New Method of Assessing Cycle Lengths in Human Atrial Fibrillation

Adam Quotb [1], Guillaume Attuel [1], Carole Pomier [2], Yuki Komatsu [1], Pierre Jaïs [1], Mélèze Hocini [1], Michel Haissaguerre [1], Rémi Dubois [1]

[1] LIRYC, Institut de rythmologie et modélisation cardiaque, Université de Bordeaux, F33000, Bordeaux, France.
[2] CardioInsight, Cleveland OH, US

Abstract

Measuring the mean cycle length (CL) of a rapidly beating heart is considered an efficient way to monitor arrhythmia such as atrial fibrillation (AF). Routinely, sequential CL mapping, using contact catheters in the atria, provides indications on the localization of regions involved in AF. In particular, this technique helps the practitioner, during ablation procedures, to identify some features of the arrhythmia, as, for instance, the driving atrium, or the fastest regions, or its complexity.

In this study, we propose a non invasive mapping of CL (niCL), using phase information extracted from electrocardiographic imaging signals (ECGI). niCL mapping provides with a real time ablation planning to the bedside of patients, prior to ablation procedure. The results of this study validate the method in showing a direct correlation between endocavitory (inside the heart) measurements of CL (enCL) and niCL mapping.

1. Introduction

Electrical impulses in the heart are initiated in the sinoatrial node, which then propagate across both atria, and enter the heart ventricles through the Aschoff-Tawara node.

During fibrillation, pathways of electrical activation are abnormal. The standard physiological description of fibrillation involves multiple waves entering a state of sustained activity, as depicted by functional reentries, triggered by focal sources and the inhomogeneity of propagation in the myocardium [1] [2].

Atrial fibrillation (AF) is the most common sustained cardiac arrhythmia affecting humans [3]. Considered as a tachycardia (atrial rate above 350 beats per minute), AF can be classified in three categories, according to its robustness [4]. If the arrhythmia is recurrent and reverts spontaneously to sinus rhythm within 7 days, it is dubbed paroxysmal AF. If it does not terminate spontaneously, but does with cardioversion, AF is classified as persistent (lasting $\geq$ 7 days). AF is termed permanent (long lasting $\geq$ 1 year) when it is resistant to cardioversion [5].

When anti-arrhythmic drugs fail, paroxysmal AF is currently treated by catheter radio frequency ablation. The discovery of important triggering focal sources, located in the pulmonary veins, opened a path to the treatment of paroxysmal AF from the electrical isolation of the pulmonary veins [6]. In persistent and permanent AF, the task is even more challenging [8] [9]. In fact, it is observed that reentries generally move around in the atria, and that focal sources have pervaded the atria [10]. For this reason, mapping of the electrical activity of the atria, prior to ablation, is very helpful.

Up to very recently, endocardial mapping was available [11]. Non invasive mapping has been developed in the meantime [12]. By moving catheters inside the atria, one can record the electrical activity locally at different sites, and elaborate a sequential mapping. Specifically, the mean cycle length (enCL) is measured, which gives the means to identify a driving chamber, or a faster region, and in general helps to evaluate the complexity of the arrhythmia.

Non invasive mapping allows a coincident visualization of the whole myocardium electrical potentials, from body surface electrocardiograms (ECGI: electrocardiographic imaging). The "inverse problem of electrocardiography" is solved in order to reconstruct the electrical activity on the surface of the heart [13] [14].

This study validates the computation of niCL during AF, since results show a direct correlation between enCL and niCL.

2. Materials and methods

Figure 1 shows an overview of the computational process used for this study.

Unipolar electrical potentials are reconstructed on the epicardial surface of the atria, after solving the inverse problem. A phase is computed for each signal with post-processing. The search for periodic events during AF makes it appropriate to consider the phase, since those

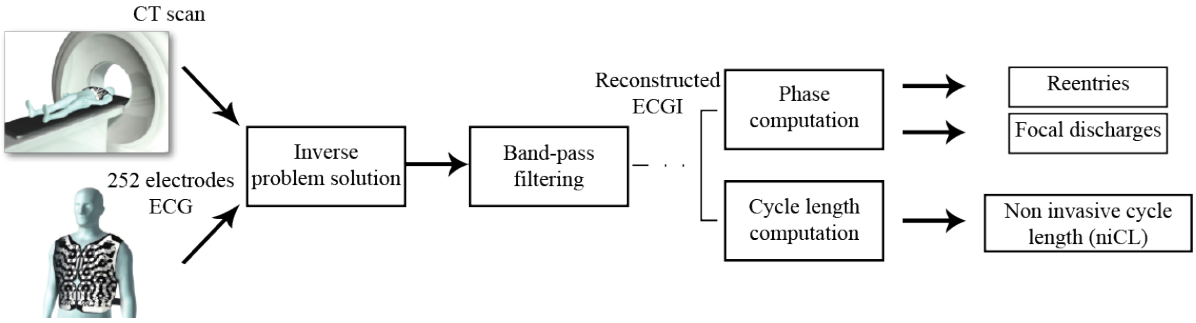

Figure 1. Overview of the computational process, from body surface data acquisition to CL mapping

events will be coherent throughout the atria, except for a finite number of singularities (winding or focal topological defects).

