THE USE OF SIMULTANEOUS MULTICHANNEL ENDOCARDIAL AND SURFACE ELECTROCARDIOGRAMS FOR VERIFICATION OF EXIT SITE LOCALIZATION USING BODY SURFACE MAPPING

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***Abstract*— Exit sites of monomorphic ventricular tachycardia and focal sites of ventricular extrasystoles can be localized using an endocardial catheter in conjunction with a multichannel surface ECG, in order to find a suitable site for ablation. For this procedure, as well as for the diagnosis of these types of arrhythmia it is desirable to know the relation between surface ECG and site of origin accurately. This knowledge can be provided by endocardial pacing on well-known sites and recording the resulting ECG, but this method is hampered by the low resolution of catheter localization techniques, breathing of the patient, and cardiac motion. By pacing on an endocardial basket catheter, that has 64 electrodes, and simultaneously recording of the endocardial and body-surface leads, we may obtain useful data to establish the relation between pacing site, endocardial activation spreading, and surface ECG. These data can be used to create and verify localization methods for ectopic and paced beats. In this paper, we investigate the stability of basket-paced beats and localization results.**

Introduction

Electrocardiographic body surface mapping is used in the catheterization laboratory to perform high resolution localization of endocardial foci of ectopic ventricular beats and exit sites of monomorphic ventricular tachycardia (VT)[1], [2], [3], [4], prior to radiofrequency (RF) ablation. Several methods exist to estimate the endocardial exit site from the measured surface ECG. Some groups use volume conductor models and other inverse solutions to compute the epicardial potentials from the surface ECG, in order to deduce the activation sequence and the site of activation onset. In our group, localization is based on the QRS *integral map* (QRSI): The 64-channel surface ECG is summed over the QRS interval, resulting in a 64-element vector.

The QRSI is compared to one of three specific databases, each consisting of 18–25 mean paced QRSIs[1], [2]. Each mean QRSI in a database corresponds to a known endocardial segment of activation onset. The exit site is identified as the segment corresponding to the best matching database map. The three databases have been obtained from three different patient groups: patients with a structurally normal left ventricle (NLV), with a previous anterior myocardial infarction (AMI), and with a previous inferior myocardial infarction (IMI).

Recently, we presented a method to interpolate positions in these databases, to obtain a continuous localization[5]. This procedure is also based on the QRS integral map.

Verification of these methods is possible by inducing ("pacing") cardiac beats with the tip electrode of an endocardial catheter, recording the resulting ECG, and applying the solution method to this ECG to see if the predicted exit site corresponds to the measured position of the catheter tip. Several difficulties arise, however. In the first place, it is difficult to indicate an endocardial site because the shape of the heart differs between individuals, and changes in time within one individual. Second, the resolution of methods to localize the catheter tip is less than what is needed for a useful localization algorithm: If such an algorithm is used to guide a catheter to an RF ablation site it must be accurate enough to place the catheter at a position at most 5 mm from the focal site of the arrhythmia. Using a 64-channel Body Surface Map it is possible to differentiate between QRSIs that are paced a few millimeters apart, while, for example, the resolution of biplane cineradiography is about 5 mm[6]. Third, the relation between exit site and surface ECG depends on the respiratory phase, which can result in errors of several millimeters.

If the pacing is done using a basket catheter—a catheter consisting of 8 thin splines each containing 8 electrodes—that is unfolded in a stable position in the left ventricle, we know exactly the distance between electrodes on the

same spline, and have less exact, but still relatively good information on the distance between the splines. Thus, we know the relative positions of the electrodes very well. Their position relative to the heart is less well known, but is also less important to this research because we are mainly interested in estimating the direction and length of the distance between an exit site and a pacing site, or between two pacing sites.

Methods

pacing

The basket catheter (Constellation Basket, Boston Scientific, San Jose CA, USA) is inserted through a sheath via the aorta into the left ventricle, where it is unfolded. The pacing protocol is performed to determine the local pacing threshold. Pace spikes are delivered with a 500 ms interval, or a shorter interval if necessary, to one of the basket electrodes. For each spike, the current is increased until the heart captures, or the maximum value of 20 mA is reached. If the heart captures, the pacing current is fixed and a few more beats are induced. This procedure is performed for all electrodes on the basket.

recording

61-lead endocardial and 64-lead body surface electrocardiograms were simultaneously recorded with equipment similar to that described by Metting van Rijn and Grimbergen[7], [8]. The sampling frequency was 2 kHz, and the resolution was 16 bits at 2 μV/bit. The noise level of the surface electrodes was 3 μV_{RMS}, of the amplifiers at most 1 μV_{RMS}.

