPLICATIONS

POST MYOCARDIAL INFARCTION

Most of the occurrences of sudden cardiac death are believed to be due to malignant ventricular tachyarrhythmias. Identification of individuals at risk of such an event has previously been an enigma. Screening the high-risk population for the presence of late potentials on High Resolution Electrocardiography would identify individuals so predisposed. The majority of instances of sudden cardiac death due to ventricular tachyarrhythmias occur in post myocardial infarction patients or those with significant coronary artery disease. High Resolution Electrocardiography has revealed a high incidence of late potentials in these individuals[12].

Treatment of acute myocardial infarction with thrombolytic agents has been shown to reduce the incidence of late potentials[13]. Also prompt reperfusion by angioplasty of the infarct related artery has been associated with a decrease in the incidence of late potential.

After successful coronary artery bypass grafting, late potentials are rarely found in patients without a previous myocardial infarction. In patients with prior Infarction, abnormalities on High Resolution Electrocardiography may improve or resolve after successful surgery[14].

Whereas all patients following an acute myocardial infarction have the potential to develop a cardiac arrhythmia substrate, the risk is greater in patients with larger infarct sizes and lower ejection fraction[15]. Hence individuals with large anterior myocardial infarctions are at greater risk, which can be ascertained by recording a High Resolution Electrocardiography in all such individuals.

The presence of ventricular late potentials is a sensitive but not a specific predictor of ventricular tachyarrhythmias and sudden death in patients with acute myocardial infarction. Infact the finding of a negative High Resolution Electrocardiography (no late potentials) in patients with a previous large anterior myocardial infarction would be very reassuring[16].

PATIENTS WITH SYNCOPE

High Resolution Electrocardiography has been found to be a sensitive diagnostic test for evaluation of patients with syncope to identify individuals susceptible to sustained ventricular tachycardia[1]. In this setting it can serve as a useful non-invasive screening to select patients for invasive electrophysiologic studies, since there is a good correlation between the presence of late potentials and induction of monomorphic ventricular tachycardia by programmed ventricular stimulation[17, 18].

The overwhelming majority of patients with syncope have a neurocardiogenic basis; the so-called ‘vasovagal’ syncope. Such patients are identified by a typical hypotensive bradycardic response on head-up tilt test[19.] However if a head-up tilt test does not reveal a hypotensive response in individuals with a previous myocardial infarction, High Resolution Electrocardiography would serve as an independent screening test for risk of life threatening ventricular tachyarrhythmias.

PATIENTS WITH NON-ISCHEMIC HEART DISEASE

Several studies have shown a positive correlation of abnormal Signal Averaged Electrocardiogram with the occurrence of ventricular arrhythmias and clinical outcome in patients with dilated non-ischemic cardiomyopathy. The predictive value of spectral analysis of High Resolution Electrocardiography has been considered to be superior to that of programmed stimulation in patients with dilated non-ischemic cardiomyopathy[2]. Patients with non-ischemic congestive cardiomyopathy have a high incidence of life threatening ventricular tachyarrhythmias and sudden death. High Resolution Electrocardiography has been found to be a sensitive test in identifying patients with non-ischemic congestive cardiomyopathy at risk for sustained ventricular tachyarrhythmias[20]. As such High Resolution Electrocardiography ought to be recorded in patients with dilated cardiomyopathy.

Abnormal High Resolution Electrocardiography have been described in patients with arrhythmogenic right ventricular dysplasia[21], idiopathic ventricular tachycardia[22], left ventricular hypertrophy[23], mitral valve prolapse[24], systemic sclerosis[25], muscular dystrophies[26], diabetes mellitus[27], in relation to ventricular function in human immunodeficiency

various infection[28], and after surgical repair of congenital heart disease, especially Tetralogy of Fallot[29]. They have also been found useful in identification of myocardial rejection in cardiac transplant recipients[30].

PREDICTION OF EFFICACY OF ANTIARRHYTHMIC DRUGS

The technique is considered promising for assessment of the efficacy or proarrhythmic effect of antiarrhythmic drug therapy in patients with ventricular arrhythmias[31,32]. High Resolution Electrocardiography is a cost effective, simple and non-invasive marker of ventricular arrhythmias. Though, when used alone, its positive predictive value is not very high but when used with other predictors of ventricular arrhythmias e.g. heart rate variability, QT dispersion, left ventricular ejection fraction, baro-receptor sensitivity test, T wave alternans etc, Its positive predictive value becomes significant.