2.1. ECGI

ECGI requires two sets of data: extensive electrocardiograms over the torso (a vest comprised of 252 electrodes), and a geometric relationship in space between the heart (epicardium) and the torso surfaces. Torso signals are amplified. The geometric information is obtained from a computed tomography scan (CT). The inverse problem solution gives epicardium electrical potentials (ciEGMs : cardioinsight electrograms).

2.2. Phase analysis

The typical frequency of AF in humans is in the range of 4Hz-8Hz. Since we want to extract the phases, and since the frequency of AF in patients can vary from one area of the atria to another, it is well founded in our post processing to apply a non recursive band pass frequency filter, i.e. with linear phase. For each node of the atrial geometry, we computed the phase using a Hilbert transform. From the band pass filtered ciEGM real signal $u_x(t)$, on node x, at time t, an analytic signal may be constructed as $U_x(t) = u_x(t) + i\tilde{u}_x(t) = R\exp(i\Phi)$, where $\tilde{u}_x(t) = \frac{1}{\pi}\int_{-\infty}^{+\infty} dt' \ \frac{u_x(t')}{t-t'}$ is the Hilbert transform. A full cycle is then represented by the phase Φ that increases from $-\pi$ to $+\pi$.

When abnormal activity appears, cycles are perturbed. Because pulses propagate through the heart coherently, these perturbations may occur in a finite amount of abrupt changes in phase: singularities. A winding singularity occurs at node x, and time t, if $I \equiv \oint_{\mathcal{C}} \vec{\nabla}\Phi_x(t) \cdot d\vec{l} = \pm 2k\pi$, where $\mathcal{C}$ is a close contour around x, and $\vec{l}$ is the unit curvilinear vector along $\mathcal{C}$, and k is an integer. A source singularity occurs when $J \equiv \oint_{\mathcal{C}} \vec{\nabla}\Phi_x(t) \cdot d\vec{n} \neq 0$, where $\vec{n}$ is the unit vector normal to $\mathcal{C}$. We compute discretized versions of I and J on every lattice node for each sample.

An example of a reconstructed ciEGM is provided in figure 2.A, and its phase representation in figure 2.B.

2.3. Non-invasive cycle length computation

For each node x of the CT geometry, the algorithm finds the delay between two consecutive isophases, arbitrarily chosen to be equal to $\frac{\pi}{2}$, cL_x. The mean CL at node x is computed following $CL_x = \frac{\sum_{j=0}^{N} cL_x(j)}{N}$, where N is the number of CL intervals identified by the algorithm during the measuring period. To compute niCL, the user first selects a point of interest on the atria, then the mean is evaluated among the n neighboring nodes, labeled y,

$$niCL_x = \frac{(\sum_y CL_y) + CL_x}{n+1}. \qquad (1)$$

2.4. Measure regions and population

The common protocol to measure enCL in the lab is to first measure cycle length in both appendages. Indeed, due to their anatomy cycle length are considered as quite more regular and give a good overview of the AF. When the fast side of the atria is selected, practioner find regions involved in AF and measure cycle length even if it can be not regular.

Our cycle length computing method follows the same protocol:

We compare niCL and enCL in both appendages firstly to verify our method. The performance of the algorithm is evaluated on P=73 patients (average age: 59, minimum age: 21, maximum age: 79) who underwent AF ablation procedure (mean AF duration: 8.6 month). niCLs were mapped to the bedside of patients, between one day and an hour prior to ablation procedure, while enCLs were estimated from catheter electrograms during ablation.

Secondly, for P=9 patients, we confirm on several other regions, which were identified as being involved in the perpetuation of the arrhythmia. To simplify matters, we reduce patient number according to the number of regions

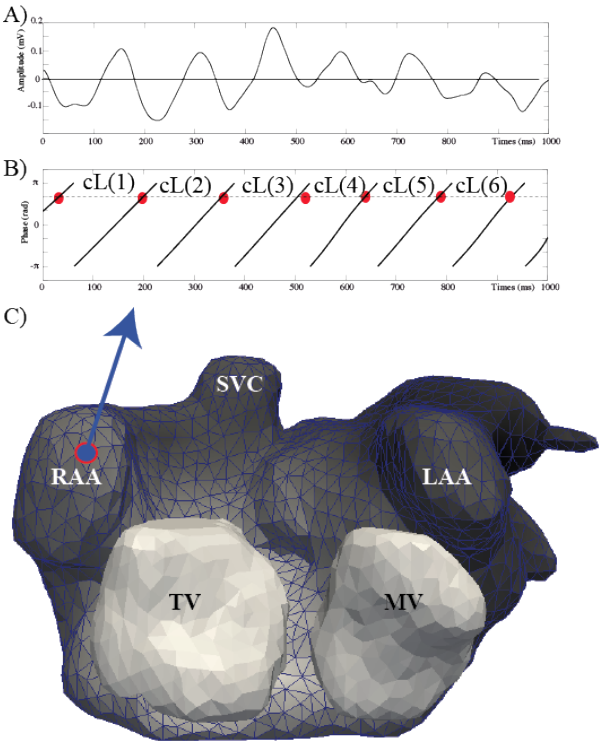

Figure 2. Cycle length computation. Example of a reconstructed band pass filtered ciEGM, taken from the right appendage (RAA) A), and its phase B). The red dots correspond to the isophases. Sketch of the mesh grid of the 3D atria CT geometry (SVC: Superior Veina Cava, LAA: Left Appendage, TV: Tricuspid Valve and MV: Mitral Valve)

involved in AF(< 3). Among these 9 patients, niCLs and enCLs were compared in 18 regions in total.

