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Posterior ECG: Producing a New Electrocardiogram Signal from Vectorcardiogram Using Partial Linear Transformation

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***Abstract*—Various techniques are used in diagnosing cardiac diseases. One of these techniques is using electrocardiogram (ECG) tool. In special cardiac cases like atrial fibrillation and posterior myocardial infraction the cardiologist need some information from posterior side of the patient heart, that it can be achieved by using right-posterior ECG method (17 lead ECG). In right-posterior method, position of the patient must be changed in his/her side, so time is waste and patient would be more tired because of taking ECG signals two times. In this study vectorcardiogram (VCG) signals are used as a tool for providing posterior information of the heart. However because for cardiologists is much easier to work with ECG signals for detecting some cardiac diseases, in this study a new method using partial linear transformation is introduced to get posterior ECG leads (V7,V8,V9) from VCG signal. VCG and ECG signals that were used in this study obtained from 30 healthy persons. We presented a statistical approach to transform 3-lead Frank VCG to 15-lead ECG signals and vice versa, based on partial linear transformation (Least Square Method). Also our linear transformation function would be compared with affine transformation functions. The recorder device was Cardiax digital recorder system. The results show that for healthy subjects, the partial linear transformation (least square method) that is presented in this paper maps 3-lead VCG to15-lead ECG, is more accurate than affine transformation function. Regarding the obtained results in this study, ECG signals that derived from VCG signals by using our method was more similar to measured ECG signals than ones derived by using affine transformation. Therefore, by using this transformation function achieving to posterior information of the case heart would be more accurate and useful.**

***Key words*—VCG, ECG, partial linear transformation, least square estimation method.**

I. INTRODUCTION

Electrocardiographic analysis is one of the first areas in medicine in which a computer processing has been introduced. An electrocardiogram (ECG) has been studied starting since the late 19th century. It studies the function of the heart by reviewing the electrical potentials measured on the body surface and it is the primary tool in clinical diagnosis of the heart [1]. But when standard 12 lead ECG is measured, all the chest leads are on the front side of the body, so there would be no information from posterior side of the heart.

The clinical presentation of some carciac diseases like posterior myocardial infarction is not always easy, not even for the cardiologist. True posterior myocardial infarction is usually resulted from occlusion of the left circumflex coronary artery but the anatomy can vary a little. Occlusion of the right coronary artery may be the cause. Therefore this cardiac disease is difficult to recognise because the leads of the standard 12-lead electrocardiogram are not a direct representation of the area involved. In another word there is no leads "look" at the posterior wall in the normal ECG, no leads show ST-elevation in case of a posterior wall infarction. The ST depressions in V1-V3 that can be observed in case of a posterior wall infarction are in fact mirrored ST elevations and the high R-waves are the Q-waves of the infarct. To be able to confirm a posterior-infarct, leads V7, V8 and V9 (Right-Posterior ECG method) may be helpful. These leads are horizontally placed from V6 to the back and do show the ST elevations of the posterior wall.

A number of lead systems exist today with standardized electrode positions, but the standard 12-lead ECG and orthogonal lead system producing a Vectorcardiogram (VCG) [2] have received most attention. The orthogonal Frank lead system is one of the most common ways to measure VCG. It was introduced in 1954 and is based on the torso model and theoretical mathematic considerations (Frank 1954, Frank 1956) [3-4]. Although the information contained in VCG leads has been found useful in many applications [5], the 12-lead ECG has remained the preferred lead system in the clinical environments due to the existence of well-established criteria for its interpretation. However, lately the synthesizing of VCG from standard 12-lead ECG has been implemented with success [6-7], and synthesized VCG has contributed to improved detection of certain electrocardiographic abnormalities.

VCG determines the direction and magnitude of the heart's electrical forces. In vectorgardiography the placement of electrodes are in X,Y,Z directions, therefore it can provide total information from all sides of the heart specially the posterior side in Z direction.

