Three-dimensional Frequency Mapping from the Noncontact Unipolar Electrograms in Atrial Fibrillation

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Abstract

Three-dimensional (3D) colour-coded mapping of dominant frequency (DF) from noncontact unipolar electrograms in real-time can serve as a powerful tool for identifying potential atrial fibrillation (AF) drivers allowing the analysis and identification of re-entrant circuits sustaining AF. The main problems with the current technology of 3D DF mappings are the lack of spatial resolution and the long acquisition time required. The DF mapping developed in this study generates the 3D representation of the inner surface of the atrium with high resolution (2048 measurement points from noncontact unipolar electrograms) and can be performed in quasi real-time.

1. Introduction

In 1990, spectral analysis was used to predict atrial rate, regularity and coarseness from surface ECG in humans based on dominant frequency peak, bandwidth and total power [1]. Later, in 1998, frequency analysis in epicardial electrograms and optical recordings in animals showed that dominant frequency (DF) correlates well with the rotor responsible for the periodic activity of the arrhythmia, suggesting that it can be used to identify re-entrant circuits sustaining atrial fibrillation (AF) [2].

Clinical studies in humans showed that ablation of these DF regions in the atrium can contribute to terminate AF [3-5]. In clinical practice, ablation of the sites guided by frequency mapping has been mainly performed through advanced mapping systems that are based on point-by-point sequential acquisition [6] and thus the resolution of these maps can be limited and it is difficult to assess temporal variation [6, 7].

The electrodes used in this kind of contact mapping acquire electrograms over time taking up to 30 minutes to generate a single DF map [3, 6]. As a consequence it assumes temporal stability over long periods of time [3] and extends the overall time for an ablation procedure.

Noncontact mapping (NCM) is done by non-contact multielectrode array catheter (Ensite) and analysis system (Ensite 3000 System, Endocardial Solutions Inc) that generate electrophysiological and anatomic mapping of any cardiac chamber [8]. The system allows simultaneous reconstruction using inverse solution mathematics from far-field electrograms up to 3,600 non-contact electrograms sampled at 1200 Hz and voltage sensitivity of 10 μV, translating them into a three-dimensional (3D) graphical representation of the cardiac chamber in colour-coded representation [9]. In this paper we describe the methodology for using such a system to perform frequency mapping during AF [6] with high resolution for developing online frequency analysis [10].

The aim of this study was to develop three-dimensional (3D) colour-coded mapping of DF in quasi real time from the inner surface of the atrium for 2048 measurement points from noncontact unipolar electrograms.

2. Methods

As well as describing the methodology for generating the DF maps we show how the spatial distribution of DF changes on the surface of the atria along time, after drug infusion (isoprenaline and atropine), before and after ablation and with ventricular far-field cancelation (QRS subtraction).

2.1. Clinical procedure

Virtual electrograms were obtained in four patients with persistent AF using Ensite Array balloon with non-contact mapping and creation of 3D geometry of the left atrium at the beginning of the EP procedure. During continuous recording, drugs were given including intravenous isoprenaline infusion followed by washout and intravenous atropine injection. Virtual electrograms were obtained and analysed in 20 second segments under steady state during the different conditions: baseline, isoprenaline and atropine. This was then followed by the ablation procedure which included ablation around the pulmonary vein ostia aimed at electrical isolation of the 4 pulmonary veins. This was performed either using point-

by-point ablation as guided by Ensite NavX or with the PVAC catheter.

This study had approval from the Local Ethics Committee for mapping and ablation studies in patients undergoing AF ablation which includes blood sampling and collection of electrical data during the procedures.

2.2. Three-dimensional (3D) surface of the atrium

Before generating the 3D DF maps, it was necessary to compare the accuracy of the 3D geometrical surface of the atrium developed with the 3D surface of the atrium generated through the Ensite 3000 System. Figure 1(a) shows an example of the 3D surface of the right atrium (RA) generated automatically using Matlab (MathWorks Inc., USA) with 2048 points and the figure 1(b) shows the an example of the 3D surface of the RA generated through the Ensite 3000 System with 2048 non-contact points. Figure 1(b) was obtained during electrophysiological study in Glenfield Hospital by Cardiologists from Department of Cardiovascular Sciences, University of Leicester.

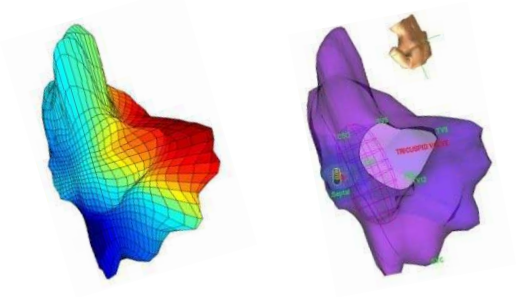

Figure 1(a) – 3D surface of the RA atrium generated automatically using Matlab and 1(b) the 3D surface of the RA.

