Original Article

Pak Armed Forces Med J 2015; 65(Suppl): S5-10

EFFECT OF NOISE ON IDENTIFICATION OF VENTRICULAR LATE POTENTIALS

Muhammad Alamgir Khan, Syed Muhammad Imran Majeed*, Madiha Sarwar**

Army Medical College, Rawalpindi, *Armed Forces Institute of Cardiology Rawalpindi, **Foundation University Medical College Rawalpindi

ABSTRACT

Objective: To determine the effect of noise on identification of ventricular late potentials.

Study Design: Cross sectional comparative study.

Place and Duration of Study: Armed Forces Institute of Cardiology / National Institute of Heart Diseases, Rawalpindi from May 2006 to February 2007.

Methodology: The study included 37 patients with Mitral Valve Prolapse for the identification of ventricular late potentials. Patients with acute or old myocardial infarction, diabetes mellitus and systemic hypertension were excluded from the study. Signal averaged ECG was recorded according to the standard protocol. On the basis of noise level, the patients were divided in two groups i.e. low noise group (<0.20 μv) and high noise group (≥0.20μv).

Results: Sixteen patients were in low noise group and 21 were in high noise group. Frequency of patients with ventricular late potentials was significantly higher in low noise group as compared to the high noise group i.e. 44% vs 10% (p-value 0.02). Mean values of noise and SAECG parameters were also significantly different between low and high noise groups. Noise was significantly correlated with the durations of filtered QRS complex and low amplitude signal below 40μv but not with the root mean square voltage of signal in the last 40ms of filtered QRS complex.

Conclusion: Ventricular late potentials are noise dependent and the probability of their identification increases at reduced noise levels.

Keywords: Electrical noise, Signal averaged ECG, Ventricular late potentials.

INTRODUCTION

Ventricular Late Potentials (VLPs) are the cardiac signals of high frequency and very low voltage which are present at the end of QRS complex but may also extend into the early part of ST segment[1]. They appear in the areas where cardiac tissue architecture is modified due to necrosis, fibrosis or dystrophy causing delayed and fragmented depolarization[2]. This leads to the formation of high-resistivity zones where the speed of cardiac impulse decreases. Such heterogenous areas giving rise to ventricular late potentials represent electrophysiological substrate for the development of re-entrant ventricular tachycardia[3]. There is substantial evidence that ventricular late potential are associated with the development of ventricular arrhythmias. Hence, they are the noninvasive markers of ventricular arrhythmias which may lead to sudden cardiac death, and thus play an important role in risk stratification[4].

The classic cardiac signal detected on 12 lead surface ECG has voltage of the order of a few millivolts and it contains most of the information at frequencies below 100 Hz[5]. Ventricular late potentials are at least two orders of magnitude smaller than the typical ECG signal. Their voltage is generally in the range of 1 to 20 μv making them extremely low voltage cardiac signals[2]. Due to this, these tiny cardiac potentials remain hidden below the noise produced by the non-cardiac signals. This is the reason, ventricular late potentials are not visible on standard ECG[6]. Thus detection of ventricular late potentials requires a high resolution ECG technique that should amplify the signal of interest and reduce unwanted random noise[7].

Biological and environmental electrical signals occurring simultaneously with the cardiac signal are known as electrical noise or simply 'noise'[8]. Reduction of this electrical noise is an essential step in processing the cardiac signal for identification of ventricular late potentials. Noise particularly becomes a

Correspondence: Dr Muhammad Alamgir Khan, Associate Prof of Physiology, AM College Rawalpindi.

Email: docalamgir@gmail.com

problem when the cardiac signal is amplified for the detection of ventricular late potentials[9]. Several noise sources have been identified like artifacts from respiratory muscles, electrical noise arising from electrodes, electrical power lines (60 Hz noise) and other nearby placed electronic equipment[10].