One reason for the slow development of the vectorcardiography in clinical cardiology may be that the three-dimensional vectorcardiography was developed too early without any comparable methods to understand its meaning or powerful computers available [8]. However, VCG analysis offered an additional help in the diagnosis already before digital recordings. Specific advantages of the vectorcardiogram was the recognition of undetected atrial fibrillation and atrial & ventricular hypertrophy, greater sensitivity in identification of posterior myocardial infarction, and more capability for

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diagnosis of multiple infarctions in the presence of fascicular and bundle branch blocks [9].

Especially vectorcardiography has shown its possibilities during the last decade because of digital ECG signal. There are many novel vectorcardiographic parameters that had been implemented and applied in clinical studies during the last decade.

As we said beforehand in some special cardiac disorders like posterior MI [11] the 12 lead ECG, is often misjudged and this may be the reason for under treatment because the lack of information of posterior side of the heart.

In search of faster and more reliable methods in identifying posterior MI, the extra posterior leads V7 to V9 significantly increase the detection of posterior injury patterns compared with the standard 12-leads ECG. Lead V7 should be placed at the level of lead V6 at the posterior axillary line, lead V8 on the left side of the back at the tip of the scapula and lead V9 is placed halfway between lead V9 and the left paraspinal muscles.

Therefore, if cardiologists doubted bout posterior MI, ordered to get the 15 lead ECG signal from the patient by using right-posterior method [10] in locating ECG leads. In this trend the recognition of posterior MI could not be prepared at the primary 12 lead ECG test and after the result of the test observed by the cardiologist, he/she recommended to get the 15 lead ECG signal from those cases. So, the time is waist, patient would be more tired and the recognition of exact problem of patient postpones.

Because the standard 12 lead ECG is the most common way to measure electrical function of the heart, the essential question is: Is it better to use VCG instead of ECG to get more accurate results? When standard 12 lead ECG is measured, all the chest leads are on the front side of the body, compared to Frank lead system, where two chest leads locate on the back. Therefore the measurement by Frank lead system is more three dimensional than the standard 12 lead ECG.

As a result 3 lead Vectorcardiography [4] provides 3D information of the heart, by showing the 3D vector of the heart. Some projections of this vector in 2D pages will prepare the information about posterior side of the heart. But because using of vectorcardiogram signals is not usual for cardiologist and it is a bit hard to understand so in this study we introduce a new method to convert a VCG to ECG signals by using partial linear transformation. In this trend for each part of the VCG and ECG signals like P, QRS or ST segments was found new conversion coefficients. In this method we got the ECG data of each patient or case by using this partial conversion on real VCG data.

By converting VCG to ECG signals posterior information of the heart would be prepared. So, just with 3 leads (Frank leads) and one VCG test of the patient and using this partial linear transformation the information about posterior side of the heart will be prepared. ECG test is a fashionable diagnosing tool for cardiologist for the primary exam. So, by converting VCG to ECG, the data would be more understandable and useful for cardiologist and the information about posterior side of the heart (V7,V8,V9) would be prepared.

A. Current transformation functions between ECG and VCG:

Pioneering studies on lead transformation by Dower [12] has down. This conversion made happen for the first time the possibility to derive the 12-lead ECG from the Frank leads. Dower used geometric transformation principles to obtain a matrix based on Frank's torso model, widely referred to as the Dower transformation matrix. But in dower method there are no coefficients to get posterior leads (V7,V8,V9), so it can not be useful for the posterior MI cases.

The other method to derive ECG data from VCG, was developed transformation matrixes using statistical least squares fitting of an affine function [13]. Every derived lead is a linear combination of the known leads values plus a constant. The affine transformation structure provides a convenient means to automatically compensate for some of these constant biases so that the resulting empirical transformation scan would be more consistent and accurate.

Linear regression model assumes that every derived lead (the individual 8-lead value (V1,V2,…..,V6, I,II) denoted as Y = [y1, y2,…, y8]T can be obtained from a linear combination of the 3 Frank VCG values (the 3 leads are denoted as X = [x1, x2, x3]). So we would have:

$$Y = AX + e = a0 + a1x1 + a2x2 + a3x3 + e \quad (1)$$

where a0, a1…an are the columns of the transformation coefficients, and A is the transformation matrix and e is the error. Thus, by knowing the input lead values, the corresponding coefficient vectors can be used to derive each of the 8 leads from VCG.

