Development of an Individually Corrected Vectorcardiographic Lead System

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Abstract

Vectorcardiography is a technique focused on the spatial representation of the cardiac vector. Many vectorcardiographic systems have been proposed over the years, and Frank's lead system is the most extended one. Frank's system uses orthogonal lead axis corrected by fixed coefficients. We propose a novel vectorcardiographic lead system based on Jouve's theories, where correction coefficients are computed for each patient according to electrical measurements taken over the body surface. First, the centre of symmetry (O point) is obtained by the estimation of the whole body surface voltage distribution. This O point is considered to be the electrical origin of the cardiac vector and any orthogonal axis system centred on it can be used. Correction coefficients for any lead system are then computed from the amplitude ratios found on the body. This system does not use approximations of correction coefficients as proposed by Frank and other author and so, it appears to be a more accurate representation of the electrical cardiac vector

1. Introduction

Vectorcardiographic techniques (VCG) attracted special interest in the 50's decade but its clinical use has not been as widely applied as the ECG. This was not so much related to its diagnostic potentiality but to the technological difficulty for the recording and correct representation of the VCG.

Several scientists tried to solve these problems with different approaches. The most prominent in the bibliography are Grishman, Duchosal and, above them, Frank, who designed a lead system for Vectorcardiography that has been widely accepted and is still being used today. Grisman's Cube [1] is one of the simplest lead systems. This cube is composed by four electrodes: one of them is used as the reference voltage and the other three provide the axes of the vectorcardiogram. Grishman placed these four electrodes creating an ideal cube with equal distance between all the axes and the reference.

Nonetheless, his assumptions did not take into account two essential characteristics: 1) the human torso is quite far from the spherical model and, 2) the electrical distance is not equivalent to the physical distance.

Ernest Frank [1, 2, 3], basing his lead system in an experiment with a plastic model of a human thorax filled up with a saline solution, determined the optimal electrode placement and the applicable correction coefficients in order to adjust each electrode with the same weight that his system specifies on the patient body. For many scientists, this system seems to be the most accurate, and that is why it is widely accepted. However, the variability of the patient characteristics is omitted.

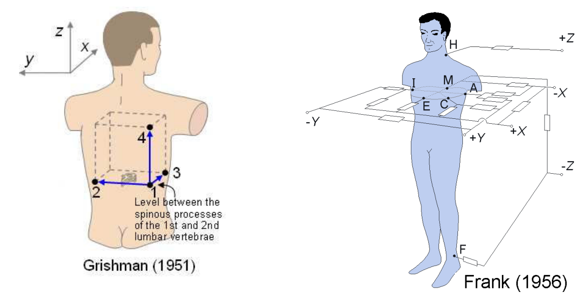

Figure 1. Electrode distribution of two of the most accepted VCG lead systems. On the left, Grishman's Cube, with three electrodes forming the axes and a fourth electrode used as voltage reference. On the right, the seven leads of Frank's system, where several resistances have been placed, symbolizing the correction coefficients.

A different lead system for vectorcardiography proposed by A. Jouve [4] did not become as popular as Frank's even though his theses were well fundamented and avoided simplifications and assumptions about the patient's anatomy. Jouve based his studies only on the accepted assumption that the human heart can be electrically modeled as a dipole. The electric field of a dipole has a symmetrical behaviour, which lead him to suppose that every lead would have its respective symmetrical anywhere in the body surface. Jouve used this electric field property in order to design a lead system.

Jouve lead system stipulates that three electrodes have to be placed on the patient's torso, in positions that might move depending on the subject characteristics. In order to determine these electrodes, it seems to be necessary to calculate the exact situation of the symetry origin, or O point [4].

The O point is defined as the center of the electrical activity taken from outside the patient's body. After computing the O point, we get the null activity point: the vectorcardiogram origin. From this starting point, Jouve established that perpendicular leads might conform the three needed axis. Correction coefficients for each lead could be simply computed using the amplitude ratios found on the thoracic surface for symmetrical leads (with the O point as the center of symmetry). Departing from conventional ECG lead placement, he selected: V_2, V_6 and aV_F. As the aV_F axis is larger than the others, Jouve established a gain coefficient of $\sqrt{3}$ to this axis, and a factor of 1 to the others.

The biggest advantage of this lead system is its adaptation to patients, as well as the situation of the VCG origin (O point). Nonetheless, this system does not stipulate that axes have to be orthogonal, even when this property is necessary to interpret a vectorcardiogram. Moreover, the $\sqrt{3}$ factor is only an approximation.

