Validation of a Novel Imageless Non-Invasive Electrocardiographic Imaging for the Characterization of Atrial Tachycardias

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Abstract

Electrocardiographic Imaging (ECGI) has attracted widespread clinical interest for the diagnosis and treatment of regular atrial tachycardias. However, current ECGI systems require a patient-specific cardiac geometry obtained from computed tomography (CT) scans and its clinical adoption is notoriously difficult. We present a novel imageless ECGI system, that does not require CT scans for the reconstruction of cardiac epicardial potentials. Computational models and clinical data from regular atrial tachycardias were used to evaluate how this novel ECGI system can characterize atrial arrhythmogenic circuits and determine the potential target of ablation. Clinical results were compared against endocavitary high-density electroanatomical mapping (EAM) showing a high agreement between both technologies.

1. Introduction

Regular atrial tachycardias (AT), maintained by regular re-entry (atrial flutter or AFL) or focal activity (focal AT), represents one of the most common supraventricular arrhythmias [1]. In recent decades, AT is becoming a potential secondary effect of atrial fibrillation ablation due to proarrhythmogenic role of the lesion set.

The current clinical diagnosis of AT relies on interpretation on the 12-lead surface electrocardiogram (ECG). Therefore, diagnostic, and therapeutic strategies for complex AT cannot be planned before invasive procedure due to the limited predictive value of ECG for precise ablation target localization [2]. Catheter ablation guided by endocavitary EAM is the gold standard therapy for AT. However, EAM systems require point-by-point sequential mapping. Consequently, the arrhythmia has to be sustained for several minutes so that it can be completely characterized, which in many cases is a limitation and prevents the precise localization of the region that maintains the arrhythmia.

To avoid these limitations, non-invasive ECGI is presented as a potential diagnostic tool that can help in guiding the treatment of AT [3]. However, the clinical adoption of this technique is limited as current ECGI systems need CT scans for obtaining patient-specific cardiac geometry, and the associated ionizing radiation may not be justified for AT patients. In addition, there is poor clinical evidence of the predictive capacity of ECGI compared to the EAM for the characterization of AT, especially for complex AFL such as non cavotricuspid-isthmus (CTI) dependent flutters, known as atypical AFL.

The purpose of this study is to validate the predictive capacity of a novel imageless ECGI system for the characterization of AT. The imageless ECGI neither requires CT scans nor magnetic resonance imaging (MRI) for the epicardial reconstruction of the atria. This technique was verified by employing computational models and evaluated clinically to assess its potential as a relevant diagnostic tool.

2. Methods

The AT characterization was evaluated in activation times maps by identifying the:

(1) Cavity origin, right atrium (RA) or left atrium (LA).
(2) AT mechanisms, i.e., focal or re-entrant.
(3) Target site of ablation for AT termination.

2.1. Clinical database

Sixteen consecutive patients (10 male, 57 ±13 y.o.,10 redo procedures) with an indication of AT ablation and without a precise ECG diagnosis (e.g., typical flutter) were included in the study at Hospital Clínic de Barcelona. The protocol was approved by the Institutional Ethics

Committee of the centre. All patients underwent simultaneous EAM and ECGI mapping during the invasive ablation procedure. Results of the ECGI maps were not considered during the procedure, that followed the standard of care ablation strategies.

2.2. Imageless ECGI system

Before the invasive procedure, 64-electrodes were attached to the torso skin of each patient, and a 3D reconstruction of the patient torso was obtained by an infrared structured light camera. Electrodes were connected to the imageless ECGI system (ACORYS MAPPING SYSTEM, Corify Care SL) and signals were recorded at a sampling rate of 1000 Hz during the entire procedure. From this information, body surface potentials (BSP) were obtained and electrode localizations on the torso surface were identified.

The novel non-invasive imageless ECGI system estimated the most plausible bi-atrial geometry and its localization and orientation inside the 3D torso reconstruction by a method based on anatomical data of the patient. Neither CT scan nor MRI were needed for the ECGI reconstruction.