A full EP session takes approximately 3 hours, the pacing procedure about one hour. Recording took place almost continuously, covering the pacing procedure in 30–45 minutes of ECG, which is more than a gigabyte of data. Because of this huge amount of data, detection of paced QRS complexes was performed automatically, using our MAPLABtoolbox[9], that uses a commercial mathematical software package (MATLAB, The Mathworks Inc., Natick MA, USA). A tailor-made algorithm was used, that was able to reject spontaneous beats. Isolated paced beats, that were not part of a train of paced beats, as well as beats that did not seem to be paced from the same electrode as their neighbours, were also rejected. For each pacing electrode, zero upto 58 paced complexes remained.

Onset and offset of the QRS interval, and suitable time instants for baseline correction were selected automatically. A linear correction for baseline drift was applied. The QRS integral map was computed by summing each lead over the QRS interval, and then interpolating the irregularly spaced sites to a regular 16×12 matrix[10], covering the chest and back.

For every pacing electrode, all paced QRS complexes were collected and a mean map was computed. For each map, the correlation to the mean map was computed. Maps whose correlation to the mean map was less than 0.8 were rejected because the large majority of these maps appeared to be spontaneous beats that were incorrectly recognized as paced beats by the detection algorithm.

localization

The algorithm for continuous localization in the left ventricle using a database of paced QRS integral maps[1] was described previously[5]. In short, a Karhunen-Loève transform is applied to the QRS integral map, handled as a 192-element vector. The first three elements of the resulting vector contain more than 80 % of its energy content. These three elements are handled as a vector in 3D space, and transformed to spherical coordinates. The radius is discarded, and the remaining two coordinates are transformed by two smooth mapping functions to a position estimate specified in left ventricular polar coordinates, as illustrated in figure 1.

Results

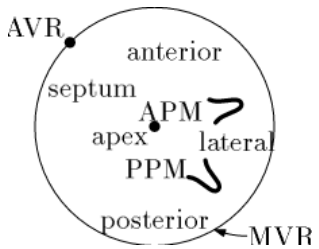
For this study, data from a single pacing procedure was used. In 12 of the 61 pacing electrodes, no paced complexes remained, for several reasons: For five electrodes, no data was acquired, for five electrodes (for three of which no data was acquired) the heart did not capture even with the maximum pacing current of 20 mA, and for another five electrodes the mean correlation coefficient was less than 0.8.

In the 49 remaining electrodes, 21 ± 11 paced complexes were accepted. The mean correlation coefficient between individual maps and the mean maps of these groups was 0.96 ± 0.07, corresponding to a mean distance of approximately 10 mm between the pacing sites. The largest mean correlation coefficient found was 0.996 (with 7 maps in the group), corresponding to a mean distance of 4 mm.

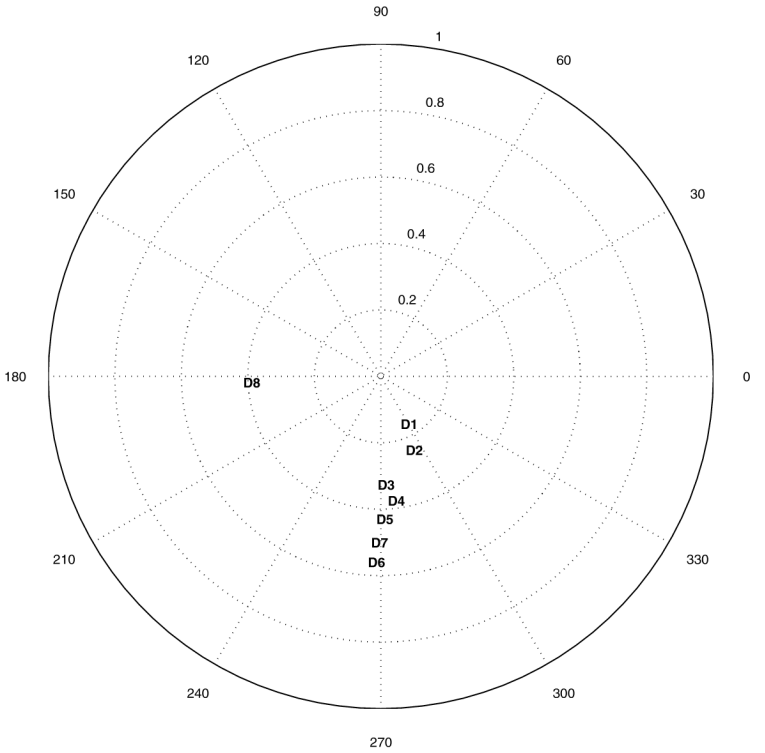
The continuous localization method was applied to the mean maps of the electrodes on one spline. The positions are depicted in a left ventricular polar projection in figure 1.