One of the first methods developed to reduce noise in cardiac signal was the signal averaged electrocardiography[11]. Ventricular late potentials become visible after amplifying, averaging and filtering many heart beats and by reducing random noise. This enhances signal of interest by improving signal to noise ratio. Although it is not possible to completely eliminate the residual noise, nevertheless, it is significantly reduced[12]. Averaging of 200 to 300 beats is enough if the baseline noise level of the recording is low otherwise greater number of beats need to be averaged for adequate noise reduction[13].

Along with signal averaging, the technique also uses digital filters for noise reduction. The bidirectional four-pole Butterworth filter with either 25 Hz or 40 Hz high pass corner frequency is used.14For time-domain analysis, noise is measured in the last 40 milliseconds of ST segment of the averaged and filtered signal. Acceptable upper limit of noise depends upon the type of filter used. For 25 Hz high pass filter the noise should be less than 1μv and for 40 Hz it should be less than 0.7 μv[14]. Generally below a noise level of 0.3 μv, signal averaged ECG recording is considered to be of good quality and this noise level is achieved in less than about 450 beats[15].

Detection of ventricular late potentials is noise dependent and there is inverse correlation between the two[16]. The terminal point of ventricular late potentials is determined where the cardiac signal becomes greater than three times the standard deviation of noise. Hence, the accuracy of ventricular late potential detection depends upon the degree to which noise is reduced[17]. Initially the end point of signal averaging process used to be the fixed number of beats. Due to this, different recordings were used to be obtained at different noise levels leading to the probability of false results[18]. Later on, realizing the effect of noise on detection of ventricular late potentials, American Heart Association guidelines instructed that noise must be the end point of the averaging process[14]. This led to standardization of the noise level (<1μv for 25 Hz and <0.7μv for 40 Hz filters) at which signal averaged ECG is carried out[14]. However, a few studies have pointed out that noise levels even below the recommended upper limits affect detection of ventricular late potentials[19,20].

Despite refinements in the recording technique, some background noise always remains and interferes with the cardiac signal leading to false negative results and decreasing sensitivity of the procedure[21]. The purpose of this study was to evaluate the effect of noise on identification of ventricular late potentials through signal averaged ECG.

MATERIAL AND METHODS

It was a cross sectional, comparative study, conducted at Armed Forces Institute of Cardiology / National Institute of Heart Diseases, Rawalpindi from May 2006 to February 2007. Formal approval was obtained from medical ethics committee before starting the study. Written and informed consents were also acquired from the patients. Patients of both the gender and any age with mitral valve prolapse were included in the study. Mitral valve prolapse was diagnosed on 2 dimensional echo-cardiography as per the standard diagnostic criteria[22]. Patients with acute or old myocardial infarction, diabetes mellitus and hypertension were excluded from the study.

Table-1: Comparison of patients with and without VLPs in low & high noise groups.

VLPs	Low noise group	High noise group	*p*-value
Present	7 (44%)	2 (10%)	0.02*
Absent	9 (56%)	19 (90%)	

**p*-value significant

Thirty seven patients were included in the study through non-probability convenience sampling. Signal Averaged Electrocardiogram was recorded using SAECG recording machine '1200 EPX High Resolution Electrocardiograph'. Three orthogonal, bipolar leads X, Y and Z were used to record Signal Averaged ECG as described by Micheal Simson, MD.120 The Lead placement for a Signal Averaged ECG is as under.

1. Positive X electrode was placed at left fourth intercostal space, midaxillary line.
2. Negative X electrode was placed at right fourth intercostal space, midaxillary line.
3. Positive Y electrode was placed at the left iliac crest.
4. Negative Y electrode was placed at superior aspect of the manubrium of sternum.
5. Positive Z electrode was placed at fourth intercostal space just left of the sternum (V2 position).
6. Negative Z electrode was 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.
7. A ground electrode (G) was placed on right eighth rib.

Recording of the three leads was amplified, averaged, filtered with 25 Hz high-pass filter, and combined into a QRS vector magnitude. The recording was carried out for about 1000 beats. The filtered QRS complex was analysed for the presence or absence of the ventricular late potentials. Ventricular late potentials were considered to be present when at least two out of the following three criteria were fulfilled[14].

