# Comparison of Different Methods and Catheter Designs to Estimate the Rotor Tip Position – A Simulation Study

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## Abstract

*There is still a need for research to understand the coherences of the origin of arrhythmias such like rotors and possible ablation strategies. The aim of this work was the analysis of typical signal characteristics near a rotor center. Rotors were simulated on 2D patch geometry (100 mm x 100 mm) with spatial resolution of 0.1mm. Based on extracellular potentials, different features were evaluated: Local activation time, peak to peak amplitude, steepest negative slope and approximate entropy were compared regarding their ability to indicate the rotor tip location. Furthermore, typical signal patterns of different mapping catheters centered at the rotor tip position were analyzed. The determined maximum distances between the focal point of phase singularities and determined centers by the peak to peak amplitudes were maximal 1.7 mm.*

## 1. Introduction

Atrial fibrillation (AF) is the most common arrhythmia and a risk factor of stroke. Many mechanisms of AF are not understood, but with high resolution mapping they could be quantified better [1]. Spiral wave reentry can induce AF and atrial tachycardia [1] [2]. The rotor center is anchored in a low-voltage, fractionated area [3] and wavefronts show 360 degree rotations [3]. The aim of this work was to analyze typical signal characteristics near a simulated rotor center. EGMs of different catheter types near the rotor tip are analyzed. The spatial characteristics of features like the local activation time (LAT), approximate entropy (ApEn) or the signal amplitude could help to identify the rotor tip in clinical diagnosis. Furthermore, specific maps could be matched to evaluate the position of a rotor center.

## 2. Methods

### 2.1. 2D Rotor Initiation and Tracking

In an isotropic virtual 2D tissue patch with the dimension 100 mm x 100 mm and a spatial resolution of 0.1mm, a rotor was generated by a cross- field protocol [4]. The monodomain equation was solved using the electrophysiological cell model of Nygren et.al.[5] using the finite difference method and the parallel solver acCELLerate [6]. In order to obtain the rotor tip position the phase singularity was tracked [4]. Based on layers of transmembrane currents, extracellular EGM signals were obtained by forward calculation.The resulting extracellular potentials were sampled with the sampling rate of 1000 Hz.

### 2.2. Methods to Detect the Rotor Tip

*LAT Map*
The LAT was determined by the time instance where the maximum value in the non-linear- energy operator (NLEO) signal was detected [7, 8]. The NLEO signal E was calculated with the samples x as:

$$E_j = x_j^2 - x_{j+1} \cdot x_{j-1} \tag{1}$$

*Peak to Peak Amplitude Map*
Clinical data show a peak to peak amplitude decrease near the rotor center [3]. The peak to peak amplitude is calculated by the maximum voltage added by the absolute value of the minimum voltage.

*Map of Steepest Negative Slope*
The time point of the steepest negative slope in the EGM signal is often used for the determination of the local activation time [9]. Also the value of steepest negative slope has an extremum near the rotor center.

*ApEn Map*
ApEn is a method to determine the regularity of statistical data [10] and was also used for identifying rotor centers [11] in simulation studies.

*Different Mapping Catheters*
We studied the signal characteristics of different clinical mapping catheters. Therefore, we extracted simulated EGMs in the virtual electrode positions given by the specific catheter geometries.We used the electrode positions of the circular mapping catheter (Inquiry Optima, St. Jude

Medical, St. Paul, MN, USA) with 10 electrodes. Furthermore we used the electrode positions of the PentaRay catheter (Biosense Webster, Diamond Bar, USA), which consists of 20 electrodes.

## 3. Results

### 3.1. Signal Morphology Near Rotor Center

Simulated unipolar pseudo EGM signals of electrodes in distances of 4 mm in a line through the rotor center are depicted in Fig. 1. Near the rotor center the simulated signal morphology changed considerably (see Fig. 1F and Fig. 1G). On the one hand, the amplitudes decrease and on the other hand there is a phase delay near the rotor center, see Figure 1F and Fig. 1G. Furthermore, in this simulation study slopes have small values near rotor tip.

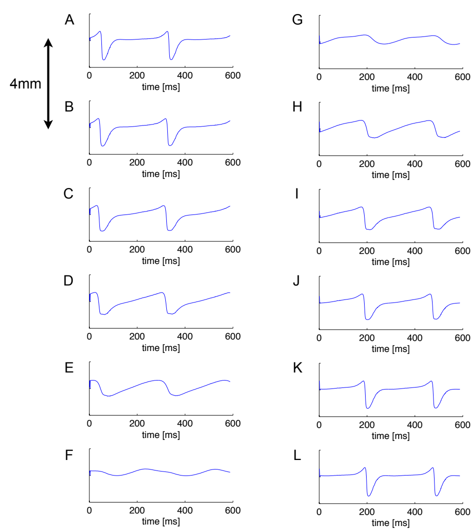


Figure 1. Simulated unipolar pseudo EGM signals from the left to right in a line through the rotor center. The distances between two neighbouring electrodes are 4 mm. The unipolar signal F and the unipolar signal G are close to the rotor center.