Inverse epicardial cardiac electrograms were estimated by solving the inverse problem of electrocardiography [4] in a single beat segment of the AT. First, we computed the field transfer matrix between the bi-atrial and torso geometries. Then, the bi-atrial epicardial electrical activity was estimated by solving the inverse problem using zero-order Tikhonov and L-curve methods. Activation time maps were calculated by computing a set of sinusoidal wavelets for all time instants with a negative slope within the ECGI electrograms and with an amplitude proportional to the slope at the time. Then, the instantaneous phase of Hilbert's transform of a composite signal of all computed sinusoidal wavelets was obtained. Finally, the activation times were identified at the points where phase inversions occurred in that instantaneous phase.

2.3. Invasive ablation procedure

All patients were subjected to an invasive electrophysiology ablation procedure. The electrophysiologist was blinded to the noninvasive ECGI diagnosis during the entire procedure. All patients were planned for endocardial access to the RA, and if needed, LA access via transseptal puncture was performed. A reference catheter was initially placed in the coronary sinus, and an irrigated catheter was used for ablation. High-density local activation (LAT) mapping with a 3D navigation system (Carto 3™, Biosense Webster, Ensite Precision™ or EnSite X™, Abbot or Rhythmia HDx™, Boston Scientific) was performed in all patients. LAT maps were analyzed using activation and propagation mapping, and the ablation target was defined as the earliest site of activation for focal AT, and the critical isthmus or the optimal anatomical line of block for AFL.

2.4. Computational models

Atrial activity was simulated in a volumetric three-dimensional model of the human atria [5]. To simulate different types of AT, we implemented an electrophysiological remodelling on several parts of the tissue as previously described [6]. An ensemble of 3 different re-entrant patterns was simulated: a typical AFL (CTI-dependent), an atypical AFL around the right pulmonary veins (peri-RPV), and an atypical AFL around the mitral valve (perimitral).

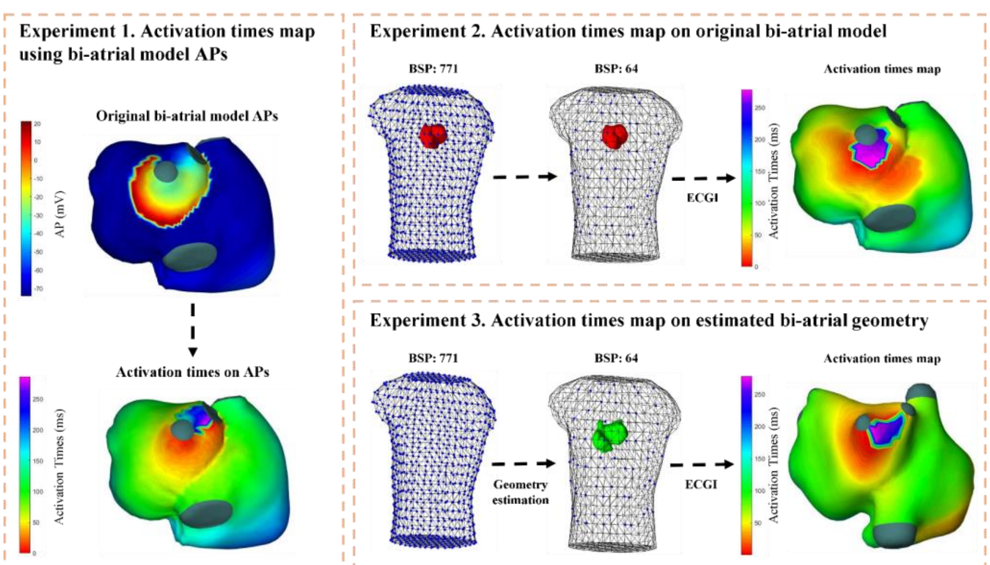

Figure 1. Experiments for the peri-RPV AFL simulation. Experiment 1: Ground truth, Experiment 2: Original bi-atrial model and Experiment 3: estimated bi-atrial geometry.

For each AFL simulation, a uniform bi-atrial model mesh of 4098 unipolar action potentials was calculated surrounding the epicardial surface (1-mm distance), and they were processed at a sampling frequency of 500Hz. BSP were computed by solving the forward problem in a torso model mesh formed by 771 nodes.