1. Duration of total filtered QRS complex (fQRS) > 114 ms
2. Low amplitude signal under 40 μv (LAS 40) > 38 ms
3. Root mean square voltage of last 40 ms of fQRS (RMS 40) < 20 μv.

Patients were divided into two groups based upon noise level. Patients whose SAECG was recorded at noise level below 0.20 μv were categorized as low noise group whereas those with recording at or above 0.20 μv were categorized as high noise group.

Statistical analysis was performed by using IBM SPSS statistics version 22. Descriptive statistics were used to describe the results. Mann-Whitney U test was used to compare means of the quantitative variables whereas Chi square test was used for the comparison of qualitative variables. Pearson correlation coefficient was used to determine correlation between quantitative variables. Alpha value was set at < 0.05 for significance.

RESULTS

The mean age of patients was 26.27 ± 6.18 years and male to female ratio was 1.6:1.

Low noise group had 16 patients (43%) whereas there were 21 patients (57%) in the high noise group. Out of 16 patients in low noise group, 7 (44%) had ventricular late potentials whereas in high noise group, 2 patients (10%) out of 21 had the late potentials. The difference was statistically significant (*p*-value = 0.02) as shown in table-1. Noise and SAECG parameters between low and high noise groups were significantly different as shown in table-2.

Noise was inversely correlated with the durations of filtered QRS complex and Low amplitude signal under 40 μv and the correlation was statistically significant (*p*-value < 0.05). There was direct correlation between noise and the root mean square voltage of signal in last 40 ms of fQRS complex but the correlation was statistically insignificant (table-3).

DISCUSSION

Reduction of random noise is required to uncover ventricular late potentials by signal averaging process. Noise reduction is dependent upon ambient noise before the recording and the number of QRS complexes which are averaged. Results of our study indicate that reducing noise increases the

likelihood of detecting ventricular late potentials. Large variations in sensitivity and specificity of signal averaged ECG had been reported in literature[23]. A convincing explanation for this seems to be the recording at different noise levels despite the 'so called' standardization.

Christiansen, et al studied the effect of noise on detection of ventricular late potentials[21]. They performed a detailed analysis of each parameter of signal averaged ECG at various noise intensities. They recorded signal averaged ECG of ten healthy volunteers at four different noise levels i.e. 0.1, 0.2, 0.3 and 0.4 μv. At each noise level, time domain analysis of filtered QRS complex was carried out in accordance with the standard criteria. On the average, durations of fQRS complex and low amplitude signal under 40μv were prolonged by 7.0 ms and 5.9 ms respectively per 0.1μv reduction in noise level. Whereas, root mean square voltage of the signal in last 40 ms of fQRS complex was reduced by 9.1 μv per 0.1 μv drop in noise level.Number of late potential positive subjects were 1, 2, 4 and 6 at noise levels of 0.4, 0.3, 0.2 and 0.1 μv respectively. The finding thatreduction in noise level from 0.4 μv to 0.1 μv led to 500 percent increase in the frequency of late potential positive subjects confirmed the results of our study that ventricular late potentials are noise dependant.

Frances RJ carried out a comprehensive study whereby he evaluated the sensitivity and specificity of signal averaged ECG along with the effect of noise on detection of ventricular late potentials[20]. Group one of his study included eight patients with sustained or nonsustained spontaneous or induced ventricular tachycardia and ischemic heart disease whereas group two had eight healthy volunteers without heart disease or ventricular tachycardia. He performed signal averaged ECG of all the participants in both the groups at two noise levels i.e. 0.3 μv and 0.1 μv. He reported that in group one only two patients had ventricular late potentials at noise level of 0.3 μv and when the noise level was reduced to 0.1 μv all the patients became late potential

Table-2: Comparison of noise and SAECG parameters in low & high noise groups.