### 3.2. Characteristical Maps Near Rotor Center

Figure 2 shows the LAT map, peak to peak map, steepest negative slope map and ApEn map near the rotor center.

*LAT Map*
Near the rotor center in a zoomed area of 50 mm x 50 mm the characteristic LAT map is shown in Fig. 2a.) with typical 360 degree rotations.

*Peak to Peak Amplitude Map*
The peak to peak amplitude has contour lines like an oval form (see Fig. 2b). The rotor center can be found at the minimum of the peak to peak amplitude map.

*Map of Steepest Negative Slope*
We used the steepest negative slope in the signal to generate a first derivative map (see Fig. 2c). The rotor center is in the maximum of the steepest negative slope map.

*ApEn Map*
In an area near the rotor center the ApEn increased and the ApEn had maxima in an oval shape (see Fig. 2d).

#### 3.2.1. Measurements with Different Virtual Catheter Designs

The used PentaRay catheter was centered at the rotor center position. The simulated unipolar signals are shown in Fig. 3. It is evident that the phase of all 4 unipolar signals is nearly constant in every ray. Furthermore, there is an decreasing amplitude.

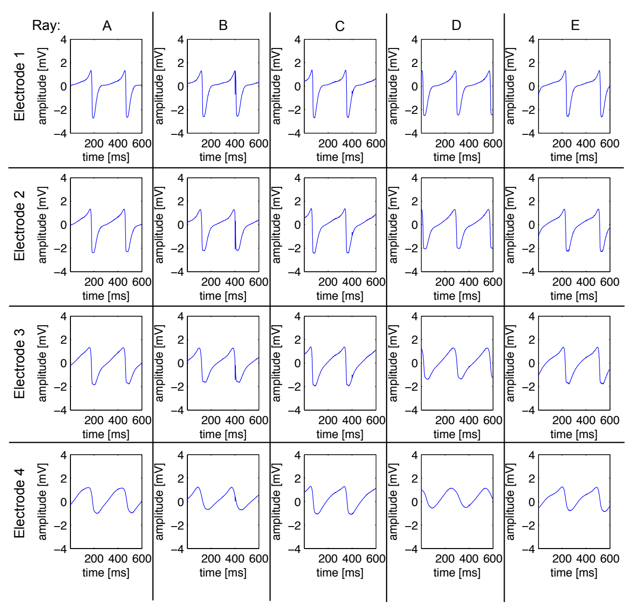


Figure 3. EGMs of virtual electrode positions of the PentaRay catheter: In each column are the four signals of an ray. Electrode 1 of each ray is distal of the rotor center.

With the circular catheter we obtained the resulting unipolar signals shown in Fig. 4. A nearly constant phase shift is visible and the amplitudes of these signals have nearly the same values.