To evaluate the performance of the imageless ECGI system for each simulation, computed activation time maps were calculated, as described in section 2.2, and the results were evaluated in three different experiments (Figure 1):

- **Experiment 1.** Bi-atrial model nodes action potentials were used to compute activation time maps.
- **Experiment 2.** We selected 64-BSP sources from the torso model to mimic a real-case scenario, and activation time maps were computed on the original bi-atrial model surface.
- **Experiment 3.** The imageless ECGI system estimated a bi-atrial geometry according to the torso model. We selected 64-BSP sources from the torso model, and activation time maps were computed on the estimated atrial geometry.

3. Results

3.1. Validation of the imageless ECGI system using computational models

In Figure 1, experimental results for the peri-RPV AFL simulation are shown. The ground truth activation map was computed on the activation potentials signals (Experiment 1). The result reveals the AFL circuit around the RPV. Then, we calculated the ECGI activation maps for the original (Experiment 2) and the estimated (Experiment 3) bi-atrial geometries. In both cases, the ECGI system correctly identified the active circuit in the LA cavity, the macro-reentrant mechanism around the RPV, and therefore, the target region for AFL termination. This result agrees with the ground truth map (Figure 1, Experiment 1), in which the AFL circuit is known in detail.

For the typical and perimitral AFL, the AT characterization was also accomplished. However, differences in the propagation pattern existed for the perimitral case. In these simulations, the atria used for the reconstruction of ECGI activity was estimated using the same methodology applied to patients. As can be shown in Figure 1, these atria (green-colored) show slight anatomical variations compared to the original geometry (red-colored) such as volume and shape. Despite these differences, the imageless ECGI reconstruction allowed the identification of the ablation site.

3.2. Clinical Validation of the Imageless ECGI system

A total of 18 ATs (309±63,8 ms cycle length) were mapped with EAM and ECGI systems. The non-invasive ECGI system correctly identified 100% of the AT as originating from the right (n=8) or the left (n=10) atrium. Unnecessary transeptal access to the left atrium was performed in 3 patients whose ECGI precisely identified the right location. ECGI identified the AT mechanism in 17 of 18 ATs (94,4%): focal onset in 4 of 4 and re-entry in 13 of 14 (one identified as focal). The earliest site of activation was accurately located in all focal AT by the non-invasive system. Among the re-entrant AT, ECGI identified the type of the re-entry in 11 of 14 (78,6%). ECGI detected the ablation target for AT termination in 15 of 18 AT (83,3%).

4. Discussion

In this study, we have evaluated for the first time the feasibility of using an ECGI system that does not require CT scan for the non-invasive characterization of AT. We have studied the potential of this technology to unmask RA regular ATs that apparently were originating from the LA in the 12-lead ECG, which can avoid unnecessary LA transseptal punctures. This new ECGI methodology opens the possibility of its application in clinical settings (e.g., medical consultation), and to plan and guide ablation procedures.

Shah et al [6] validated the ECGI as a potential tool for AT mapping. In this multicentric study, they analysed 52 patients, and a precision of 92% on the AT characterization was observed. Despite these interesting results, clinical application of ECGI is still limited to reference centres that have the resources to be able to perform a CT scan on each patient. In our study we focused on that type of AT for which the clinical diagnosis using 12-lead ECG remains challenging (e.g., non-CTI dependent flutters). In this study, 11 of the 14 flutters were atypical and the imageless ECGI had a precision regarding the ablation target identification of 72,7% (8 of 11), while in Shah et al. reported a precision of 55,5% in a set of 9 atypical flutters (5 of 9).

The novel imageless ECGI allowed to correctly identify the atrium responsible for AT in all the cases, avoiding useless and potentially risky transseptal puncture although the precise location of the ablation target was less precisely detected than with EAM, especially if the AT was septal, perimitral or in complex congenital hearts. Further investigation in larger cohorts is needed to precisely know the potential limitations of the technique.

5. Conclusion

Our study validates a novel non-invasive ECGI system that accurately characterizes AT before endocavitary procedure without the need for CT scans. ECGI could help guide the ablation procedures by detecting the target site for ablation.

Acknowledgments

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Conflict of interests

AMC, MSG and IHR are co-founders and shareholders of Corify Care SL.

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