Model Study of the Relationship between the Heart and Vectorcardiographic Vectors

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Abstract: *Computer models of the ventricular activation and the inhomogeneous human torso were used to study the relationship between two dipolar representations of the heart activation: the heart vector and the measurable vectorcardiographic vector. Results demonstrated good correspondence between these two vectors except of relatively small time interval during the ventricular depolarization that may reflect their different sensitivities to the non-dipolar pattern of the cardiac electric field.*

Keywords: model of ventricular activation, inhomogeneous torso model, heart vector, vectorcardiographic vector.

1. Introduction

In theoretical and practical electrocardiology the electrical activity of the heart is often characterized by two similar vectorial parameters – the heart vector (HV) and the vectorcardiographic vector (VCGV). These two vectors are defined as follows: The heart vector represents a vector obtained as the (vectorial) sum of individual dipole moments representing all elements of the instantaneous myocardial activation. At any time instant, the locus of this vector is the centroid of the active elements. The VCGV is a measurable vector whose moment is determined from simultaneous voltage values in three surface vector leads. The locus of the VCGV remains fixed during the whole activation and is usually assumed to be at the centroid of the heart [1]. Since the relationship between these two vectors representing activation of the human heart can not be determined experimentally, computer modeling provides a convenient tool for such a kind of studies.

2. Method

For the calculation of the heart vector at any time instant of the ventricular activation the finite model of human cardiac ventricles with elements of 1mm^3 was employed. General description of this model, enabling the simulation of ventricular activation, is given elsewhere [2]. The geometry of ventricles is defined analytically by parts of ellipsoids representing their inner and outer surfaces. To simulate the repolarization heterogeneity, ventricular walls are sliced to 5 layers, paralleling with their inner and outer surfaces. The characteristics of model elements may be defined differently in dependence on their localization in respective layer [3]. The gross dimensions of ventricles, the thickness of walls and the parameters of activation propagation for the presented model simulation of normal activation were derived from published data [4, 5]. The structure of the ventricular walls was then represented by 142200 regularly distributed elements. These elements were the loci of model action potentials (MAP), that approximated the real transmembrane action potentials of cardiac myocytes. In this study, only the durations of MAP were varied in such a way that the transmural gradient of MAP duration defined as the difference between the MAP durations of element localized at the inner and at the outer surfaces was 25 ms in the left and 20 ms in the right ventricle, respectively.

At any time instant of the ventricular activation, the heart vector was calculated as the vectorial sum of the dipole moments of all individual elements. The instantaneous locus of this heart vector (centroid of active elements) was computed as the mean locus of all elements with non-zero dipole moment.

The above described model of ventricular activation was incorporated into the model of human torso with two basic inhomogeneities: ventricular cavities and lungs [6]. Relative electrical conductivities of these parts of the torso, given in regard to the conductivity of other tissue was 3.5 and 0.25. For such a combined model consisting of the torso and the heart ventricles the transfer matrix for calculation of surface potential values was determined and instantaneous surface potentials were computed. Components of the VCG vector were determined as orthogonal components of Frank's vectorcardiograms from surface potential values in 7 points of the torso model corresponding to the electrode placements of the Frank VCG lead system. Formulas for computation of the orthogonal components were derived in accordance with the properties of the weighting resistance network used by this lead system.

3. Results

The computed time courses of the orthogonal components and the spatial magnitude of the HV and the VCGV are in Fig. 1. The patterns of the QRS complexes and T waves were similar with the exception of the interval from 25 ms to 45 ms, where there is a noticeable deviation especially between z-components of the vectors. To analyze quantitatively the relation between the HV and the VCGV simple (linear) regression was applied.

Components of the fitted VCGV (marked as VCGV') were computed from HV components by linear regression model equations. Components of the original VCGV and the fitted VCGV', as well as the respective regression equations together with corresponding characteristics are shown in Fig.2. As it is evident from the slopes, the effect of both, the extracardiac factors and the weighting resistance network on the orthogonal components was different depending on the directions of lead axis.

