Coronary Sinus Lead Tracking for Its 3D Dynamic Position Assessment in Cardiac Resynchronization Therapy

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Abstract

Cardiac resynchronization therapy (CRT) has been successfully used in patients affected by heart failure and left ventricular (LV) systolic dysfunction with LV dissyncrony. However, a variable number of patients (20%-30%) do not respond favorably to CRT due to several possible, still uncertain factors. One possible cause is the displacement of the electrode tip from effectively resynchronizing stimulation sites. In this study we (1) developed a procedure aimed at quantifying the coronary sinus (CS) lead tip position in the 3D domain throughout the cardiac cycle and (2) tested this procedure by comparing the CS lead position at device implantation (t_0) and at three-months follow-up (t_1) using chest fluoroscopy. Our procedure for the assessment of the CS lead position was successfully applied to ten patients. The accuracy resulted in 0.8±0.4 mm, giving a resolution of 1.7 mm. The repeatability was 0.4±0.4 mm. Six patients were evaluated at follow-up and the qualitative check of displacement from fluoroscopy videos did not contradict our quantitative analysis. The proposed technique allowed quantitative evaluation of CS lead position and tracking in 3D space.

1. Introduction

Cardiac resynchronization therapy (CRT) has shown impressive results for the treatment of patients with drug-refractory heart failure, chronic symptomatic systolic heart failure and cardiac dissynchrony. The benefits of CRT include improvements in left ventricular (LV) haemodynamics, reduction of LV volumes and dissynchrony as well as improvements in clinical symptoms [1].

However about one-third of patients do not respond favorably to this therapy [2]. This may be related to various factors among which suboptimal or non-adapted stimulation, unsuitable coronary sinus (CS) branch, lead instability in time and incapability of a continuous resynchronization are being evaluated [3,4]. CS lead dislodgement can occur months after implant, without affecting even CS pacing threshold or ECG morphology but possibly interfering with CRT mechanics. Several studies investigated the lead movements in CS veins by standard X–ray exam in a qualitative and subjective bi-dimensional manner [5,6].

To overcome these limitations, we have developed an automated tracking procedure, based on region matching techniques [7,8], for quantifying CS lead position in the 3D domain throughout the cardiac cycle and we have tested it by comparing the CS lead position at implant (t_0) and at three-month follow-up (t_1), using chest fluoroscopy.

2. Methods

2.1. The tracking procedure

To evaluate the CS lead 3D dynamic position we processed the x-ray fluoroscopy videos, obtained at the device implant. Three views are usually acquired: the antero-posterior (AP), the left anterior oblique (LAO) at 30° and the right anterior oblique (RAO) at 30°, at 25 frames per second. We selected two of these views, generally the LAO and RAO, and in each one we manually selected the tip of the lead, p, in the first frame. For each acquisition, we tracked the selected point throughout the entire video applying region matching techniques [7,8].

As described in figure 1, in the frame i+1 a window V of dimensions dFs x dFs pixels, centered in the catheter tip position pi in frame i, is considered. For each pixel inside this window another window F of dimensions dFr x dFr pixels is defined and compared to the window of the same size centered in pi, in frame i, by means of the sum of the squared difference (SSD) of the image brightness I:

