Locating regions of arrhythmogenic substrate by analyzing the duration of triggered atrial activities

Abstract: Catheter ablation is the most widely used minimally invasive technique to cure atrial arrhythmias. However, the success rate of the treatment is still moderate and depends on the experience and expertise of the physicians. The aim of this work is to present a simple and feasible method to identify the arrhythmogenic areas on the atrium based on the duration of atrial activities in the intraatrial electrograms. Depolarization waves are created by giving pacing impulses from coronary sinus (CS). The duration of the activity triggered from sinus node (SN) and pacing sequences are analyzed by calculating the duration of the activity to mark regions with long atrial activity waves. The intraatrial electrograms have been analyzed on the basis of temporal and spatial information. The region specific study may favor the localization of the critical sites in the patient specific atrial anatomy and aid the physician in ascertaining the efficacy of the cardiac therapies. The identification of suitable markers for critical patterns of the depolarization waves may be crucial to guide an effective ablation treatment. In this work a novel study for point-to-point analysis of the intraatrial electrograms was carried out.

Keywords: atrial arrhythmia, pacing sequence, intraatrial electrogram, and visualization.

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1 Introduction

Atrial Fibrillation is the most common cardiac arrhythmia [1]. This condition increases with age and will increase the risk of strokes, hospitalization, as well as reduction of the quality of life [3]. Catheter ablation is the commonly used technique to cure atrial arrhythmia, if drug therapy fails. The success rate of the procedure could be increased by precisely locating the arrhythmogenic substrate.

In this work a pacing sequence with pacing protocol 400 ms - 350 ms has been used. The study includes two clinical cases. In both cases, the pacing triggers were given from CS catheter. CS is used for pacing because it remains stationary throughout the recording. SN and CS triggered intraatrial activities are analyzed. The behavior in terms of duration of the activity and differences in conduction patterns were analyzed at various locations. Arrhythmogenic tissues will either show no or multiple deflections in the activity. This is a marker for the arrhythmogenic substrate. The method is easy to integrate in routine clinical environment since it is based on routine clinical recordings. Therefore on a long run these clinical studies could help in better clinical procedures to cure atrial arrhythmias.

2 Method

2.1 Patient data

Clinical recordings of both the clinical cases have been done at Städtisches Klinikum Karlsruhe with a written informed consent. Details of both clinical cases are given in table 1. A spiral catheter was used to record the atrial electrogram. Clinical case P1 was a post ablation case while clinical case P2 was a pre ablation case.
2.2 Electroanatomical mapping

The electroanatomical mapping system Velocity (St. Jude Medical) was used to record the clinical cases. Based on the expertise and experience, the physicians selected the points of interest, to get the electrograms containing the activities triggered from SN and CS pacing sequences. Figure 2 represents the two clinical cases with all the recorded points (blue dots) and the physician selected points (red dots). The red dots represent the locations for which the electrograms have been analyzed. The stimulus protocol of 400 ms-350 ms was used for both cases. The time delay between physiological trigger at SN and trigger CS 1 was set to 400 ms. The time delay between trigger CS 1 and trigger CS 2 was set to 350 ms as represented in figure 1. Electrode 7-8 in CS catheter was used to stimulate in patient 1, while CS catheter electrode Distal-2 was used to stimulate in patient 2. The activities resulting from the triggers were considered separately for further analysis as represented in figure 3. The surface ECG signals and the coronary sinus signals were used as reference signals.

2.3 Data analysis

At each physician-selected point, the 1.5 second long electrograms were analysed separately as represented in figure 3. This comprises the activities triggered from the sinus node (SN), CS 1 trigger and CS 2 trigger. The activities triggered at SN, CS1 and CS2 are encircled in figure 3. At all the locations, the intracardiac electrogram along with the surface ECG signals and CS signals were analysed. The surface ECG was used to remove ventricular far fields (VFF). The CS signals were used to align the atrial activities initiated from the CS stimulus. The activities from SN trigger, CS 1 trigger and CS 2 trigger were segmented and analysed separately as represented in figure 4.