3. Results

As concerns CL measurements in the appendages, results are shown in figure 3. A good correlation between enCL and niCL is found (RAA: r=0.88, p<0.0001; LAA: r=0.91, p<0.0001). In the 18 other regions, similar correlations are found, see figure 4 (r=0.89, p<0.0001).

4. Discussion

4.1. Computing aspects

Even both CL measurements are not made in the same time, the correlation between endo and non-invasive cycle length is well observed in our study. But for few cases, there is a difference between enCL and niCL. This observation can be explained by the natural variabilty of the AF. Indeed, cardiac CL can changed from one day to another. Because of this time delay between endo and non-invasive

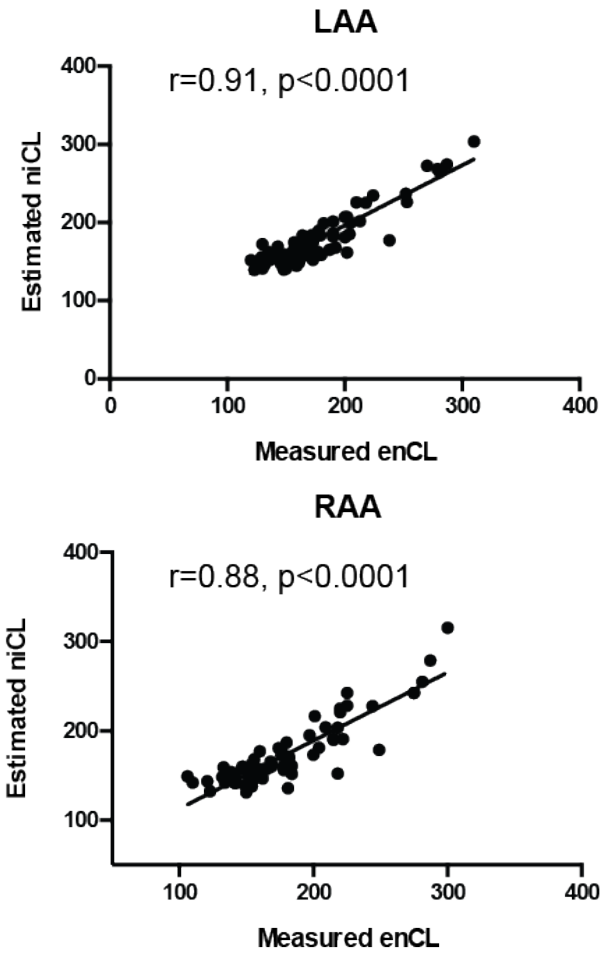

Figure 3. Correlation between enCl and niCL in both appendages.

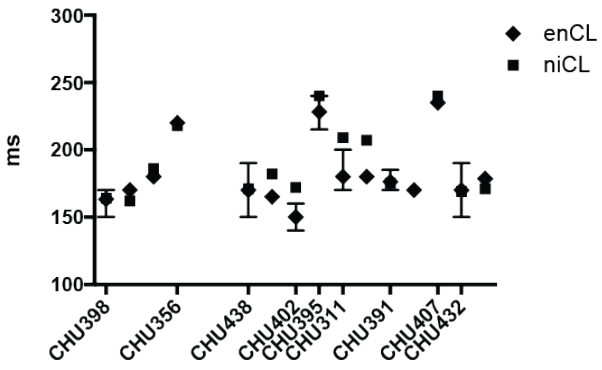

Figure 4. enCl and niCL in regions involved in AF for 9 patients. Errors bars represent the CL range (from min to max).

measurements we can observe sometimes difference between enCL an niCL.

4.2. Clinical aspects

Computing niCL mapping is a fast acquisition, and could replace enCL mapping efficiently. It gives a rapid overview of the arrhythmia (faster regions, driving chamber, etc). To provide the practitioner with better indication of the nature of the arrhythmia, niCLs maps are done in addition to singularity maps. Their combined spatio-temporal patterns are used as guidance to AF ablation procedures[7].

5. Conclusion

We had given a rapid overview of a new method of non invasive cycle length mapping of atrial fibrillation. The niCL computational method has been tested on 73+9 patients and compared to endocavitory cycle length measurements, enCL. niCL mapping is a new tool, which paves the way for new possibilities of clinical investigation of atrial fibrillation.

Acknowledgments

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Address for correspondence:

Rémi Dubois
IHU LIRYC Institut de rythmologie et de modélisation cardiaque
PTIB-Hôpital Xavier Arnozan. Avenue du Haut Lévèque 33604 Pessac