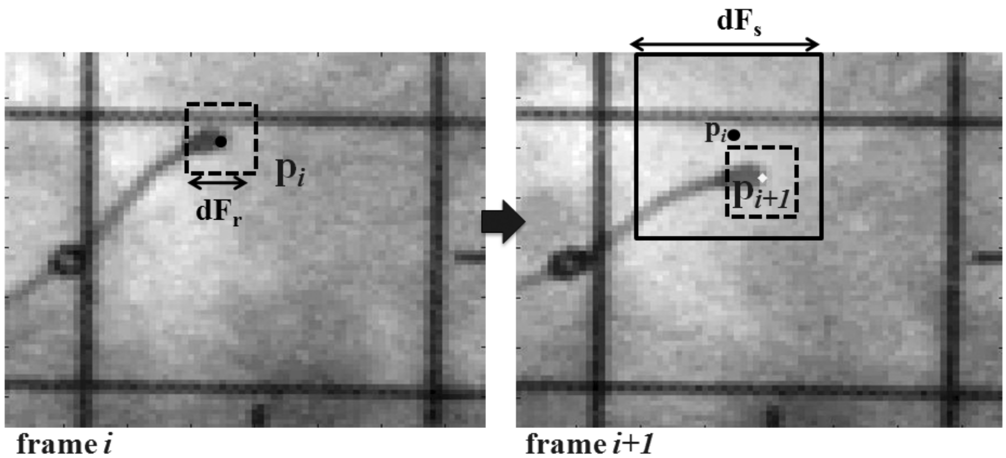

Figure 1. Schematic explanation of the region matching technique (see text for details).

$$\phi(\mathbf{p}_{i+1}) = \sum_i \sum_j F(i,j)\left[I_i(\mathbf{p}_i + (i,j)) - I_{i+1}(\mathbf{p}_{i+1} + (i,j))\right]^2$$

For each point inside $\mathbf{V}$ the function $\phi(\mathbf{p}_{i+1})$ is evaluated and the point corresponding to the minimum value of the SSD $\phi(\mathbf{p}_{i+1})$ is the one that best fitted the window around the starting point and thus it was considered as the resulting point of the algorithm:

$$\mathbf{p}_{i+1}^{final} = \arg\min \phi(\mathbf{p}_i^i) \quad \text{for } \mathbf{p}_i^i \in \mathbf{V}$$

The final location of the starting point $\mathbf{p}_i$ is:

$$\mathbf{p}_{i+1}^{final} = \mathbf{p}_i + \mathbf{d}_M$$

where $\mathbf{d}_M$ is the displacement evaluated using the region-based matching.

This procedure was applied to the point manually selected in the first frame to estimate its coordinates throughout the cardiac cycle. Each frame was analyzed starting from the point obtained in the previous frame.

This tracking resulted in the tip-coordinates time-course throughout several cardiac cycles as shown in figure 2. These signals were then filtered from fluctuation due to respiration: since the image acquisitions were carried out at a respiration rate constantly between 12 and 15 breaths/min, we applied a high-pass filter using a cut-off frequency of 0.3 Hz (figure 3).

To obtain the 3D dynamic tip coordinates, one cardiac cycle was manually selected in both views; these two curves, representing two cardiac cycles, were normalized and the 3D dynamic tip coordinates were reconstructed using stereo-Roentgen photogrammetric rules.

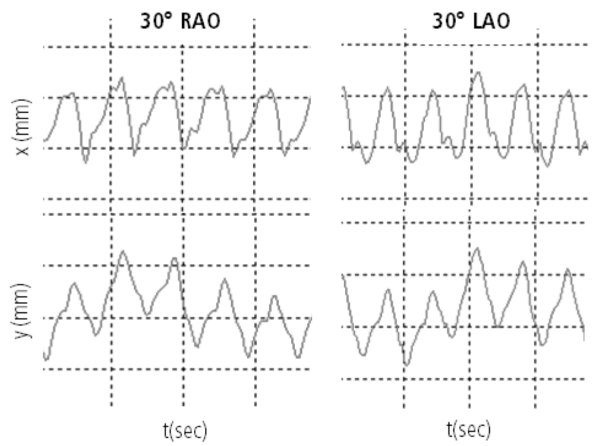

Figure 2. CS lead coordinates throughout the five acquired cardiac cycles in the two views

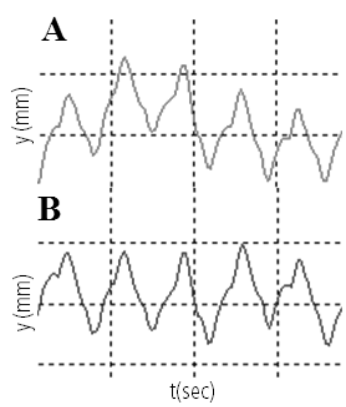

Figure 3. Example of the filtering from respiration fluctuation applied to the tip coordinates (A: pre filtering; B: post filtering).

