Identification of Myocardial Scar in Ventricular Tachycardia: Correlation between CT based results and Electro-Anatomic Map Findings

Sofia Antunes[1,2], Antonio Esposito[3], Giuseppe Maccabelli[4], Anna Palmisano[3], Caterina Colantoni[3], Sebastiano Colombo[4], Paolo della Bella[4], Sergio Cerutti[2], Giovanna Rizzo[1]

[1]Institute of Molecular Bioimaging and Physiology-CNR, Segrate, Italy
[2]Department of Electronics, Information and Bioengineering, Politecnico di Milano, Milan, Italy
[3]Department of Radiology and Experimental Imaging Center, Ospedale San Raffaele, Milan, Italy
[4]Department of Arrithmology, Ospedale San Raffaele, Milan, Italy

Abstract

The purpose of this work was to compare an image-based parametric myocardium mesh automatically segmented from multidetector computed tomographic (MDCT) volumes with the findings of electro-anatomic maps (EAM) constructed previously to radiofrequency ablation (RFa) procedures. The myocardium mesh presents distance information about myocardial thickness, as well as the localization of scar detected using a delayed enhanced DE-MDCT scan. Additionally, possible zones of epicardial fat with thickness greater than 3mm were also identified on patients that underwent an epicardial intervention. The comparison was performed on 5 patients with recurrent ventricular tachycardia (VT) undergoing angiographic and DE-MDCT scan before EAM and RFa, of which 3 patients underwent endocardial and 2 patients an epicardial procedure. We compared the findings of the myocardium mesh against EAM and our results suggest that the mesh could be an important tool for the prediction of myocardial scar localization.

1. Introduction

In the last years multi-detector computed tomography (MDCT) had a great development in terms of spatial and temporal resolution. For this reason, MDCT has been investigating as an important alternative to the delayed enhanced magnetic resonance imaging (DE-MRI) for the preprocedural planning and guidance of ventricular tachycardia (VT) ablation procedures. The main reasons are related to the reliability in visualizing epicardial fat distribution, the less susceptibility to implantable cardioverter defibrillator (ICD) related artefacts, as well as the higher spatial resolution when compared to DE-MRI with which we can have detailed information about the anatomy of the heart (e.g. wall and coronary arteries).

During substrate mapping of left ventricular myocardial endocardium (LVendo) or epicardium (LVepi), the myocardium needs to be mapped in terms of voltage differences. Today, bipolar and unipolar voltages are used as indexes of detection of scars (usual site for re-entry channels). However, the process is time consuming and leads to wrong maps (in terms of definition of the anatomy and scar presence); in the endocardium mainly due to bad contact with the endocardial surface and in the epicardium caused by a thick epicardial fat layer. The new technology of contact force has partially reduced in the last year the occurrence of this circumstance.

In this work, we constructed an image-based mesh of the myocardium, containing information about the myocardium wall thickness and epicardial fat depth of the correspondent angiographic scan and myocardial scarred areas from the correspondent late enhancement scan. The mesh was compared against the correspondent electro-anatomical map (EAM) findings to determine the agreement between both methods.

In the following, we present the definition of EAM and its acquisition protocol in section 2. In section 3 we describe the pre-procedure imaging acquisition protocol followed by the segmentation approach used to segment the left ventricular myocardium, epicardial fat and scar from DE-MDCT scan, as well as the mesh operations used to obtain the parametrical myocardium mesh. Finally, in section 4 we present the results from the comparison of EAM and the myocardial mesh and we discuss them in section 5.

2. Electroanatomical map

EAM of the myocardium is a fundamental tool used today to identify discrete sites that need to be ablated, in order to eliminate tachycardia [1]. For this purpose, bipolar and unipolar electric activation are used. The former is obtained by the difference between two

electrodes near the cardiac area of interest, and the latter is the voltage difference recorded between an intracardiac electrode and a reference electrode free of cardiac signal.

