Integration of Body Surface Mapping and Biplane Fluoroscopy for Guidance of Catheter Ablation of Ventricular Tachycardia

Potse M.,[1] Linnenbank A. C.,[1] Van Dessel P. F. H. M.,[2] SippensGroenewegen A.,[3] and Grimbergen C. A.[1]

[1]Academic Medical Center, Amsterdam, The Netherlands;
[2]Antonius Hospital, Nieuwegein, The Netherlands;
[3]Cardiac Focus Inc., Pleasanton CA, USA.

Introduction

Catheter ablation is the preferred treatment for ventricular tachycardia (VT) that cannot be treated with drugs and for VT in patients without structural heart disease. This therapy is highly effective, but it usually requires a time-consuming catheter mapping procedure performed under biplane fluoroscopy. To minimize radiation exposure, the procedure time should be reduced by directing the catheter tip to the target position as quickly as possible.

In most hospitals, the catheter position is monitored using biplane fluoroscopic imaging, while the exit site of the arrhythmia is inferred from surface ECG characteristics. In this procedure, the physician has to perform three difficult tasks: (1) convert the ECG characteristics to a target position in the heart, (2) convert this position to biplane fluoroscopic views, and (3) maneuver the catheter tip to this position.

We will present two methods, one for accurate localization of VT exit sites using multichannel ECG data, and one for presentation of localization results in the fluoroscopic views. Together, these methods may alleviate the physician's task during catheter mapping of VT.

Methods

Multichannel electrocardiography can provide improved accuracy for the estimation of VT exit site positions [1]. The development of paced body surface map databases made automated conversion from multichannel ECG recordings to positions in the heart possible with a resolution exceeding that of traditional 12-lead ECG analysis [2]. Using these databases, the exit site can be predicted as one out of 18–25 segments of the left ventricular (LV) endocardial wall (Fig. 1). This information can be used for initial catheter placement during an ablation procedure. In addition, by comparing paced maps obtained during catheterization with a map obtained during VT and with the database maps, physicians were able to estimate the position of the VT exit site with respect to the catheter position.

In order to increase localization accuracy, and to automate the estimation of the VT exit site position with respect to the catheter position, a continuous localization algorithm was developed that made use of the databases [5].

The positions of the database segments and the results of the continuous localization algorithm were expressed in left ventricular cylinder coordinates [2] and presented in a polar diagram, as illustrated in Fig. 2: from the cylinder coordinates (h, r, ϕ), the radius r was discarded, and the height coordinate h was used as a radius in the polar diagram. Since the original radius r was discarded, and the height was expressed relative to the distance between apex and mitral valve ring, the polar diagram was independent of individual ventricular dimensions, thus allowing comparison between patients.

During a catheter ablation procedure, the physician observes the heart and catheter position using biplane fluoroscopy. To move the catheter to the estimated site of origin of an arrhythmia in the left ventricle, he has to convert the catheter displacement advice obtained from the ECG to the anatomic picture that he has in mind, meanwhile translating this picture to fluoroscopic projections. These are demanding tasks, given the multitude of information that requires simultaneous apprehension in the electrophysiology laboratory, and they are necessarily subjective. In this situation, the polar diagram is not the most convenient mode of presentation. Therefore we developed a clinically practical method to present the target positions in the biplane fluoroscopic images [6]. An important characteristic of this method is that it uses a simple model of the endocardial wall, which can be parameterized by measuring only the positions of three anatomical landmarks: the LV apex, the middle of the mitral valve ring, and the middle of the aortic valve ring. These positions can often be determined from the fluoroscopic images.

Results

The continuous localization algorithm has been evaluated using the pacing positions and paced maps underlying the database for the normal left ventricle [5]. Localization errors were 15 ± 8 mm (mean $\pm$ s.d.). When differences between exit sites in the same patient were computed for pacing positions less than 15 mm apart, the error could be reduced to 10 ± 6 mm. These errors could be attributed largely to the uncertainty of upto 7 mm in the pacing position data [7].