SAECG parameters	Low noise group	High noise group	*p*-value
Noise level (μv)	0.12 ± 0.02	0.28 ± 0.03	< 0.001*
Duration of Filtered QRS complex (ms)	104.00 ± 9.45	92.80 ± 6.88	< 0.001*
Duration of Low amplitude signal under 40 μv (ms)	35.63 ± 7.01	28.38 ± 9.29	0.008*
Root Mean Square Voltage of signal in last 40ms of fQRS (μv)	24.42 ± 16.28	53.06 ± 29.94	0.004*

**p*-value significant

Table-3: Correlation of noise with SAECG parameters.

SAECG parameters	Noise	*p*-value
	Correlation coefficient (r)	
Duration of Filtered QRS complex (ms)	-0.54	0.001*
Duration of Low amplitude signal under 40 μv (ms)	-0.34	0.04*
Root Mean Square Voltage of signal in last 40 ms of fQRS(μv)	0.23	0.14

**p*-value significant

positive. In group two 100% subjects showed negative results on signal averaged ECG at both the noise levels. He reported an average increase in durations of QRS complex and low amplitude signal, of 15.88 and 68.5 percent and a drop in root mean square voltage of 48.25 percent, with reducing noise. Same results in healthy subjects at two different noise levels led to another important finding that low noise did not 'create' late potentials, hence, specificity of the test did not change with reducing noise.

Steinberg and Bigger conducted a study to find out ventricular late potentials in three different groups at two noise levels, 1.0 μv and 0.3 μv[24]. Group I of their study comprised of 26 patients with sustained ventricular tachyarrhythmias, group II included 59 patients after myocardial infarction and group III had 14 healthy volunteers. In group I of their study 49% and 69% patients showed ventricular late potentials at noise levels of 1.0 μv and 0.3 μv respectively. The difference was statistically significant at *p*-value < 0.001. Similarly in group II the percentage of patients having ventricular late potentials was 24% and 34% at noise levels of 1.0 μv and 0.3 μv respectively and the difference was statistically significant at *p*-value equal to 0.01. Interestingly, for group III, the frequency of late potentials remained the same at the both noise levels (7% vs 7%). They concluded that sensitivity of signal averaged ECG increased at lower noise levels without affecting specificity.

Results of the studies mentioned above including those of ours indicate that current acceptable noise level is not low enough to 'unmask' the ventricular late potentials, if especially the voltage of these potentials is extremely low. Our study recommends that new standards for noise need to be established for accurate detection of ventricular late potentials considering sensitivity and specificity of the test. However, in conditions where high sensitivity of signal averaged ECG is required, noise level should be kept as low as possible.

Conflict of Interest

This study has no conflict of interest to declare by any author.

