Transformation of Vectorcardiogram Due to Gravitation Alteration

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Abstract. *A set of vectorcardiograms recorded during the parabolic flights of a laboratory aircraft was analyzed. It was found that alteration of the gravitation resulted in a linear transformation (rotation and dilatation) of the QRS loop, and only in few cases with disturbances of the heart function the changes of the ECG shape were nonlinear and more complicated. Abrupt changes in the depolarization process may be detected by the nonlinearity of the QRS loop transformation. Characteristics of the transformation (eigenvalues, angles of rotation) can be used as indicators of the heart state changes.*

Keywords: Vectorcardiogram, Gravitation

1. Introduction

Changes in gravity level and direction causes a shift of body fluids and heart relocation in the thorax. These effects in turn induce changes in electrocardiograms. There are not found many works that consider the changes of the vectorcardiogram (VCG) shape due to gravity alterations. It's worth to note the investigations of VCG changes during extended spaceflights [1, 2] and parabolic flights of the laboratory aircraft [3]. But there is vast amount of works which study the closely related problem, in particular, the influence of body posture and respiration on electrocardiogram and VCG. An analytical review of these works may be found in [4]. Various VCG parameters have been examined and statistically significant trends found, but still there are more questions than answers.

In brief, the main results of the aforementioned works concerning the vectorcardiographic QRS loop are the following. Changes of gravity level and direction result in rotation of the QRS loop and in change of the QRS maximum magnitude. It looks like rotation and dilatation of the curve when changing gravity. So it is natural to study the combination of these transformations, in particular, the three-dimensional linear transformation of the QRS loop during the gravitation alteration.

2. Material

The database of VCG continuously measured during parabolic flights of the laboratory aircraft Airbus-300 (Novespace-CNES-ESA) was used in this study.

Each aircraft flight incorporated about 30 parabolic trajectories. There were five distinct phases for the parabola: normal gravity (1g); the first episode of hypergravity (about 1.8g during 20-25 s); microgravity (0g during 20-25 s); the second episode of hypergravity (about 1.6g during 20-25 s); and normal gravity again. From the continuous VCG recordings, there were extracted one (or two, if possible) 10 s periods for each flight phase. The averaged VCGs during each period were processed and analyzed (Cardionics, Belgium).

There were analyzed 50 man-flights of 23 persons. Each man-flight contains from 30 to 110 VCGs. During the flight the persons were mainly in standing position, while several VCG sequences were recorded in supine position. In some cases, a lower body negative pressure (LBNP) was applied during the microgravity phase to counteract the lack of hydrostatic pressure in the lower part of the body.

3. Methods and Results

The QRS loop changes during the flight were represented by linear transformations. One QRS loop was chosen as a reference, the other were approximated by transformations of the reference.

The algorithms for approximation of curves in the n-dimensional Euclidean space are different from the algorithms for approximation of functions and are more complicated [6]. For the purposes of these study a modification of one of the algorithms from [5] was used.

Let $\{\mathbf{f}_0(t), \mathbf{f}_1(t), \ldots, \mathbf{f}_n(t)\}$ be a sequence of n QRS loops during a flight, and $\mathbf{T}_i$ be the linear transformation that maps $\mathbf{f}_0$ to approximate $\mathbf{f}_i$ with the minimum root mean square error ε_i:

$$\mathbf{f}_i = \mathbf{T}_i\,(\mathbf{f}_0)+\mathbf{e}_i \ (i=1,..\text{n}),\ \varepsilon_i = \|\,\mathbf{e}_i\,\|$$

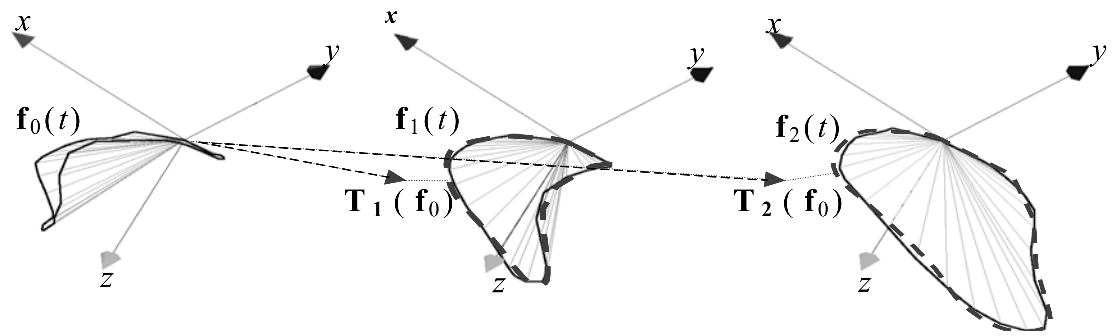

Fig. 1. Approximations of QRS loops $\mathbf{f}_1$, $\mathbf{f}_2$,… by transformations of the reference QRS loop $\mathbf{f}_0$