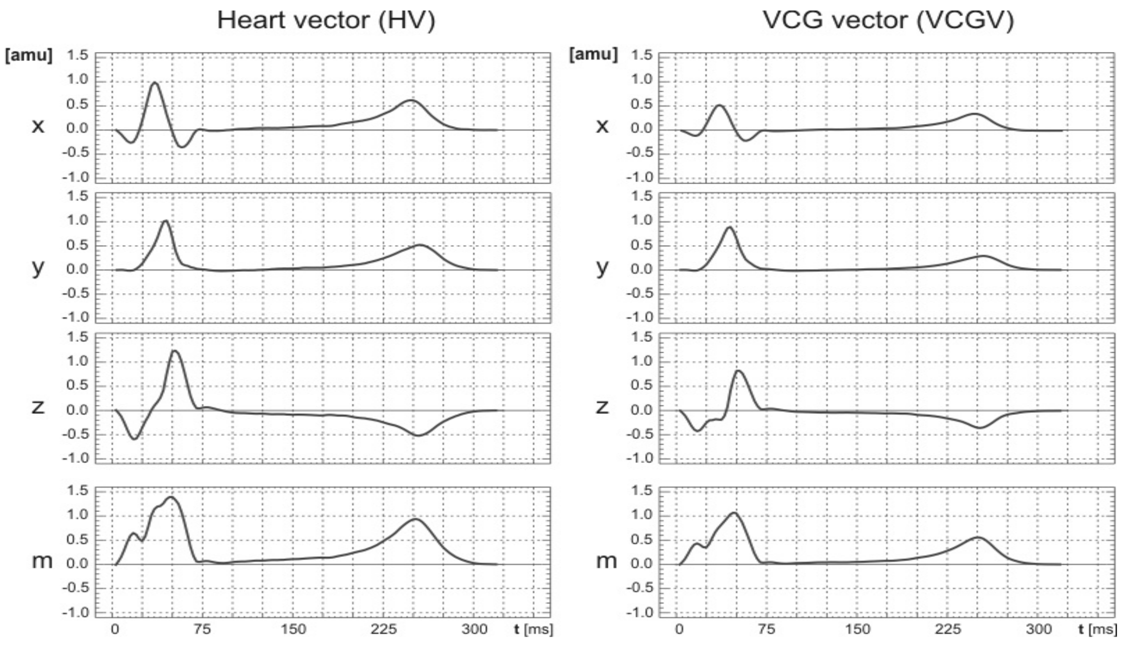

Fig.1. Time courses of orthogonal components (x, y, z) and spatial magnitude (m) of the HV and VCGV determined by computer simulation. (amu stands for „arbitrary model unit“).