REFERENCES

1. Szel T, Antzelevitch C. Abnormal repolarization as the basis for late potentials and fractionated electrograms recorded from epicardium in experimental models of Brugada syndrome. J Am Coll Cardiol. 2014;63(19):2037-45.
2. Santangeli P, Infusino F, Sgueglia GA, Sestito A, Lanza GA. Ventricular late potentials: a critical overview and current applications. J Electrocardiol. 2008;41(4):318-24.
3. Gao C, Guo Y, Yang X. [Research of ventricular late potentials detection based on approximate entropy analysis]. Sheng Wu Yi Xue Gong Cheng Xue Za Zhi. 2007;24(3):526-9.
4. Bergbauer M, Maeso Madronero JL. [The assessment of arrhythmia risks: programmed ventricular stimulation and (or) the detection of ventricular late potentials?]. Dtsch Med Wochenschr. 1992;117(44):1693-4.
5. Elmansouri K, Latif R, Nassiri B, Maoulainine FM. Developing a real time electrocardiogram system using virtual bio-instrumentation. J Med Syst. 2014;38(4):39.
6. Gadaleta M, Giorgio A. A method for ventricular late potentials detection using time-frequency representation and wavelet denoising. ISRN cardiology [Internet]. 2012 [cited 2014 20 June]; 2012 Aug. Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3432549/.
7. Lander P, Berbari EJ, Rajagopalan CV, Vatterott P, Lazzara R. Critical analysis of the signal-averaged electrocardiogram. Improved identification of late potentials. Circulation. 1993;87(1):105-17.
8. Donoiu I, Mustafa RE, Ionescu DD. A cause of falsely high noise level in signal averaged electrocardiogram recordings. Current health sciences journal. 2011;37(4):178-80.
9. Vatterott PJ, Hammill SC, Berbari EJ, Bailey KR, Matheson SJ, Worley SJ. The effect of residual noise on the reproducibility of the signal-averaged electrocardiogram. J Electrocardiol. 1987;20 Suppl:102.
10. Kulakowski P, Murgatroyd FD, Camm AJ. Critical noise level reduction for correct identification of late potentials: an illustrative case report. Clin Cardiol. 1991;14(9):779-83.
11. Avitia RL, Reyna MA, Bravo-Zanoguera ME, Cetto LA. QRS complex duration enhancement as ventricular late potential indicator by signal-averaged ECG using time-amplitude alignments. Biomed Tech (Berl). 2013;58(2):179-86.
12. Christiansen EH, Frost L, Molgaard H, Nielsen TT, Pedersen AK. Effect of residual noise level on reproducibility of the signal-averaged ECG. J Electrocardiol. 1996;29(3):235-41.
13. Bhargava V. Limitation of signal-averaged ECGs and measurement of late potentials in the presence of noise. J Electrocardiol. 1994;27(4):353-5.
14. Breithardt G, Cain ME, el-Sherif N, Flowers NC, Hombach V, Janse M, et al. Standards for analysis of ventricular late potentials using high-resolution or signal-averaged electrocardiography: a statement by a task force committee of the European Society of Cardiology, the American Heart Association, and the American College of Cardiology. J Am Coll Cardiol. 1991;17(5):999-1006.
15. Cain ME, Anderson JL, Arnsdorf MF, Mason JW, Scheinman MM, Waldo AL. Signal-averaged electrocardiography. J Am Coll Cardiol. 1996;27(1):238-49.
16. Atarius R, Sornmo L. Detection of cardiac late potentials in nonstationary noise. Med Eng Phys. 1997;19(3):291-8.
17. Gottfridsson C, Karlsson T, Edvardsson N. The short-term and long-term reproducibility of spectral turbulence and late potential variables of the signal-averaged ECG in a population sample of healthy subjects and the impact of gender, age, and noise. J Electrocardiol. 2000;33(2):107-17.
18. Barbosa PR, Barbosa-Filho J, de Sa CA, Barbosa EC, Nadal J. Reduction of electromyographic noise in the signal-averaged electrocardiogram by spectral decomposition. IEEE Trans Biomed Eng. 2003;50(1):114-7.
19. Christiansen EH, Frost L, Molgaard H, Nielsen TT, Pedersen AK. Noise in the signal-averaged electrocardiogram and accuracy for identification of patients with sustained monomorphic ventricular tachycardia after myocardial infarction. Eur Heart J. 1996;17(6):911-6.
20. Frances RJ. Low noise level unmasks late potentials on signal-averaged electrocardiography. Exp Clin Cardiol. 2010;15(3):e61-4.

21. Christiansen EH, Frost L, Mlgaard H, Thomsen PE, Nielsen TT, Pedersen AK. The signal-averaged ECG becomes late potential-positive at low noise levels in healthy subjects. Eur Heart J. 1995;16(11):1731-5.

22. Belozerov Iu M, Osmanov IM, Magomedova Sh M. Diagnosis and classification of mitral valve prolapse in children and adolescents. Kardiologiia. 20a11;51(3):63-7.

23. Pandey AK, Das A, Singwala AK, Bhatt KN. Prediction and stratification of the future cardiovascular arrhythmic events: signal averaged electrocardiography versus ejection fraction. Indian J Physiol Pharmacol. 2010;54(2):123-32.

24. Steinberg JS, Bigger JT, Jr. Importance of the endpoint of noise reduction in analysis of the signal-averaged electrocardiogram. Am J Cardiol. 1989;63(9):556-60.