Isopotential ECG Imaging Correctly Identified Endocardial Ectopic Activation Site in the Case of Arrhythmia from Right Ventricular Outflow Tract

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Abstract— **ECG Imaging using inverse electrocardiographic solution has been suggested as a potential aid to guide radiofrequency ablation of cardiac arrhythmias. However, endocardial activation patterns in terms of potential distributions have been difficult to reconstruct.**

We are reporting a case of a patient with frequent highly symptomatic right ventricular outflow tract ectopic beats that were successfully ablated endocardially at the posteroseptal region of the outflow tract. The site of ablation and right ventricular endocardial activation time map were documented using electroanatomical mapping system CARTO™. We computed early endocardial QRS minimum potential location in order to compare the computed site of the earliest activation with the recorded site. We used homogeneous Dalhousie torso model with ECG recordings at 120 electrode sites and our own model of the heart surfaces derived from CT angiogram of a patient unrelated to the study individual. We chose boundary element method and Tikhonov regularization to calculate the epicardial and endocardial isopotential maps in matter of seconds to minutes using software package SCIRun 4.0 running on a common notebook computer. The reconstructed early endocardial minimum (as opposed to the epicardial one) during initial low-amplitude 20 msec of 15 signal-averaged QRS complexes correctly located the earliest activation site to the high posteroseptal segment of the outflow tract.

If these computations prove correct and reproducible for various cardiac arrhythmias, isopotential ECG imaging of the early endocardial activation minimum potential is feasible and could aid interventional treatment by quick noninvasive localization and automated navigation. Also, improved computational algorithms aimed at volume-based finite-element method and individualized meshing of the models will improve the overall performance of this technology.

Keywords— **ECG imaging, body surface potential maps, inverse solution, automated navigation, heart and torso model**

I. Introduction

Imaging of the electrical information invasively has become commonplace and indispensable in the field of cardiac electrophysiology especially in relation to the catheter ablation of arrhythmias. Noninvasive counterpart called ECG imaging (ECGI) has been suggested as a potential aid in guiding the physician performing the invasive procedure within ventricular or atrial myocardium. [1]

One major hurdle for the ECGI seems the reconstruction of endocardial activation patterns that are most important in majority of clinical arrhythmias. Successful endocardial ECGI via inverse solution in a clinical case of ventricular arrhythmia has not yet been published to our knowledge. Therefore, we approached the endocardial activation estimate by simple comparison of inverse isopotential endocardial solutions of the initial QRS complex with the invasive electroanatomical endocardial activation map having the site of successful radiofrequency ablation recorded in the CARTO™ (Biosense Webster®) map.

II. Methods and results

A. Clinical case description

The patient was a 31-year old otherwise healthy male who underwent successful radiofrequency ablation of frequent and highly symptomatic ventricular ectopic beats from right ventricular outflow tract (RVOT). The procedure proved uncomplicated ablation at the posteroseptal segment of the high RVOT requiring 13 applications of energy ceasing the ectopy just below the pulmonary valve as reported by physician electrophysiologist.

B. Data acquisition and processing, modeling and inverse solution

ECG acquisition: We performed 123-lead ECG recordings (3 limb leads, 120 torso leads) in this patient one day before the curative procedure outside the catheterization laboratory. We acquired 15- and 30-sec ECG recordings using ActiveTwo™ hardware (www.biosemi.com) adapted to using passive disposable carbon electrodes (Tyco Healthcare®) at 2048Hz sample rate and 24-bit voltage resolution. All subsequent signal processing has been performed off line and aimed at development of computational algorithms (networks) using SCIRun 4.0 and map3d software packages. [2,3] Therefore, the results of these computations were not available to the electrophysiologist at the time of abla-

tion and consequently are retrospective. The ECG data were processed to obtain body surface potential maps (BSPM) of signal-averaged initial 20 milliseconds of 15 QRS complexes of the ventricular ectopic beats superimposed on the Dalhousie torso model [4] using Laplacian 3d interpolation algorithm. [5] The initial QRS potentials of interest that were evaluated in individual leads and maps were of 10-50 μV amplitudes and generally preceded the naked-eye discernible or summary root mean square QRS onset. The initial QRS minimum was located on the back of torso with a prominent maximum in the upper front chest. (Fig. 1)

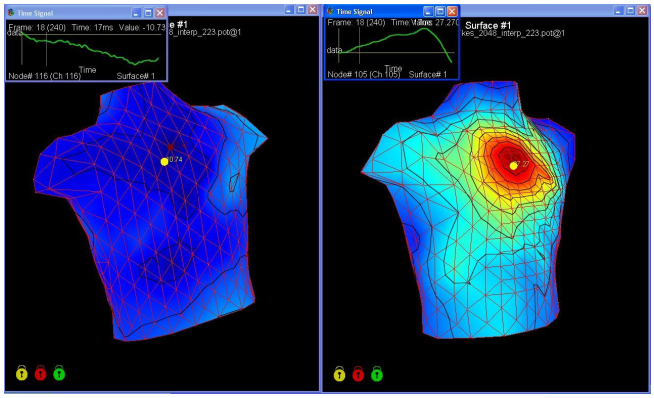

Fig. 1 Dalhousie torso model with BSPM at 15 msec into the QRS complex of the ectopic beat.

Heart Torso Model: We used contrast-enhanced angiography scans from 32-slice CT acquired from another patient unrelated to the above described patient. The epicardial and endocardial surfaces were extracted using level-set segmentation algorithm available through seg3d software. [6] The resulting isosurfaces were reduced manually into approximately 100-350-node triangulated surface meshes. We registered the resulting epicardial and endocardial meshes into the common Cartesian space within the Dalhousie torso hence creating homogeneous heart torso model.