The method for presentation of estimated positions in bi-

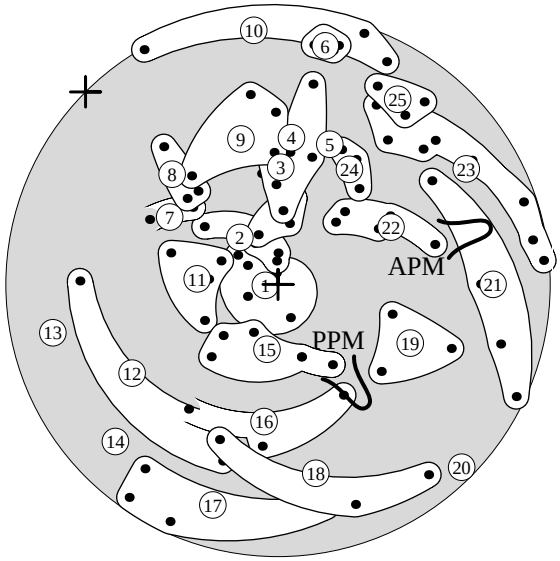

Fig. 1: *Segments with nearly identical QRS integral map (QRSI) patterns, corresponding to the database of 25 mean paced maps for the normal left ventricle [2]. By comparing a given QRSI to the database mean maps, one of these segments is identified as the predicted region of origin. The pacing positions that were used to create the database are indicated with dots. The left ventricular endocardium is represented using a polar projection, as illustrated in Fig. 2.*

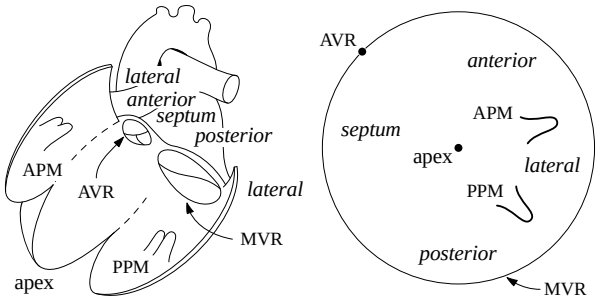

Fig. 2: *Schematic anatomic diagram (left) [3, 4] and polar projection of the left ventricle (right) [2]. The circumference of the diagram represents approximately the mitral valve ring (MVR); the position of the aortic valve ring (AVR) is indicated. The positions of the anterior and posterior papillary muscles (APM and PPM) and endocardial quadrants (septum, anterior, lateral, and posterior) are indicated in both diagrams.*

plane (RAO and LAO) fluoroscopic projections that we reported previously [6] has been improved. Its performance was evaluated by measuring catheter tip positions in biplane fluoroscopic images, computing cylinder coordinates, and reconstructing the 3-D positions using our method. The distance between measured and reconstruced positions was 5 ± 4 mm (range 0–17 mm). The maximum error in a single patient ranged from 5 to 17 mm. These errors may be in part attributed to inaccuracies in measuring the actual catheter positions in the fluoroscopic data; these inaccuracies can be as large as 7 mm [7]. A total of 107 positions, obtained in 8 patients, was used.

By cascading the continuous localization algorithm and the reconstruction algorithm, a 3-D position can be computed from a multichannel ECG and displayed in biplane projections. Results of this application are shown, for a single patient, in Fig. 3.

It may be observed that these errors are in the order of 1–2 cm. However, errors in adjacent positions are in most cases of comparable magnitude and direction. Therefore the difference in position between pacing sites can be prediced more accurately, as reported earlier [5]. Estimation of differences is used during pace mapping, when paced maps are created to estimate the catheter position relative to the exit site. Our methods can assist in this procedure by providing a quantitative estimate of the direction and magnitude of the displacement that is needed to place the catheter at the exit site of the arrhythmia.

Discussion

In the past decade our group has made three principal advances to increase localization accuracy and alleviate the physician's task with catheter guidance and positioning. First, the development of databases of paced body surface maps made accurate automated conversion from multichannel ECG recordings to positions in the heart possible [2]. Second, an interpolation algorithm allowed continuous localization with these databases, thereby increasing the accuracy of the conversion [5]. Third, we recently developed a clinically practical method to present the target positions in the biplane fluoroscopic images [6].