2.4 Parameter analysis

After getting desired segment out of the entire dataset, the statistical analysis on the basis of atrial activity duration was done. To avoid the patient going into fibrillation again, the pacing sequence of 400 ms - 350 ms was used. In both the clinical cases, the time taken by the depolarization wavefront to cover the entire left atrium after being triggered at SN and CS has been calculated. This is calculated using the local activation time (LAT) represented in table 2. The LAT of each location was calculated using the Nonlinear Energy Operator (NLEO) [4, 5]. Local activation time is the time where the maximum of the NLEO was detected, as represented in figure 4. The NLEO for the sample j of signal x was calculated using:

\[ E_j = x_j^2 - (x_{j+1} * x_{j-1}) \]
Figure 5: The atrial activity duration interpolated over the left atrium for patient P1. a) During sinus triggering, b) during CS triggering 1, c) during CS triggering 2. Red to blue represents the region with smaller to larger widths. Encircled are the regions with larger activity duration, which are suspected to be the arrhythmogenic substrate.

The step window is calculated based on the NLEO in each electrogram for each activity. This has been calculated by using the standard deviation of 0.1 to the maxima of the energy value [6]. The width of these electrograms is then interpolated over the atrium for visualization purpose. Also the differences in the time and the propagation pattern of the depolarization wavefront triggered by CS 1 and CS 2 trigger were determined over the atrium. This also gives an indication of arrhythmogenic substrates.

3 Results

3.1 Data analysis

Activity duration is computed for both clinical cases and for the activities from all three triggers, as represented in figure 5 and 6 below. The color-coding is chosen so that red to blue represents the least to maximum duration of the atrial activities. The region in which the duration of the atrial activity is large is considered to be the region of interest. These regions are encircled in figure 5 and 6 for both clinical cases. The LAT information gives the time at which a particular location is depolarized, after removing the offset, the difference of the LAT for CS 2 trigger and CS 1 trigger was calculated. This was to see the difference in depolarization wavefront propagation. This difference of LAT for CS 1 triggering as compared to CS 2 triggering for both clinical cases is depicted in figure 7. Looking at figure 5, 6 and 7, the region encircled could be suspected to be the region of arrhythmogenic substrate.
Table 2: Time taken by the depolarization wavefront to cover the entire atrium

<table>
<thead>
<tr>
<th>Clinical case</th>
<th>Sinus trigger (ms)</th>
<th>CS1 trigger (ms)</th>
<th>CS2 trigger (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>97.7887</td>
<td>88.9423</td>
<td>90.9091</td>
</tr>
<tr>
<td>P2</td>
<td>101.7190</td>
<td>103.6855</td>
<td>91.8919</td>
</tr>
</tbody>
</table>

3.2 Parameter analysis

The time taken by the depolarization wave to spread over left atrium is listed in table 2.

Figure 7: Interpolation of the difference of LAT for CS triggering 1 compared to CS triggering 2, a) for patient P1, b) for patient P2. Encircled is the region in which the conduction pattern changes.

4 Discussion

The alignment of each atrial activity is done using the CS signals. The VFF always appear after the atrial activity. The removal of the VFF is done with respect to the ECG signals. Double potentials and late potentials were absent in both clinical cases. A considerable duration should be kept between the triggering impulses, so that clear activities can be obtained from different triggers. Thus, 350 ms time difference was kept between CS 1 and CS 2 trigger. Looking at the visualization of the atrial activity durations along with the interpolation of the differences of LAT gave clear indication for the region of arrhythmogenic substrate. This has been observed in both the clinical cases. Since routine clinical recordings have been used to find the arrhythmogenic substrate, this method is easy to integrate into the clinical environment.

Author’s Statement

Conflict of interest: Authors state no conflict of interest. 
Material and Methods: Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use has been complied with all the relevant national regulations, institutional policies and in accordance the tenets of the Helsinki Declaration, and has been approved by the authors’ institutional review board or equivalent committee.

References


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