If the errors ε_i are rather small, then the sequence of transformations $\mathbf{T}_i$ is a good description of the QRS loop changes during the flight. The QRS loop for the first period of normal gravity was used as the reference standard. The other loops were approximated as linear transformations of the reference loop.

In almost all cases, the relative error of approximation $r_i = \varepsilon_i / \|\mathbf{f}_i\|$ was rather small, less than 0.05 (fig. 2A). Only in few cases with disturbances of the heart function the changes of the VCG shape were nonlinear and more complicated, the relative error r_i being more than 0.05 (fig. 2B). To detect local divergence between the QRS loop and its approximation the normalized Hausdorf distance h_i between these curves was used.

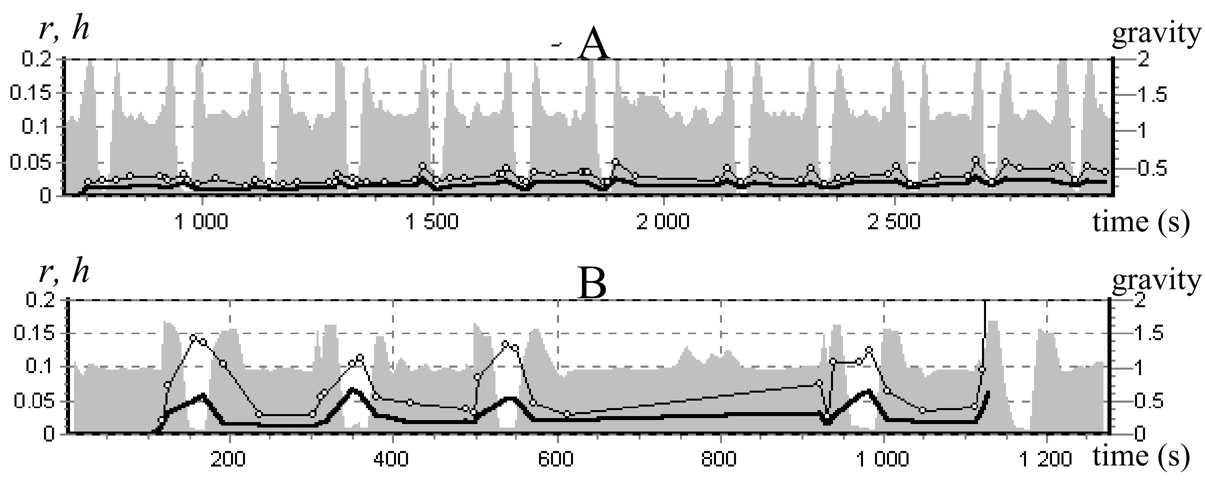

Fig. 2. The relative approximation errors r_i (heavy line) and normalized Hausdorf distances h_i (thin line with circles) during two man-flights. The gravity diagram for the flights dimmed light grey. A – normal case, B – case with disturbed heart function, at the end of the flight this person displayed an A-V-junctional rhythm with low heart rate, which led to syncope.

The inverse transformations $\mathbf{T}_i^{-1}$ applied to the corresponding QRS loops $\mathbf{f}_i$ give the curves $\mathbf{T}_i^{-1}(\mathbf{f}_i)$ that are similar to the reference loop $\mathbf{f}_0$ and lie quite near it (fig. 3).

