Comparison of Different Methods for the Derivation of the Vectorcardiogram from the ECG and Morphology Descriptors

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Abstract

Several methods have been proposed for both the derivation of the vectorcardiogram from the 12-lead ECG and the quantification of the morphology of vectorcardiograms. The aim of this study was to compare commonly used QRS/T morphological descriptors obtained with different transforms. Vectorcardiograms were reconstructed for 180 patients by applying Singular Value Decomposition and Dower's inverse transform. Planes of best fit, morphology dispersion ratio, complexity ratio, wave residuum and normalized loop area were calculated among other parameters. Parameters computed after different derivation methods were poorly correlated. Also, low correlation values were found among any of the morphological parameters under evaluation.

1. Introduction

The vectorcardiogram (VCG) is a useful tool in the study of many cardiac diseases, providing additional information over the conventional ECG as it contains spatial information. However, the VCG is not usually recorded in clinical practice, and orthogonal leads need to be derived from the conventional 12 leads. Different methods have been proposed for the derivation of orthogonal leads from the 12 lead ECG. The most widely used methods for the derivation of the VCG are: Dower inverse transform [1] and Singular Value Decomposition [2].

The objective of Dower inverse transform is the computation of Frank leads for the 12 lead ECG, while derivation of the VCG by singular value decomposition (SVD) aims at representing the ECG on its three main axes

Dower inverse transform is a linear transformation which consists in a matrix of 24 coefficients. This transformation makes use of 8 independent leads (I,II,V1,V2,V3,V4,V5,V6) [3] and results in 3 orthogonal leads that represents the electrical activity in the 3 axis. These axis have a geometrical interpretation as three orthogonal axis as defined in Frank's system.

By applying SVD to the 8 independent leads, 8 components of the ECG are obtained ordered according to their importance. The first three important components are taken as a vectorcardiographic signal which can be shown in a 3D space in the same way as leads obtained by Dower. In this case the axis don't have a geometrical interpretation as that obtained by deriving Frank leads.

Although these transform don't share the same principles, the objective of the present study is the evaluation of parameters obtained with both methods, when applicable, in order to determine if they offer similar results.

Also, many parameters have been proposed in the literature for the quantification of the information provided by the VCG. Some of these parameters aim at quantifying similar physiological disorders. However, it is unclear whether they offer similar results or which of them are more significant for a specific condition.

In this paper we compute selected morphological and spatial parameters used in previous studies and compared them by computing the correlation and paired t-tests in order to determine if there is redundancy among any of the parameters under study or they offer independent information.

2. Methods

Population under study

ECG recordings from 180 patients admitted in Universitätsklinikum Hospital of Magdeburg were included in this study. All the patiets were diagnosed with either Cardiomiopathy or Bundle Branch Block.

Our database consisted of 12 lead ECG recordings

with a duration of 10 seconds and a sampling frequency of 500 Hz and a quantization of 1 microvolt/bit.

Signal processing

Raw signals were first high pass filtered (fc=0.25 Hz) in order to remove baleline wandering and low pass filtered (fc= 30Hz) for reducing mioelectric artefacts

QRS complexes were first isolated for morphological analysis with the objective of excluding ectopic or noisy beats for further processing. QRS peaks were detected by using a modified version of Tompkins algorithm [4]. Then, a window starting 20 ms before each peak and 40 ms after each peak was taken. An averaged QRS complex was calculated for each of the 12 leads from all the windows. Every QRS complex was correlated with this mean QRS complex. QRS complexes showing a correlation higher than 0.97 were considered for further analysis.

Orthogonal leads were calculated by two methods: (1) using the so-called Dower's inverse transform [1] and (2) by taking the three main components derived from Singular Value Decomposition [2].

An averaged beat was calculated for each orthogonal lead by computing the mean of those not previously excluded due to the morphology of the QRS complex and whose correlation with the median beat (calculated from all non-excluded beats) was higher than 0.97. Beats were defined by using a fixed window starting 20 ms before the peak of the QRS complex and 40 ms after the peak of the QRS complex.

Fiducial points were detected in each beat of each orthogonal lead and for the averaged beat as follows: first a window which presumably contains the wave considered for detection is isolated; then, the main peak in that window is detected and finally onset/offset points are considered to be the first points before/after the peak whose first derivative is lower than a threshold.