The objective of the present work is to develop a new lead system for Vectorcadiography based on Jouve's theories but including the use of orthogonal axes and more accurate coefficients. The development of this new system and the results obtained for a group of patients will lead us to elucidate whether assumptions made by Frank are realistic for every patient, or a correction of Frank's coefficients is needed.

2. Methods

We started from electrocardiographic recordings taken with Body Surface Potential Mapping technique (BSPM) [5], using 64 electrodes distributed on the whole thorax, 48 in the front side and 16 in the back; 2048 Hz as sample frequency, a bandwidth of 500 Hz and quantification of 16 bits. Moreover, we did a posterior digital processing, composed by 50 Hz notch filtering, a muscular noise filtering, offset reduction and line-base shifting reduction.

From these 64 leads, we interpolate using cubic spline interpolation and accurately approximate the electrical activity at any point on the torso surface. Therefore, with this process we calculate 161×91 interpolated points from 64 real points. From these data we have made the following calculations:

1. First, our system looks for the O point situation, in order to fix it as the origin of the vectorcardiogram. We establish 10 traversal planes and choose one lead contained in each one. The O point plane will be the one containing both the departing lead and its symmetrical. Thus, we get to know the O point plane. After that, we generate 17 equidistant leads contained in this plane and we search for their symmetrical leads. The O point will be the intersection of the lines that join each lead with its symmetrical. If the torso section is quite exact, we will see that the size of this point is not bigger than a nut size.

2. Just later, we select three points in the torso that are orthogonal. These points will correspond to the three approximate leads we have already obtained from the interpolated matrix.

3. Finally, the system will have to determine the coefficients which have to be applied to every axis. With that objective, we search the relation between amplitudes of each one of these three leads and their symmetrical.

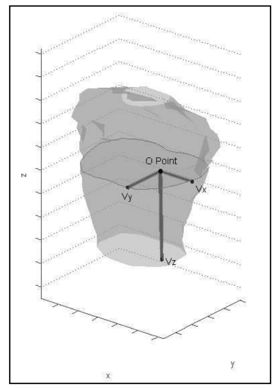

Figure 2. Jouve ON lead system.
In this figure we can see the O point situation (Vectorcardiogram origin), as well as the three leads that conform the three axes of the reference system. Note that all three leads conform an orthogonal system.

Once the new Jouve ON leads have been built, we obtain those of Frank's lead system from the 64 electrodes of the BSPM system. For that, we only need to identify the location of Frank's electrodes with the BSPM electrodes and make the necessary calculations.

After obtaining both types of leads (Frank's and Jouve's ON), we represent the characteristic loops for each plane (Frontal, Sagital & Horizontal), calculating the characteristic parameters [6-7] based on the mean axes of QRS and T loops, maximum range of these waves, etc. We calculate 149 parameters in total.

Starting from the hypothesis that there will be some similar shapes, mainly among those ones where Frank's approximations are closer to the reality, we will make a comparative study between both lead systems.

From a control group of 10 healthy individuals with BSPM registers of 10 seconds, an initial visual inspection was carried out by some medical experts, considering qualitatively the information represented in the loops. In order to measure this similarity between both systems in a quantitative manner, we computed Pearson correlation and t-student tests for each parameter, taking the value $P < 0.05$ as significant.