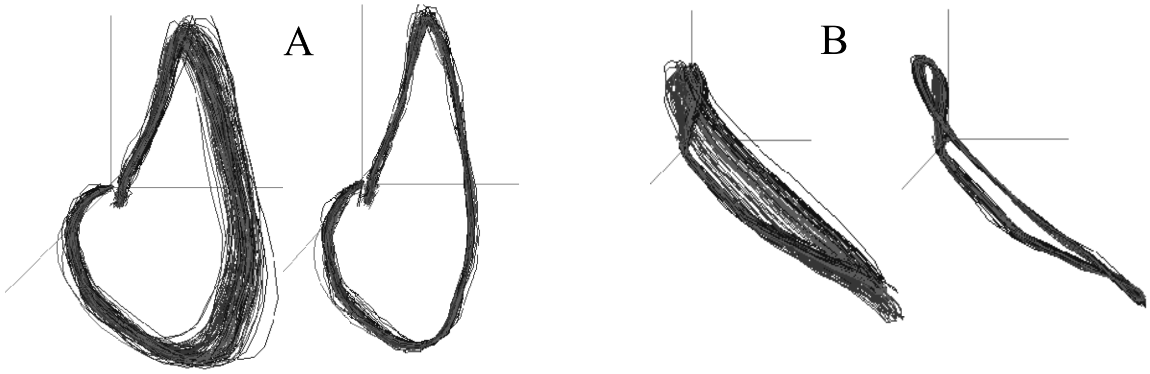

Fig. 3. All QRS loops for two man-flights before (the left figure) and after (the right figure) their inverse transformations towards the reference loop.

The transformations $\mathbf{T}_i$ of the reference QRS loop were represented by the rotations $\mathbf{O}_i$ and dilatations $\mathbf{S}_i$: $\mathbf{T}_i = \mathbf{O}_i\,\mathbf{S}_i$. Any linear transformation in the Euclidean space may be obtained by sequential executing rotation and dilatation (in any sequence). It provides separate analysis of these two kinds of transformations. The rotation of the reference QRS loop was characterized by the eigenvector of this transformation and the angle of turn around this vector.

The dilatation of the reference QRS loop was characterized by the coefficients of dilatation along three orthogonal directions, or, in other words, by the eigenvalues and three orthogonal eigenvectors of this transformation. The product of these three eigenvalues (coefficients of the QRS loop dilatation) is equal to the factor of the volume expansion for any three dimensional body after the transformation. The changes of this factor (QRS Volume Factor) during a man-flight are shown on fig. 4.

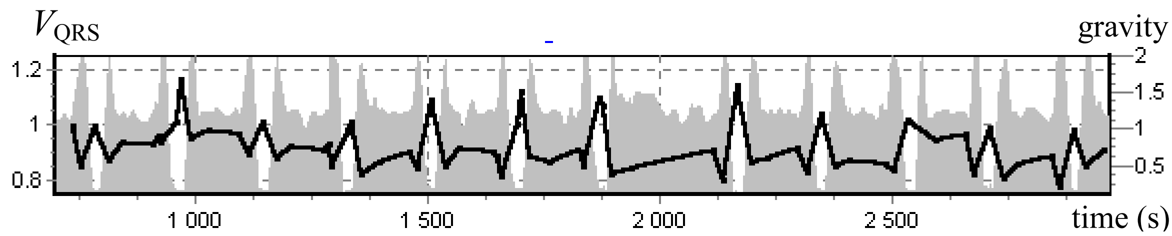

Fig. 4. The changes of the V_{QRS} (QRS Volume Factor) during a man-flight. The gravity diagram for the flight dimmed light grey.

4. Discussion

The QRS loop for each person, as a curve in the three dimensional (3D) vectorcardiographic space, remains unchanged (invariant) after the proper 3D linear transformation. In other words, for any two QRS loops there exists a linear transformation that approximates one loop by another. The 3D matrix of such transformation accumulates all alterations caused by variation of the body posture, gravity, and other factors that do not affect the process of heart depolarization. The quality of the QRS loop superposition is estimated by the distance between initial and transformed QRS loops in the VCG space. This distance between the superposed QRS loops serves as an indicator of changes in the heart depolarization process. Characteristics of the transformation (eigenvalues, angles of rotation) can be used as indicators of the heart state changes.

It seems quite evident that rotation of the VCG may be explained by rotation of the heart. The orthogonal electrocardiogram describes the value and direction of the heart electric dipole. If the heart turns, the electric dipole and, therefore, the VCG make the same turn.

More complex analysis is needed to understand the nature of the QRS loop dilatation. For a bidomain model of excitable media, it can be shown that a dilatation, or, in other words, linear deformation of the excitable media leads to dilatation of the dipole component under the condition of the topological invariability of the depolarization process. The relation between these two dilatations was found and it was not identity. It is interesting to find the real connection between the QRS loop dilatation and deformation of the myocardium.

The behaviour of the analyzed transformations during the flight is individual. It will be productive to find out any common regularities or to form groups of persons with similarity of linear transformations of the QRS loop due to gravitation changes.

Acknowledgements

This work was supported by INTAS project No. 99-01391

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