2.3. Three-dimensional (3D) mapping of noncontact unipolar electrograms in frequency and voltage

We are validating the first 3D Dominant Frequency map with high density (2048) of non-contact electrograms. The time necessary to generate these 3D DF maps can be considered almost real-time. After generating the maps it is possible to rotate the 3D DF of the atrium in any orientation on screen.

3D dominant frequency mapping

Three-dimensional dominant frequency maps during ongoing AF were performed automatically using Matlab (MathWorks Inc., USA) in quasi real-time. Spectral analysis allowed determination of DF from 20-second long segments of each 2048 non-contact unipolar electrograms for each protocol (baseline, after each drug, and after ablation). DF was defined as the frequency with highest amplitude within the physiologically relevant range (4 to 12 Hz) using 4-second long windows [11]. The time-domain unipolar signals were sampled at 1200 Hz. The spectral resolution was 0.29 Hz.

3D voltage mapping

The 3D electro-anatomic mappings during ongoing AF for each protocol were also performed using Matlab (MathWorks Inc., USA).

2.4. Movies of 3D distribution

3D movies of DF maps and 3D electro-anatomic maps were performed in AVI format during ongoing AF using Matlab (MathWorks Inc., USA). There are different settings to create these movies according with the number of frames per second, percentage of quality of the movies and compression. We have tested a large range of number of frames per second settings, 100% of quality and Compression Cinepak or no-compression. The advantage of using compression is that the size of the resulting files is in Kilo-bytes instead Mega-bytes and there is not a big difference in terms of visual quality.

2.5. QRS subtraction

We have developed a technique for the removal of ventricular signals from virtual atrial electrograms. The surface ECG is used as a guide to identify the ventricular activity of the signals. QRS subtraction was based on the application of a band pass filter between 8 Hz and 20 Hz and low pass filtering the rectified signal. The cut-off of frequency of the low pass filter is determined by the lowest RR interval of the ECG signals (354 beats per minute) and was chosen as 6 Hz. The peaks of the resulting signals were determined and areas corresponding to QRS complexes were replaced by flat interpolation which is similar to the baseline value before frequency analysis is performed.

2.6. Average spectrum

The average spectrum in the whole segment was obtained to observe the distribution of DF for each protocol. In addition, the cancelation of ventricular far-field (QRS subtraction) for all 2048 non-contact unipolar electrograms was implemented to observe its effects.

The average spectrum was obtained for the 2048 points for each 4-second long window of 20 second long segments. The average of all windows represents the average spectrum of the atrium for each protocol, making it possible to compare spectra before and after ablation and drug effects with or without ventricular influence.

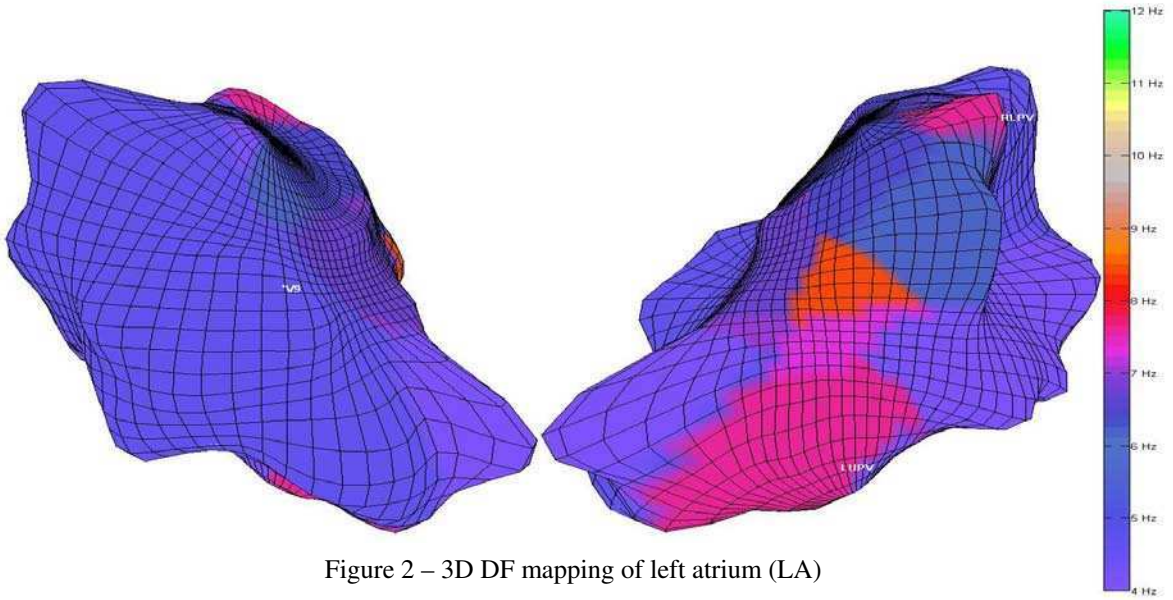

Figure 2 – 3D DF mapping of left atrium (LA)

3. Results

3.1. 3D DF mapping and movies

Figure 2 shows an example of the 3D DF mapping from 2048 non-contact unipolar electrograms of the left atrium (LA) with two different angle rotations. In this case the 3D DF mapping of LA was generated with line divisions to highlight the subareas of the atrium. The time required to generate the 3D DF maps and the corresponding AVI movie for a 20 seconds segment undergoing AF using 2048 non-contact unipolar electrograms was about 2 minutes using a personal computer (dual core 3.16 GHz, 2 Gb RAM). The visual analysis of the temporal evolution of the 3D DF mapping showed that DF evolves in size and position along time.