Isopotential inverse solution: The realistic heart and torso meshes constituted the framework for the boundary element method (BEM)-based inverse solution. We used Tikhonov regularization L-curve and also experimental selection of regularization parameter while observing the resulting epicardial and endocardial maps of the 20 selected initial QRS samples. We retrospectively compared the resulting inverse isopotential epicardial and endocardial maps with the electroanatomical CARTO activation map and successful ablation site location. The computed inverse solution maps showed corresponding initial QRS minimum located in the posteroseptal segment of the RVOT (Fig.2)

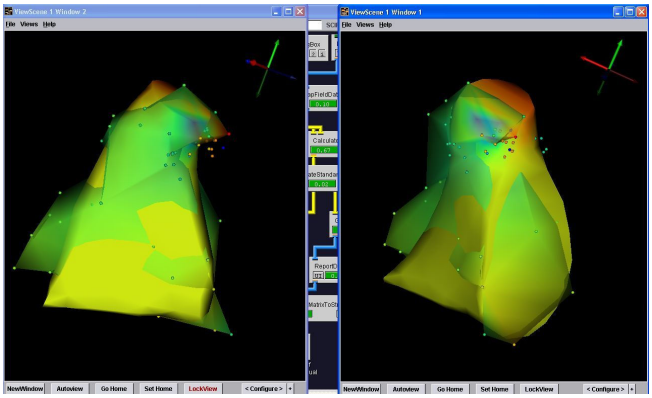

Fig. 2 ECG images (potential distributions) obtained by inverse solution computed on the triangularized mesh (model) of the right ventricle. The blue spot is the initial QRS negativity with the potential minimum at its center. Overlapping is the CARTO right ventricle map (it is the rougher and light green coloured surface with its nodes in the form of small balls) at a computed minimum distance from the model. The orange and red balls are the earliest sites and also sites of the successful ablation on the CARTO map.

whereas the epicardial solution showed a minimum significantly displaced off this site. These computations were performed using a common notebook computer (ThinkPad R61i, Intel Core2Duo, 1.5GHz, 2.99GB RAM). The critical computations (Tikhonov inverse solution module) ran in matter of seconds up to tenths of minutes (if taken in series of samples using L-curve).

III. DISCUSSION

In this report we sought the simplest way to reconstruct initial QRS endocardial activation patterns and sites by means of ECG imaging. We believe, together with others that prerequisite of ECGI application into clinical algorithms is its feasibility and light-weightiness. [7] ECGI would be always inherently less accurate in comparison with invasive techniques; nevertheless, it could still be of significant help if it proves fast, correct, and easy to apply nearly the same as other noninvasive methods.

Generally, most of the attempts to noninvasively reconstruct cardiac activation and recovery have resulted in fairly accurate epicardial patterns and imaging either in terms of isopotentials [8] or isochrones [9]. Therefore, elaborate iterative algorithms for best-fit reconstruction of complete electrograms and computing activation times have been developed in order to estimate activation of deep structures of myocardium. As a consequence, these algorithms as yet require significant computing time and resources, and their accuracy is difficult to validate [10] due to often incomplete (even though clinically sufficient) invasive recordings and

reconstructions in the real-world patients with arrhythmias. Typically, esp. in the case of ventricular arrhythmias, successful radiofrequency ablation as guided by electroanatomical maps provided by the CARTO system does not require the entire or complete endocardial or epicardial activation pattern to be reconstructed and rather a rationed approach has been used by most physicians with variable mapping density or even partial maps. Instead of need for complete activation pattern, they have long been exercising the ability to estimate the region or wider site of origin using extensive experience in ECG QRS patterns recognition [11] with high degree of accuracy. Validity of this approach was also documented by meticulous statistical QRS integral analysis of BSPM. [12] The only routinely available technology for obtaining a complete reconstruction of endocardial activation patterns requires introduction of a special non-contact and rather invasive endocardial cavity probe. [13]

In our case report, we respected the clinical approach by acknowledging that the arrhythmia comes from RVOT (based on the typical QRS shape in the 12-lead ECG) and require just a refinement of the segment or wider site of origin. In respect to the general assessment of the accuracy of the inverse isopotential calculations, we should compute inverse solution also using the left ventricle endocardial surface including the outflow tract. Spatial mismatch between the computed early minimum and measured earliest activation site together with the successful ablation site in our case was introduced most likely by the anatomical mismatch between the patient's heart and torso and our arbitrary model. This should be solved by creating individualized patient heart torso models using effective and automated segmentation and registration methods.

Generally, the issue of limited sampling of the cardiac volume by boundary element method should be improved by sampling the tissue volume by finite element method. Also, the activation time computations by iterative methods are legitimate and, perhaps, more accurate in terms of inverse solution reconstructions, especially in the case of continuous activations without clear isoelectric line typically found in the case of reentry arrhythmias that are common in structurally challenged hearts with scarring and other morphological abnormalities.

IV. CONCLUSIONS

Our experimental and rather simple inverse solution-based endocardial activation reconstruction seems realistic and feasible in terms of computing power and practical use. It could aid clinical arrhythmia interventions by offering automated coordinates and enhanced navigation. It needs further validation in various cases of arrhythmias with different mechanisms. Also, it requires improvement of the computations by means of automated meshing and working with tissue volumes.

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