The detection process of fiducial points was fully automated. Detections were visually inspected, and patients with a wrong detection of either the P wave, QRS complex or T wave (N=33) were excluded from further analysis. The population under study after exclusion of patients with a misdetection in any fiducial point consisted of 147 patients.

Waves belonging to a same recording present a certain degree of variability, as observed in Figure 1. This variability is partially due to inhomogeneity in the depolarization or repolarization sequence, while some of this variability can be attributed to the movement of the heart in the thoracic cavity caused by respiration. In order to reduce the effect of respiration on the vectorcardiogram, spatiotemporal alignment was performed separately on P loops, QRS loops and T loops as described in [3]. The performance of this method can be observed in Figure 2.

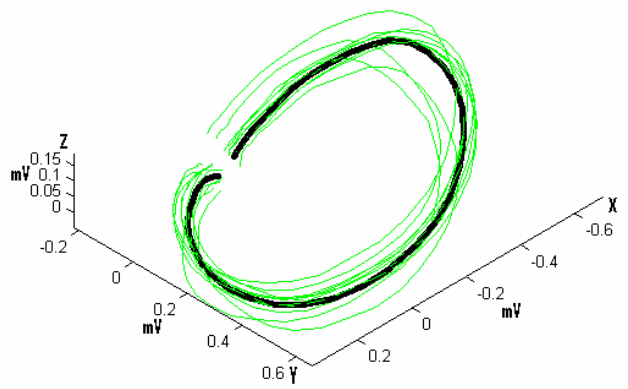

Figure 1: Variability of loops in a 3D space. Ten consecutive QRS loops are represented by a thin line. The averaged loop was represented by a thick line.

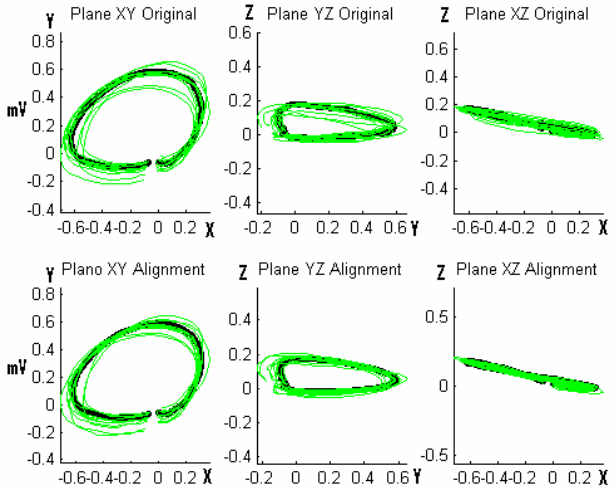

Figure 2: Alignment of loops. Top panel shows the VCG before alignment as projected in the 3 main planes. Bottom panel shows the VCG after alignment.

Measurements

Planes of best fit. Planes of best fit were calculated for each loop (P wave, QRS complex and T wave), for all the loops of each patient and for each averaged loop by Least Squares optimization [2] (See Figures 3-4).

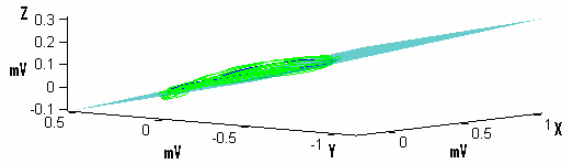

Figure 3: Plane of best fit for all QRS-loops in Figure 1 in a 3D view.

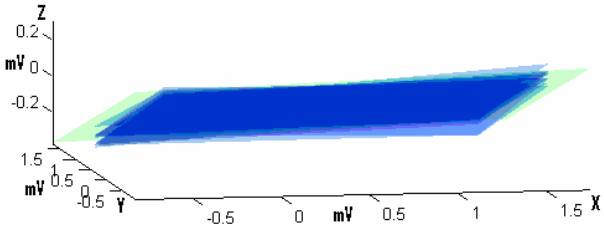

Figure 4: Plane of best fit for every QRS-loops in Figure 1 in a 3D view (dark blue) and for the averaged QRS (light blue).