II. MATERIALS AND METHODS

In this investigation, First of all three signals (ECG & Right-Posterior ECG& VCG) for each case must be gotten. After that 15 channel ECG and VCG must besynchronized. So by using differential threshold method we could find the R peak of each signal and synchronize the ECG and VCG signals for each case. This process must be taken because in recording VCG signal, the position of the case changed from the position in ECG recording [4]. Cardiax recorder which was used in this investigation has the ability to give some information about duration of the P, QRS and ST segments of the ECG and VCG signals of each special case. So we got duration of these segments in milliseconds, more ever we knew that the sampling frequency is 500 HZ, so by having this data we could get exactly each segment of our signals had how many samples by this equation:

For example:

QRS segment = 40 ms

$$\Rightarrow \quad \frac{1000(\text{ms})}{500(\text{sample})} = \frac{40(\text{ms})}{x\ \text{sample}}$$

Sampling rate = 500 hz

By this equation X would be calculated. So after make ECG and VCG synchronized that would be possible to extract each segment of both signals.

After that we used the least square fitting method to find partial coefficients for each segment of ECG & VCG signals. Final formula would be like this:

$$[a\ b\ c]^T = (UT.U)^{-1}.U^T.Y \quad (2)$$

where

U= (VCG data)

Y= (ECG data (just one lead))

Three coefficients (a-b-c) were provided for each segment of the signal. In right-posterior method of ECG two electrodes locate on the right side of the heart and three electrodes locate at the back of the heart horizontally. In this way we would have real information about posterior side of the heart too. By changing the position of the patient (lay down on right side of the body) the VCG test is given. Now we have both signals and we could find local coefficients for each segment of our signals.

In this investigation, we have used 30 healthy cases. The sampling rate was 500 Hz, and the samples were typically gathered for 16- second duration and the recorder device was Cardiax recorder. For testing this method we calculated a-b-c coefficients for 5,10,20,30 healthy cases and observed that when the number of our cases increased from 15 persons the coefficients are approximately constant so we got that this method is trustable.

Finally For comparing our method with affine transformation, we use affine matrix to convert the VCG signals to ECG ones and then calculate some statistical parameters for comparing the precision of our method and existed one.

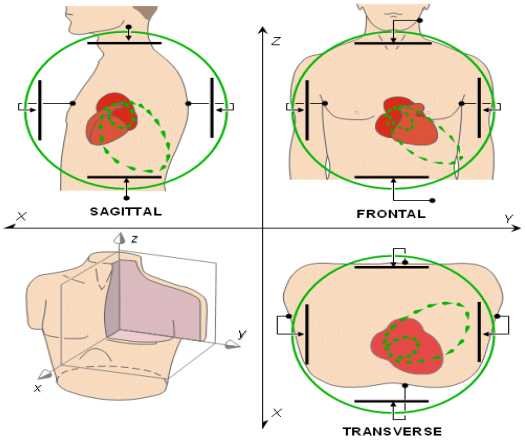

Figure (1): placement of VCG electrodes.

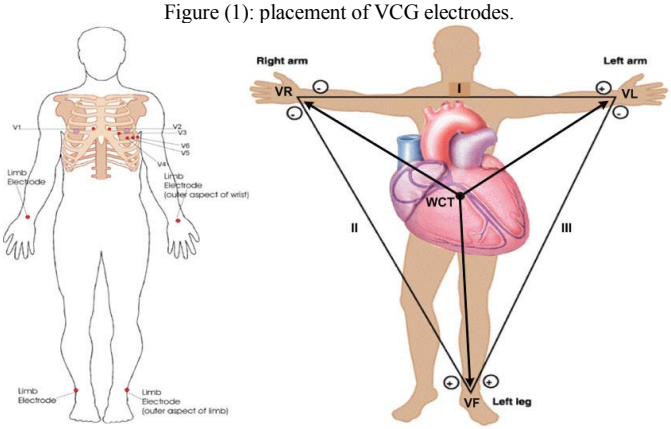

Figure (2): placement of ECG electrodes.

The Figures 2-3 show the placement of VCG and ECG electrodes.