Discussion

We observed that the size of a cluster of localized beats that were paced on the same electrode is very small (4 mm) in some cases and relatively large in other. There are several possible explanations for these differences. First, they may be due to inaccuracies of the automatic QRS detection algorithm, which is not as good as manual detection; a thorough comparison with manually detected complexes will have to make clear how important this is. Furthermore, it is possible that electrodes move because of the beating of the heart and the breathing of the patient, and the contact with the endocardial wall may be unstable. At larger pacing currents (currents upto 20 mA were used) it



a.



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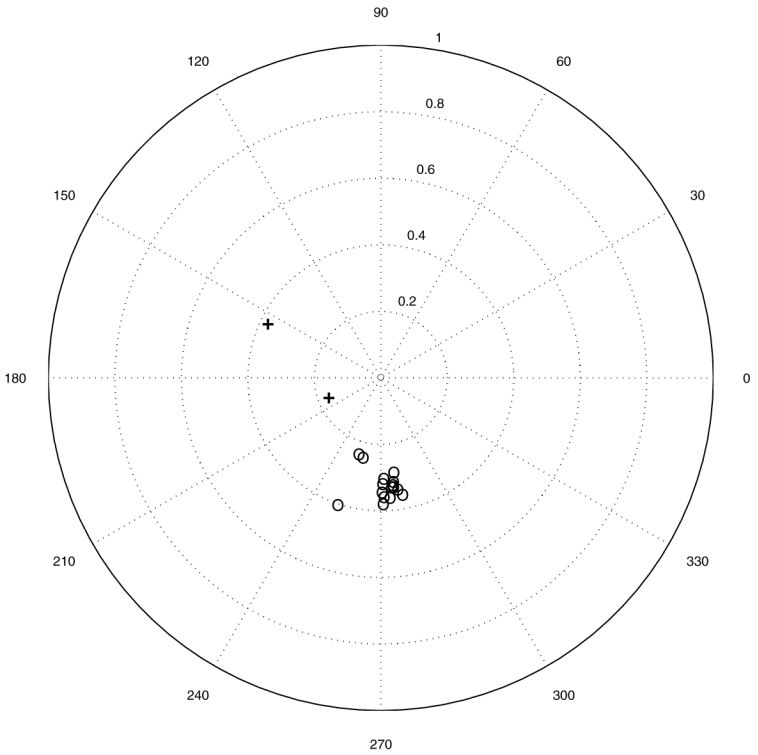

c.

Figure 1. a. Illustration of a left ventricular polar projection. The center of the left ventricular apex is at the center of the circle; the mitral valve ring (MVR) is represented by the circumference. Also indicated are the 4 quadrants (septum, anterior, posterior, lateral), the anterior and posterior papillary muscles (APM, PPM) and the direction of the aortic valve ring (AVR). **b.** Localized mean pacemaps of spline D. Note that D1 to D6 are nearly on a perfect line. **c.** Localized pacemaps of electrode D3 for 20 consequitive beats. For two pacemaps, the correlation with the mean map of D3 was less than 0.8; their positions are indicated with plus signs; the other positions are indicated with open circles.

is possible that relatively distant tissue is excited, resulting in different foci for subsequent beats. This hypothesis is supported by the observation that the cluster size correlates ($r = 0.54$) with the threshold current. Moreover, large pacing spikes sometimes cause long artefacts that can extend into the QRS complex[7]. It is hard to remove these well enough to obtain a useful QRS integral map. These effects (moving splines, poor contact, distant pacing, and pacing artefacts) can have a different impact on different pacing electrodes.

Conclusion

The stability of the localization of the position of the pacing electrodes appears to be very good in some cases, despite of breathing and the motion of the heart. In other cases the localization is less stable. The source of this instability was not yet established, it can be because of instabilities of the pacing electrode positions or it might be attributed to errors of the detection algorithm.

Using recordings from a subject where the basket unfolds well and makes good contact with the endocardial wall, as well as a careful pacing protocol and an improved analysis, these recordings are suitable for evaluation of localization algorithms.

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