In order to quantify the spatial dispersion among the loops angles between the normal vectors of the planes of best fit (among all of them, with respect to the fit for all beats) were calculated and given the mean value and standard deviation was obtained.

ABF *(Angle Best Fit)* Angle between the plane that fits each loop and the plane that fits everyloop at the same time

Dev Mean Quadratic Deviation corresponding to the whole wave under study.

Dev26% Mean Quadratic Deviation corresponding to the the last 26 % of samples (*for QRS complex, that is the final depolarization phase, while for the T-wave represents the terminal repolarization phase*).

Angle of TCRT *(Total Cosine R to T)*: Angle between the maximum vector of the QRS loop and T loop for each beat [5].

SPT *(Spatial Angle)*: Angle between the mean spatial QRS axis and the mean spatial T axis [6].

Ventricular Gradient: Difference vector between the mean QRS vector and the mean T vector. [7]

MD (*Morphology Dispersion, PMD TMD*): Measure of spatial wave morphology variation that reflects the dissimilarities between wave shapes based on the differences between reconstruction vectors of individual ECG leads created from the three-dimesional wave loop obtained by Singular Value Decomposition. MD is calculated as the mean value of the angles between reconstruction vectors [8].

nLA (*Normalized loop area*): Describes the shape and irregularity of the wave loop by expressing its area as a fraction of the rectangle that encompasses the loop.

CR (*Complexity ratio*): Describes global shape abnormalities of the wave, defined as the second component divided by the first component of eigenvalue decomposition given as percentage.

WR (*Wave Residuum*): Degree of non-dipolarity obtained after eigenvalue decomposition.

Statistical Analysis

For each parameter described above, mean value, range and standard deviation was computed. Comparison of vectorcardiogram derivation techniques was evaluated by computing the correlation among the parameters obtained with both Dower inverse transform and SVD derivation. Redundancy among the parameters under study was assessed by correlation and paired T-tests.

3. Results

Comparison of vectorcardiogram derivation techniques: Dower vs SVD

Results of the comparison of parameters measured after both derivation methods are summarized in Table1. Only correlation values with $p<0.05$ are presented.

Table 1: Correlations between values of angles and square mean deviation of every patient

	ABF	Dev	Dev26%
T	0.3**	0.8**	0.7**
QRS	0.4**	0.2**	0.3**

* $p < 0.05$, ** $p < 0.01$

Evaluation of redundancy among morphological and spatial parameters

Results of the comparison among selected pairs of morphological and spatial parameters are summarized in Tables 2-3.

Table 2: Correlations among morphological parameters applied on the T wave.

	Value
TMD/nTLA	0.3*
TMD/tCR	0.4*
TMD/TWR	0.3**
nTLA/Tcr	0.4
nTLA/TWR	0.1
tCR/TWR	0.6**

* $p < 0.05$, ** $p < 0.01$

Table 3: Correlations among spatial parameters.

	Value
TCRT/SPT	0.9**
Gradient/TCRT	0.2**
Gradient/SPT	0.3**

* $p < 0.05$, ** $p < 0.01$

4. Discussion

As it is shown in table 1, Dower and SVD derivations offer different results both for the QRS complex and T wave. Correlation values for parameters obtained for the QRS complex and T wave are low except for the deviation, with a correlation value of 0.8. So, it is possible that in T-loops, although the planes from Dower and SVD have a different orientation, the dispersion among them could be similar.

None of the pairs of morphological parameters under study were found to be similar, with a maximum correlation found for the pair tCR-TWR equal to 0.6.

Finally, the study on spatial parameters, confirmed that the parameters TCRT and SPT are closely related with a correlation value equal to 0.9.

5. Conclusions

In this study we have confirmed that the two methods most commonly used for the derivation of vectorcardiographic measurements: Dower and SVD are different, not only because of their principle but also because of the results that can be obtained by using both methods.

Different parameters which aim at quantifying similar effects have been evaluated. It has been shown that most parameters under study are different except for SPT and TCRT which are very similar.

Similarity among parameters proposed by different investigation groups has been evaluated. It was not the purpose of the present study to evaluate their clinical value or their significance for the diagnosis of any pathological condition. Further analysis of the clinical data of the patients that constitute our database will help in identifying the best markers for each pathology.

Acknowledgements

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