There are some advantages and drawbacks in each of the two measurements: bipolar recordings provide an improved signal-to-noise ratio when compared to unipolar; nevertheless, the precision of local activation is less defined. However, unipolar recordings can provide a more accurate measure of the timing of local activation. Additionally, for its intrinsic characteristics, it can better identify the presence of intramural scar not visible to the bipolar signal. However, due to the large far-field, it is less precise in giving local information of the contact point. Due to these considerations, differences in both unipolar and bipolar recordings are used to assess scar areas during EAM. An example of a EAM in bipolar and unipolar measurements is shown in Fig.1.

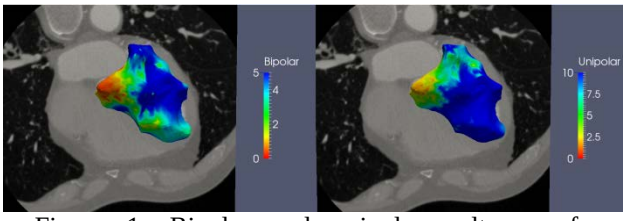

Figure 1. Bipolar and unipolar voltages of an endocardial EAM overlapped to the correspondent angiographic MDCT scan.

One issue of epicardial mapping is related to low voltage due to areas of a thick fat layer, that leads to the increase of false positives. Besides, if scar is located intramural it can also be difficult to detect such zones.

The cut off values established for EAM scar using bipolar and unipolar voltages may vary according to the protocol under study. Moreover, the best cut off value used to differentiate between the absence and presence of scar can be subject specific.

In our study, a 3.5mm distal tip irrigated catheter was used for the construction of EAM. The value of 1.5mV defined normal LVendo bipolar electrogram amplitude and a voltage < 0.5 mV defined dense scar. A value of 8 mV or higher defined normal LV endocardial unipolar electrogram amplitude. Areas with < 5mV defined dense scar and intermediate values border zones [2].

3. Parametric myocardial mesh

3.1. Clinical protocol

5 patients with recurrent VT and ICD underwent 64-slice-MDCT before EAM and radiofrequency ablation (RFa). An angiographic scan was acquired during the first pass of a high-concentration iodine contrast bolus and was followed by a low-energy (80 kV) DE scan acquired 10 minutes after the contrast media administration.

The decision of an endocardial or epicardial EAM/RFa approach was taken basing on the prevalent distribution of scars at DE-MDCT or during the failed endocardial procedure.

3.2. MDCT segmentation

The segmentation model used was a geodesic active contour [3], formulated using the level set function by the following partial differential equation:

$$\phi_t^{\,n} = g_n(I)K|\nabla\phi| - bg_n(I)\cdot|\nabla\phi| - a\nabla g_n\cdot\nabla\phi$$

with n=1,2; where the speed function includes a dependence on the curvature K, the propagation term and the advection term are weighted respectively by the constant values *b* and *a*. The edge stopping function *g* is based on a multi-scale directional edge detector *h* described in [4].

3.2.1. LV endocardium and epicardium

MDCT volumes were resliced into the short axis view and, moreover, to reduce signal to noise ratio maintaining boundary information, we applied an anisotropic diffusion smoothing [5]. The angiographic volume was thresholded based on its calibrated intensity values to obtain a rough estimation of the heart position. At 0.25 and 0.5 of the cropped heart volume a slice was extracted and segmented using a Fuzzy C Mean algorithm with 5 labels. On the label correspondent to the LV we identified seed points for the 3D region growing algorithm as described in [4]. The result of the region growing process was used as our level set initialization. After a 2-step Level set propagation with the following stopping function:

$$g_n = \frac{1}{1+e^{\left(\frac{I*h_n-\beta_n}{\alpha_n}\right)}}$$

where β_1=0.1, β_2=0.05, α_1=0.1 and α_2=0.01, we obtained the LV segmentation. On this LV structure a convex hull was applied and dilated in order to obtain our LV epicardium level set initialization. Also in this case the 2-step level set propagation was used.