Although the reconstruction method presented here was only tested with fluoroscopic data, it may just as well be used with other catheter localization modalities. In an online clinical application, for guidance during catheter mapping and ablation of ventricular arrhythmias, it may be possible to obtain catheter positions at any time from the biplane images or using magnetic or electrical catheter localization techniques [8, 9]. If it is also known at which times the catheter tip touches the endocardial wall, this 3-D position information may be used to adapt the model instantly.

Together, the methods presented here are able to generate, from a single VT QRS complex in the ECG, a position in the biplane fluoroscopic images, or other modes of presentation, where the physician may then place the catheter. Subsequently, the recommended position can be refined using pace map data and catheter positions obtained in the patient. We expect that in this way less time and less radiation exposure will be required to guide the catheter to the exit site of the arrhythmia, from where a suitable ablation site can be found quickly using activation sequence mapping [10]. Thus we have collected all elements that are necessary for a clinical prototype system, by which we may assess the gain, both in procedure time and in results, of our methods in practice.

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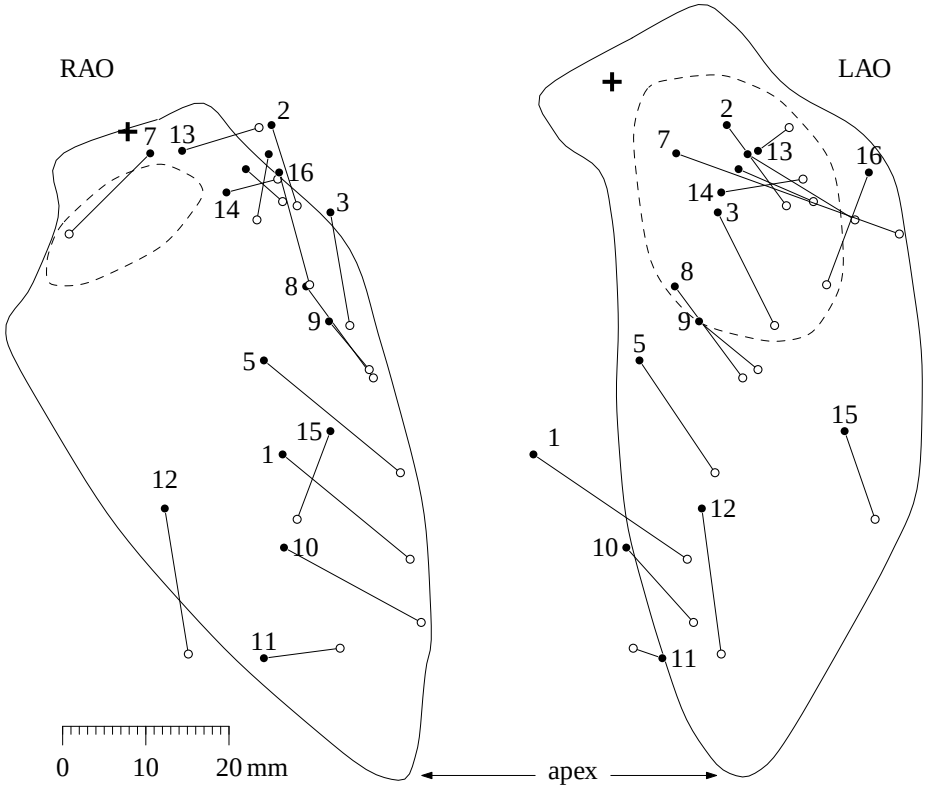

Fig. 3: *Right (RAO) and left anterior oblique (LAO) projections of the left ventricle of a single patient (male, age 25 years). Black dots indicate measured catheter positions; open circles indicate the corresponding positions reconstructed from the body surface map data obtained by pacing at these positions. The catheter positions are labeled with numbers from 1 to 16, to facilitate comparison of RAO and LAO data (numbers 4 and 6 were omitted for clarity). The mitral valve ring is indicated with a dashed line. A plus sign indicates the position of the middle of the aortic valve ring. The contours of the left ventricle, determined with contrast cineangiography, are shown for convenience; these contours were not used in our method.*

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