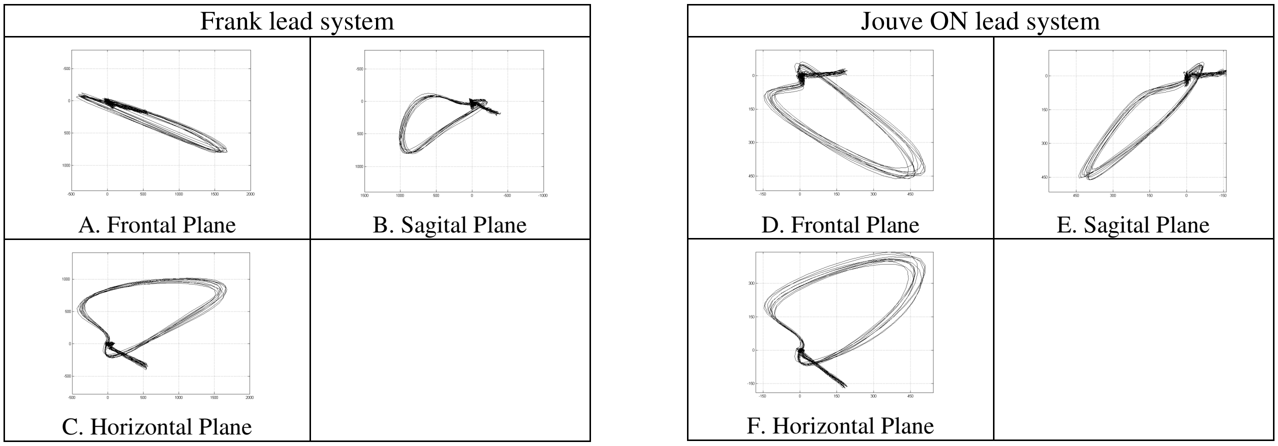

Figure 3. Likeness between VCG obtained with both systems. On the left (illustrations 3A-3C), we can see the three views of a vectocardiogram obtained by our Frank lead system simulation. On the right (illustrations 3D-3F), the same views of VCGs of the same patient and time of study but obtained by our Jouve ON system.

3. Results

In Figure 3 we can check the similar shapes of Frank and Jouve ON Vectorcardiograms in healthy subjects

Regarding a comparative/quantitative study of the parameter values obtained for both systems (Frank's and Jouve's ON), Tables 1 and 2 show the correspondences between four of the most important parameters describing the shape of a vectocardiogram, in each one of its three planes.

Plane	Mean Axis Argument (º)	Maximum Axis Argument (º)
Horizontal	-34.21 ± 21.57 *-13.66 ± 37.81* R = -0.1592 p = 0.6604	-28.83 ± 24.45 *-9.35 ± 43.30* R = -0.7544 p = 0.0117
Frontal	33.76 ± 17.42 *44.81 ± 17.22* R = 0.7892 p = 0.0066	36.00 ± 23.65 *45.92 ± 21.24* R = 0.9286 p = 1.0430e-004
Sagital	130.48 ± 27.54 *109.76 ± 30.45* R = 0.4518 p = 0.1899	126.62 ± 17.36 *109.66 ± 31.02* R = -0.2285 p = 0.5255

Table 1. Most important QRS loop parameters. For each plane of a VCG we have the value for both systems (Frank: top, normal font; Jouve ON: bottom, italics).

Twelve values corresponding to different planes are presented in mean +- standard deviation for each system (Frank: normal font; Jouve ON: italics), apart from the correlation value of Pearson (R) and the value of significance p.

Plane	Mean Axis Argument (º)	Maximum Axis Argument (º)
Horizontal	41.48 ± 22.33 *32.71 ± 44.63* R = 0.5944 p = 0.0700	26.20 ± 6.61 *29.24 ± 35.53* R = -0.5032 p = 0.1382
Frontal	33.54 ± 23.98 *16.24 ± 41.02* R = 0.9810 p = 5.6044e-07	31.31 ± 16.13 *17.44 ± 33.26* R = 0.9448 p = 3.8017e-05
Sagital	37.99 ± 13.32 *38.26 ± 66.99* R = 0.4494 p = 0.1926	48.10 ± 17.26 *39.92 ± 56.68* R = 0.4125 p = 0.2362

Table 2. Most important T loop parameter. Here we have the same parameters than in the previous table (Table 1) but calculated for T loop.

4. Discussion and conclusions

There are many known lead systems to reproduce vectorcardiograms, and a common factor exists in all of them: approximation errors due to simplification assumptions. Even the most accepted one, Frank's system, is based on an experiment with plastic models filled up with a saline solution.

A more realistic alternative is Jouve's system. This system makes use of the electric field symmetry generated by a human heart in order to design a lead system. The situation of the three electrodes used varies in every patient. However, this system has a big disadvantage: it is not orthogonal. This fact makes vectocardiogram interpretation more difficult.

We propose a new lead system based on Jouve's theories but offering orthogonallity and total adaptation to the subject. In our case, the reference system will be formed by three orthogonal axes and, the O point will be the voltage reference origin. Theses two properties will be different in each patient.

Moreover, the coefficients applied to these three axes will be calculated depending on the subject, i.e., this lead system (Jouve ON) is totally adapted to the changing characteristics of a patient. With it, we can suppress the approximate error which other systems have.

From the comparative study with Frank's lead system we have found a great number of similarities between both systems in some parameters, mainly in those related to the Frontal plane. However, there are some important differences between other parameters, even in intra-patients, mainly caused by the individual correction of the weight of every lead. It is worth noting the opinion of most experts in relation to Jouve ON, which offers a spatial representation more in agreement with what is expected of a vectorcardiogram. This fact becomes more evident in those patients with any kind of cardiac pathology, as it has been proved by a preliminary study, and which is directly related to the main objective of proposing a new vectorcardiogram system.

Finally, it is important to stress that the results have been obtained from the 64 BSPM leads. At the present time, the practical implementation with fewer electrodes (following Frank's system) is not still feasible.

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