2.2. Image acquisition protocol

To assure reproducibility of x-ray data acquisition at device implant and at follow up we defined an acquisition protocol using a radio opaque tattoo and a Leed grid (figure 4).

A marker (visible in each view) was placed on the patient chest and a Leed filter was fixed on the x-ray camera; the acquisition was performed with the marker superimposed on a specific grid lines intersection. A tattoo was then made where the marker was placed. At follow up, the acquisition was repeated using the tattoo to re-position the marker and the grid.

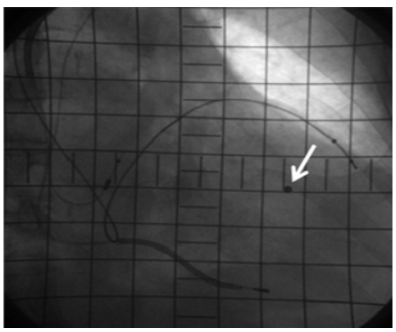

Figure 4. Leed grid superimposed to the x-ray camera and the marker/tattoo (arrow) as required by the image acquisition protocol.

2.3. Population and data analysis

In a single centre, ten consecutive patients (age: 69±11 years; 7 men and 3 women) undergoing CRT because of conventional class I indications, were evaluated, after obtaining their informed consent. Follow-up data were available in six patients.

All patients at implant were in NYHA functional class III, with a mean ejection fraction of 28±5%

To reduce variability due to cycle length and respiration, all acquisitions were carried out at rest, after 15 minutes in supine position, with a cardiac rate of approximately 70 bpm and a breathing rate between 12 and 15 per minute.

To evaluate the accuracy and the resolution of our measurements we hypothesized that the 3D catheter tip trajectories in consecutive cardiac cycles should be approximately the same and any difference is supposed to be related to limitations of our estimation method. Therefore, at t_0, we analyzed four consecutive cardiac cycles and computed three mean catheter tip displacements with respect to the first cycle; the procedure accuracy was assessed as the average value of these displacements. The resolution of our technique was fixed as the mean accuracy ± 2 SD.

To test if the manual selection of one cardiac cycle influences our measurements, we computed the catheter tip displacement by selecting three different cardiac cycle pairs between t_0 and t_1.

Depending on catheter tip displacement (d) values, patients were categorized in four classes: 0 = no change (d < resolution); 1 = moderate displacement (d ≤ 5mm); 2 = significant displacement (d > 5mm); 3 - tip completely dislodged from the CS.

3. Results

X-ray data acquisition and analysis were feasible in all subjects, except one in which the catheter tip overlaid on the grid and an additional initialization was required to complete the tracking.

Analysis time (including data retrieval, region matching application, filtering, cardiac cycle selection and normalization, 3D trajectory reconstruction) was less than 3 min, of which only few seconds were required for the computations once user interaction was complete.

The window dimensions used for the tracking were: dFs = 8 pixels and dFr=5 pixels.

An example of the tracking procedure is shown in figure 5.