REFERENCES

1. Beriberi EJ, Lazzara R, Samet P. Noninvasive technique for detection of electrical activity during the PR segment. Circulation 1973; 48:1005.
2. Cain ME, Anderson JL, Arnsdorf MF, Mason JW, Scheiman MM, Waldo AL. ACC expert consensus document: signal averaged electrocardiography. J Am Coll Cardiol 1996; 27: 238-49.
3. Berbari EJ, Scherlag BJ, Hope RR, Lazzara R. Recording from the body surface of arrhythmogenic ventricular activity during the ST segment. Am J Cardiol 1978;41:697-702.
4. Gardner P1, ursell PC, Fenoglio JJ. Electrophysiologic and anatomic basis for fractionated electrograms recorded from healed myocardial infarcts. Circulation 1985; 72: 596-611.
5. Breithardt G, Beeker R, Scipel I, Abendroth RR, Ostermayer J. Non invasive detection of late potentials in man:a new marker for ventricular tachycardia. Eur Heart J 1981; 2:1-11.
6. Wojcik ND. The signal averaged electrocardiogram (SAECG). A SCP/SCM National Meeting Washington D.C. 1996
7. Ros HH, Koeleman ASM, AkkerTJ. Technique of signal averaging and its practicle application in the separation of atrial and His purkinji activity: Hombach F, Hilger HH, editors. Signal averaging technique in clinical cardiology. New York: Springer – Verlag, 1981:3.
8. Buckingham TA, Thessen CM, Hertweck D, Janosik KL, Kennedy HL. Signal averaged electrocardiography in time and frequency domains. Am J Cardiol 1989;63: 820-5.
9. Breithardt G, Cain ME, Sherif N. Standards for analysis of ventricular late potentials using high resolution electrocardiography: a statement by task force committee between the European Society of Cardiology, the American Heart Association and the American College of Cardiology. J Am Coll Cardiol 1991; 17:999-1006.
10. Kulakowski P, Malik M, Poloniecki J. Frequency versus time domain analysis of signal averaged electrocardiogram: identification of patients with ventricular tachycardia after myocardial infarction. J Am Coll Cardiol 1992;20:135-43.
11. Ishikawa Y, Mochimaru F. Wavelet theory based analysis of high frequency, high resolution electrocardiograms: A new concept for clinical uses. Prog Biomed 2002; 7:179-84.
12. Kuchar DL, Thorburn CW, Sommel NL. Late potentials detected after myocardial Infarction: natural history and prognostic significance. Circulation 1986; 74:1280-9.
13. Moreno FL, Karagonis L, Marshall H, Menlove RL, Ispen S, Anders JL. Thrombolysis related early patency reduces ECG late potentials after myocardial Infarction. Am Heart J 1992; 124: 557-64.
14. Maki H, Ozawa Y, Tanigawa N . Effect of reperfusion by direct percutaneous transluminal coronary angioplasty on ventricular late potentials in cases of total coronary occlusion at initial coronary arteriography. Jpn Circ J 1990; 57: 183-8.
15. Mukarji J, Rude RE, Poole WK, Gustafson N,Thomas LJ, Strauss HW, et al. Risk factors for sudden death after acute myocardial infarction: two year follow up. Am J Cardiol 1984; 54(1): 31-6
16. Lewes SJ, Lander PT, Taylor PA, Chamberlain DA,Vincet R. Evolution of late potential activity in the first six weeks after acute myocardial infarction. Am J Cardiol 1989;63:647-51
17. Winters SL, Stewart D, Gomes A. Signal averaging of the surface QRS complex predicts inducibility of ventricular tachycardia in patients with syncope of unknown origin: a prospective study. J Am Coll Cardiol 1987; 10:775-81.
18. Gang ES, Peter T, Rosenthal ME, Mandel WJ,Lass Y. Detection of late potentials in surface electrocardiograms in unexplained syncope. Am J Cardiol 1986; 58:1014-20.
19. Kapoor WN, Smith MA, Miller NL. Upright tilt testing in evaluating syncope: a comprehensive literature review. Am J med 1994;97:78.
20. Pou DS, Marchlinski FE, Falcone RA, Josephson ME, Simson MB.Abnormal signal averaged electrocardiograms in patients with non ischemic congestive cardiomyopathy: relationship to sustained ventricular tachyarrhythmias. Circulation1985; 72:1308-13.
21. Blomstrom-Lundqvist C, Hirsch I, Olsson SB, Edvardsson N. Quantitative analysis of the signal averaged QRS in patients with arrhythmogenic right ventricular dysplasias. Eur Heart J 1988; 9: 301-12.
22. Mehta D,McKenna WJ, Ward DE, Davies MJ, Camm AJ. Significance of signal averaged electrocardiography in relation to endomyocardial biopsy and ventricular stimulation studies in patients with ventricular tachycardia without clinically apparent heart disease. J Am Coll Cardiol 1989; 14:372-9.
23. Raineri AA, Yraina M, Lombardo RM, Rotolo A. Relation between late potentials and echocardiographically determined left ventricular mass in healthy subjects. Am J Cardiol 1991; 76:425-7.
24. Jabi H, Burger AJ, Oraweic B, Touchon RC. Late potentials in mitral valve prolapse. AM Heart J 1991; 122:1340-5.
25. Moser DK, Stevenson WG,Woo MA. Frequency of late potentials in systemic sclerosis. Am J Cardiol 1991; 67:541-3.
26. Yostsukura M, Isizuka T, Shimada T, Ishikawa K. Late potentials in progressive muscular dystrophy of the Duchenne type. Am Heart J 1991;121: 1137-42.

27. Yang Q, Kiyoshige K, Fujimoto T. Signal averaged electrocardiogram in patients with diabetes mellitus. Jpn Heart J 1990; 31:25-33.
28. Hsia J, Colan SD, Adams S, Ross AM. Late potentials and their relation of ventricular function in human immunodeficiency virus infection. Am J Cardiol 1991; 68: 1216-20.
29. Stelling JA, Danford AD, Kluger JD. Late potentials and inducible ventricular tachycardia in surgically repaired congenital heart disease. Circulation 1990;82:1690-6.
30. Lacroix D, Kacet S, Savard P. Signal averaged electrocardiography and detection of heart transplant rejection: comparison of time-and frequency domain analyses. J Am Coll Cardiol 1992; 19: 553-8.
31. Cain ME, Ambos HD, Fischer AE, Markham J, Schechtaman KB. Non invasive prediction of antiarrhythmic drug efficacy in patients with sustained ventricular tachycardia from frequency analysis of signal averaged ECGs . Circulation 1984;70 Suppl II: II-252.
32. Hopson JR, Kienzle MG, Aschoff AM, Shirkey DR. Non-invasive prediction of efficacy of type IA antiarrhythmic drugs by signal averaged electrocardiogram in patients with coronary artery disease and sustained ventricular tachycardia. Am J Cardiol 1993; 72: 288-93.

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