A. Evaluation of the method

An R2 is a statistic parameter that is used to quantify the extent to which a transform captures the trends in the relationship between the inputs (3 VCG leads) and each of the measured data. An R2 statistic of 100% indicates that the transform is able to correctly reproduce the actual measured data (lead value) every single time. An R2 statistic is given by:

$$R^2 = \{1 - \frac{\sum_{All\ ECG\ samples}[Derived(samplek\quad k) - Measured(samplek\quad k)]^2}{\sum_{All\ ECG\ samples}[Measured(samplek\quad k)]^2}\} \times 100 \quad (3)$$

R2 is used to evaluate how close the outputs are calculated from the model relative to the actual measured lead values.

III. RESULTS

When we compared statistical parameter (R^2) of the conversion in partial linear method with affine transform, we observed that our recommended method was much more reliable and accurate. So for healthy cases, the partial linear transformation presented here yields improved accuracy (R^2 values) over affine transform (see Table 1 for details).

TABLE 1: COMPARISON OF STATISTICAL PARAMETER OF PARTIAL LINEAR TRANSFORMATION AND AFFINE METHOD

leads	**R^2** ***partial linear method***	**R^2** ***Affine method***
V_7	72.53	63.46
V_8	45.01	7.4
V_9	88.49	87.74

These results show that for healthy subjects, our method (partial linear transformation) presented here maps 3-lead VCG to 15-lead ECG more accurately than affine lead transformation matrices. Therefore we can conclude that partial linear transformation method would be useful for detecting posterior MI by providing trustable information from posterior side of the heart.

The Figures 3-4 show the similarity of real ECG and derived ones from VCG for P segment in leads (V7-V8 -V9). Real ECG is in red line and derived one in green line. (Horizontal vector expresses number of samples and vertical one expresses the amplitude of segments in mv).

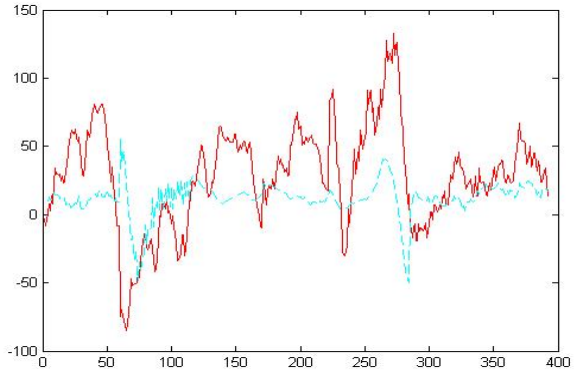

Figure (3): Comparison between extracted P segment using partial linear method (blue) and original data (red) for lead V9.

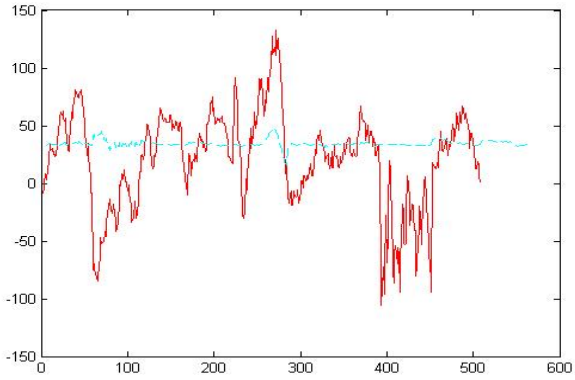

Figure (4): Comparison between extracted P segment using affine method (blue) and original data (red) for lead V9.

IV. DISCUSSION

Regarding the obtained results in this study, ECG signals that derived from VCG signals by using our method (partial linear transformation) had more similarity with general ECG leads than ones derived by using dower and affine transformations. As a result by finding a reasonable and more accurate method for converting these signals (electrocardiograph and vectorcardiograph) to each other that would be possible to reach the information about posterior side of the heart that were equivalent to V7,V8,V9 in original ECG, from vectorcardiograph by using partial linear transformation function.

By providing total information from posterior side of heart walls for cardiologist just from 3lead VCG, it could be really helpful for them to have a better recognition of patient diseases, and the time of diagnosing process would be decreased dramatically.

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