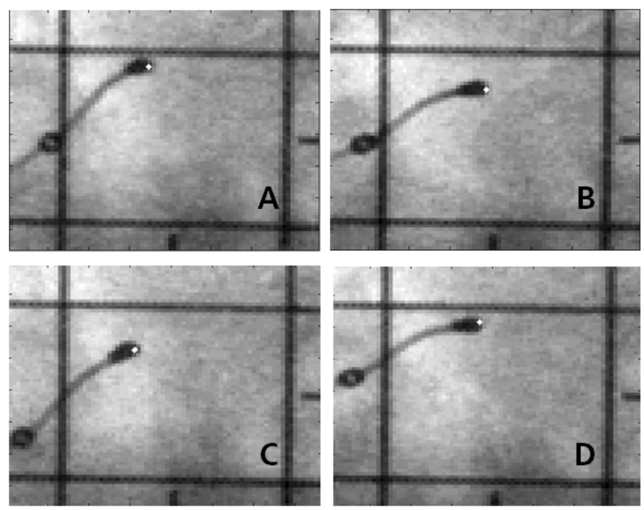

Figure 5. Examples of the tracking results in four frames (A-D); the CS lead tip is highlighted with a white point.

The accuracy resulted in 0.8±0.4mm, giving a resolution of 1.7 mm.

An example of the 3D trajectory computed for three consecutive cardiac cycles in one patient is shown in figure 6. The repeatability was 0.4±0.4 mm.

The six patients in whom the catheter tip 3D location was evaluated at t_1, belonged to class 1 (3), class 2 (1) and class 3 (2). An example of the 3D trajectory at t_0 (dark gray) and t_1 (light gray) in one patient is shown in figure 7. The qualitative check of fluoroscopy videos did not contradict the quantitative analysis results.

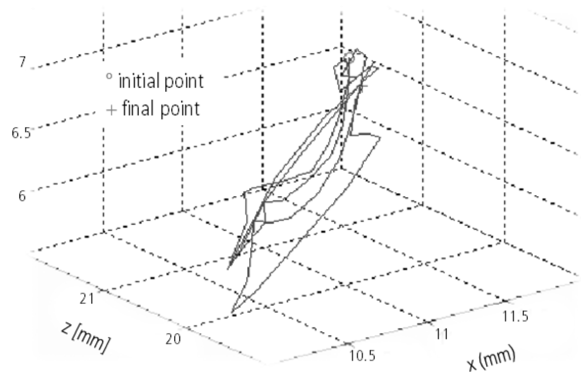

Figure 6. 3D plot of CS lead tip in three consecutive cardiac cycles.

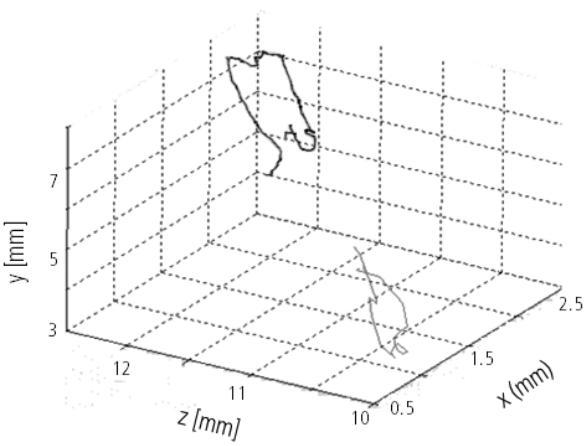

Figure 7. Example of the 3D trajectory at t_0 (dark gray) and t_1 (light gray) in one patient. For this patient the displacement resulted in d = 1.9 mm (SD = 0.6 mm).

4. Discussion and conclusions

To our knowledge this preliminary study is the first to propose a methodology for a quantitative evaluation of CS lead position in 3D space from x-ray acquisition.

Several limitations characterize this study. Ideally AP, RAO and LAO views should be acquired at the same time; though consecutively and in the same clinical setting, in this study the delay between the three acquisitions was 30-60 seconds. During the acquisition the Leed filter may hide the catheter tip; in these cases an additional initialization for the tracking algorithm was necessary. Finally, as no method for real-time study of the catheter tip in 3D has been so far validated, the gold standard for tip movements and cut-off values does not exist.

Although our hypothesis needs confirmation, and despite study limitations, measurements were accurate and reproducible.

Future correlation, on a larger population, between tip electrode location/displacement and electrical parameters could provide both an additional explanation for non–responsive patients and the basis for new implantation directions.

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