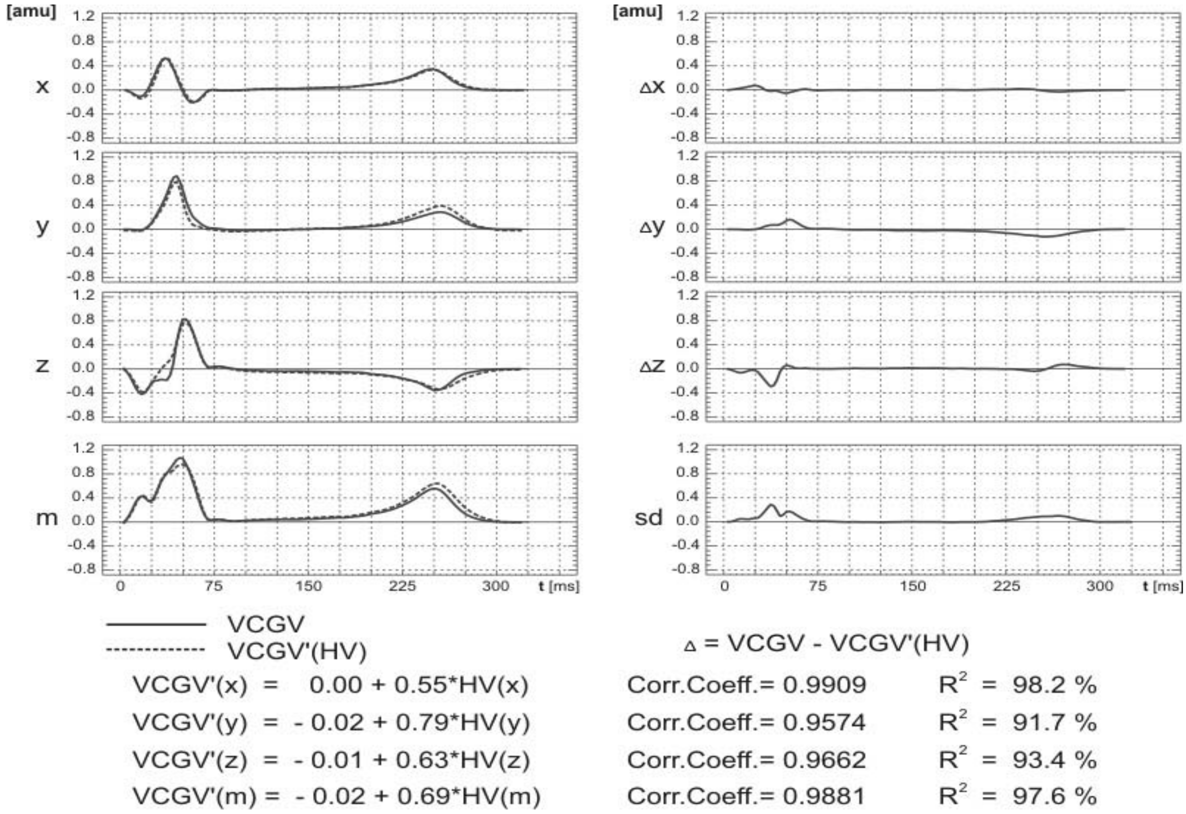

Fig.2. Time courses of orthogonal components (x, y, z) and spatial magnitude (m) of the original (VCGV) and fitted (VCGV') vectorcardiographic vectors. Δx, Δy, Δz are differences of respective components, sd is spatial distance between the end points of the VCGV and VCGV'; amu – arbitrary model unit; below - derived linear regression equations; Corr.Coeff. – correlation coefficient; R^2 – coefficient of determination.

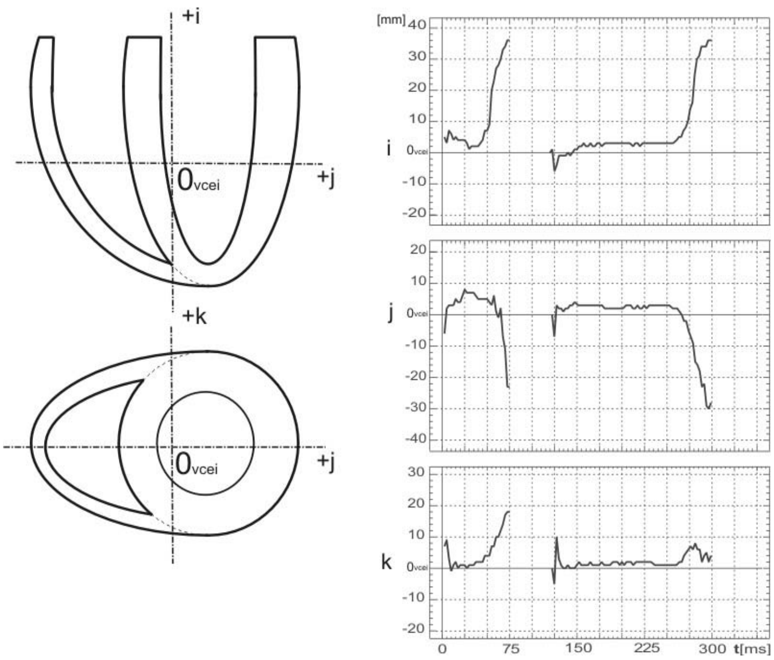

Fig.3. Projection of the spatial trajectory of the heart vector locus during the ventricular depolarization and repolarization into the orthogonal axes i, j, k. The origin 0_{vcei} is localized in the centroid of the model ventricles.

4. Discussion and Conclusion

Obtained results demonstrate good correspondence between the heart and vectorcardiographic vectors: standard error of the estimation was less than 5 % of the maximal VCG vector, determination coefficients R^2 were in range from 91% to 99% and correlation coefficients were in range from 0.957 to 0.991. However, during the middle part of the ventricular depolarization (middle third of the QRS complex), the maximal deviation between these vectors reached 28.5 % of the magnitude of maximal VCG vector. This deviation appeared mainly in the z-component (i.e. in the anterior – posterior direction) and also in the y-component (i.e. in the inferior-superior direction). Elucidation of this phenomenon is possible from the different definition of the heart and the VCG vectors as well as from the varying shape of the activation front during this period of ventricular depolarization. Namely during this time interval, the activation front spreading toward the ventricular apex is disintegrated into parts propagating toward the free lateral and basal regions of the ventricles. The spatial balance of the depolarization propagation during this period was documented by the position of the heart vector locus (the centroid of the activation region) which was relatively constant (Fig.3). Since both evaluated vectorial characteristics are based on dipolar representation of the cardiac electric field, the observed deviations can reflect their different sensitivities to the non-dipolar pattern of the cardiac electric field.

Acknowledgements

This work was supported by the grants VEGA 2/3203/25 and 2/4089/24 from the Slovak Grant Agency for Science.

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