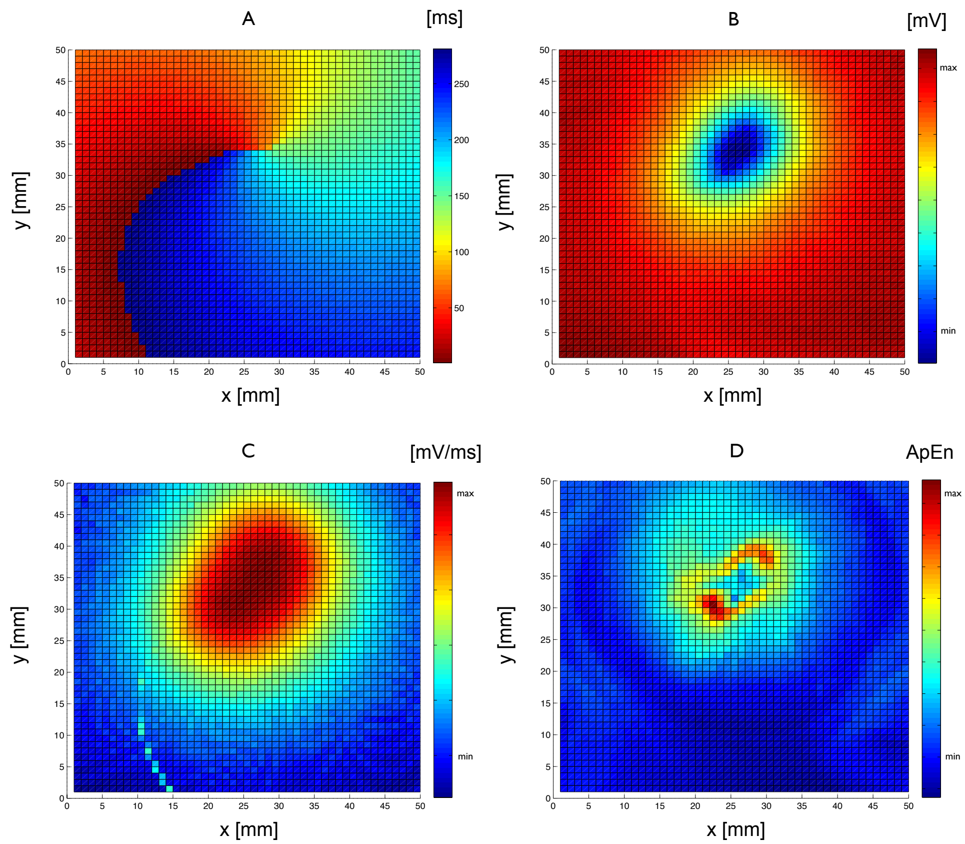


Figure 2. Zoomed area (50 mm x 50 mm) of the simulated patch (100 mm x 100 mm). A: LAT map, B: peak to peak map, C: steepest negative slope map, D: ApEn map. All maps indicate the position of the rotor tip.

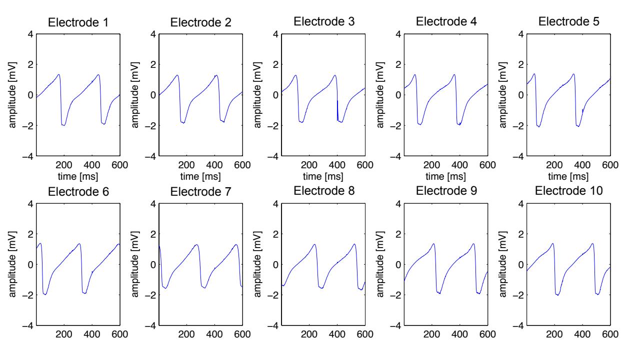


Figure 4. EGMs of virtual electrode positions of the circular catheter: In the first column are the first 5 unipolar signals of the circular catheter. The second column shows last 5 unipolar signals.

## 3.3. Determination of the Rotor Center

The tracked rotor center determined by phase singularity moves in an area of 2.7 mm x 6 mm in an oval shape (compare gray line in Fig. 5). The red points are the determined rotor center positions by the minimum of the peak to peak amplitude map after each cycle. The blue dots are the determined rotor center positions by the maximum of the steepest negative slope map. Both, determined positions of the rotor center from the peak to peak amplitude map and the steepest negative slope map are near the phase singularity. In this simplified simulation study the maximum distances between the focal point of all phase singularities and the rotor center estimated by the peak to peak amplitudes are 1.7 mm and determined by the steepest negative slopes 0.7 mm.

## 4. Discussion

We calculated maps of several features, which are promising candidates for rotor tip determination based on simulated data. The LAT map had typical 360° rotations of the wavefronts and was a reliable method to evaluate a rotor. We could demonstrate the correlation of decreasing peak to peak amplitude of EGMs with the phase singularities. This relation is also confirmed in clinical stud-

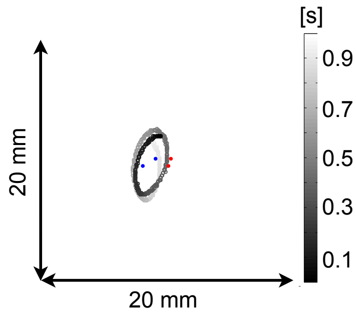


Figure 5. The rotor center moved in forms of oval shapes. (Red) Rotor centers from minimum of the peak to peak amplitude map. (Blue) Rotor tips from the maximum of the steepest negative slope map.

ies. Furthermore, we could point out that the calculated maxima are consistent with the referenced phase singularities. Nevertheless, decreasing amplitudes can originate also from inhomogenous tissue, like fibrotic tissue or increasing distance between electrodes and tissue. In addition, we analyzed the slope of the unipolar EGMs, especially the steepest negative slope, which is a commonly used parameter. In our simplified simulation, the steepest negative slope is small at the rotor tip position and was also a qualified parameter to analyze the rotor center. But clinical data also show fractionated electrograms near the rotor center. The trajectory described by the maximum values of the ApEn showed a high degree of agreement with the trajectory of the rotor tip extracted from transmembrane voltage. But in clinical data the signal morphology is more irregular than in this simplified simulation model. This was the first simulation study, known to the authors, to evaluate different catheter geometries near the rotor center. Due to the limited coverage of the circular catheter centered at the rotor tip position, we found that the virtual PentaRay catheter provided in more information. In this simplified simulation study with the virtual circular catheter centered at the rotor tip position it was not possible to detect the characteristic amplitude changes, which were seen by the PentaRay catheter. In our simulation study, we compared essential parameters to determine the rotor position and analyzed different catheter types. Our simulation study may open new possibilities for detection of rotors and may offer assistance for evaluation of rotors in clinical diagnosis.

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