3.2. Movies in AVI format

Figure 3 shows a sequence of a 3D DF mapping during isoprenaline infusion and a window of its movie in AVI format.

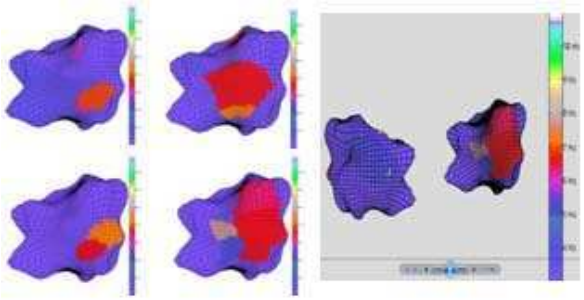

Figure 3 – (left side) Sequence of a 3D DF map during isoprenaline infusion and (right side) frame of the movie in AVI format.

3.3. Average spectrum - results

The behaviour of the average baseline spectrum before and after QRS subtraction can be observed on figure 4.

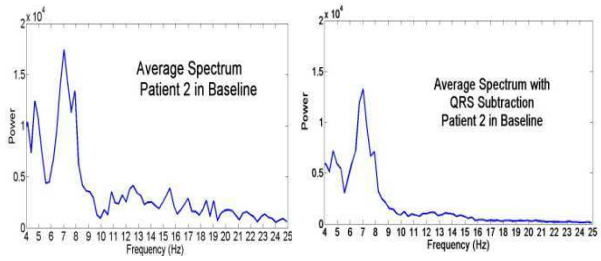

Figure 4 – Analysis of Average Spectrum for Baseline

QRS subtraction was important to reduce the spectral power in the range of frequencies above 9 Hz on the average spectrum. In addition, we confirmed the effect of drugs on DF: Isoprenaline - two wide bands with DFs on 7.6 Hz and 3.5 Hz; atropine - a narrow band with DF in 6.4 Hz, as shown in figure 5.

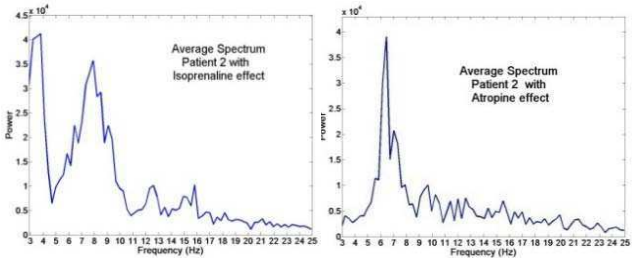

Figure 5 – Analysis of Average Spectrum for Isoprenaline and Atropine

The post ablation map was compared with the baseline in figure 6. In addition, the 3D map of the inner surface of the atrium was generated showing the places ablated in this patient with persistent atrial fibrillation.

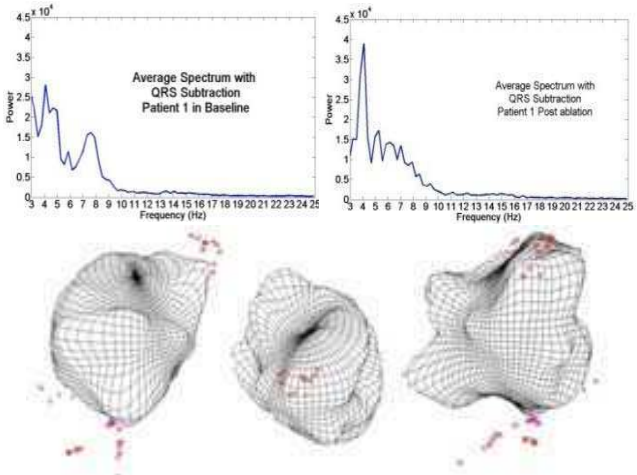

Figure 6 – Analysis of Average Spectrum for Post ablation and the 3D image of the atrium showing the places ablated together with pulmonary vein isolation.

4. Discussion and conclusions

It is expected that the use of DF mapping as a clinical electrophysiological tool to localize and terminate AF drivers by RF ablation will benefit from high resolution mapping, with multiple simultaneous electrograms and online power spectral analysis.

Using the tools described here detailed dominant frequency maps (based on 2048 channels of non-contact unipolar atrial electrograms) can be made available to the electrophysiologist in theatre during the ablation procedure, in real-time, provided that a powerful enough PC (current technology) is used.

The next stage of this project will include detailed analysis of the behaviour of the DF maps along space and time and a retrospective comparison of the DF maps and the ablation sites in successful interventions. We also intend to use mapping resulting from alternative analysis techniques (such as complex fractionated electrograms).

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