3.2.2. Epicardial fat

As MDCT intensities are calibrated measures, we used the Hounsfield values of -190 to -30 as fat tissue [6] mask for the possible positions of the level set propagation surface. Using the segmentation result of the LV epicardium as initial level set, we guided the propagation using only the reduced scale (σ_x=3, σ_y=1) of the multi-scale edge detector *h*, with the form:

$$g = \frac{1}{1 + e^{\left(\frac{I*h-0.05}{0.01}\right)}}$$

3.2.3. DE MDCT scar

On DE-MDCT volumes, scar is shown as a hyper-enhanced zone when compared to normal myocardium. Taking advantage of the previously segmented myocardium, we identified those zones after registering both angiographic and DE scans. The angiographic volume was used as the reference image. Despite the two MDCT volumes under study are from the same CT scanner, the DE scan presents intensity information that does not coincide with the angiographic scan. For this reason we used the mutual information as similarity measure to deal with this diversity [7]. After a rigid registration, and due to the movements of the beating heart, we performed additionally an elastic registration, with a B-spline interpolator [8]. After registration, and because DE-MDCT has a very low signal to noise ratio, this scan was filtered using a Gaussian kernel. Using the MDCT LV segmentation as mask on the DE-MDCT scan, we calculated the mean vascular signal intensity to apply as threshold segmentation on these LE volumes.

As we are dealing with patients that present ICD, we excluded artefacted areas caused by the metallic equipment, because they are not analyzable using any tomographic imaging modality.

3.3. Surface distance measurements

After segmentation of all structures of interest, explained in the previous section, we generated each surface using a marching cubes algorithm.

3.3.1. Myocardial wall thickness

On the LVendo and LVepi surfaces we computed the correspondent convex hull. From each endocardial triangle vertex, a ray was casted outwards, and the distance to the epicardial wall was taken as the myocardium wall thickness. Zones where the thickness was less than 5 mm were considered scared areas according to [9].

3.3.2. Fat layer thickness

For each triangle vertex of the LVepi mesh, the distance from LVepi to the epicardial fat surface was mesasured, and points above 3 mm were considered as scar (based on [1]). In this way, for an possible epicardial intervention this additional information will be taken in consideration, to avoid overestimation of EPI scar on EAM due to areas of fat distribution.

4. Comparison between EAM and myocardial parametric mesh

After the catheter ablation procedure, the created EAM mesh was superimposed on the correspondent angiographic MDCT volume using the reversed registration matrix [1]. The myocardial parametric mesh, with the distance information and the scar from DE-MDCT, was compared to EAM, using a surface to surface distance error range of 3mm, due to registration errors that can occur and the fact that we are comparing a surface (EAM) with a volume (CT findings).

An example of the 3D EAM for an endocardial intervention overlapped to the imaging-based defined scar is shown in Fig 2 for the unipolar voltage.

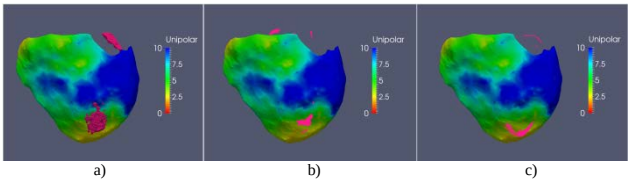

Figure 2. Unipolar voltage color-map of an endocardial EAM overlapped to a) DE MDCT scar, b) epicardial fat with thickness greater than 3mm and c) myocardial wall thinning to a value lower than 5mm, represented in pink.

For the 2 patients that underwent an epicardial intervention, fat thickness >3mm was added to the myocardial mesh to be considered as scar. 2 patients presented DE-MDCT with scar areas (1 with endocardial and the other with an epicardial intervention), that were also included in the comparison, and all 5 patients had zones with reduced myocardial thickness. In 3 patients we had more than one scar detection procedures and for these 3 cases we calculated also the characteristics of the intersection zone of more than one scar index. In Fig. 3 is shown an endocardial EAM overlapped to the imaging-based defined scar.

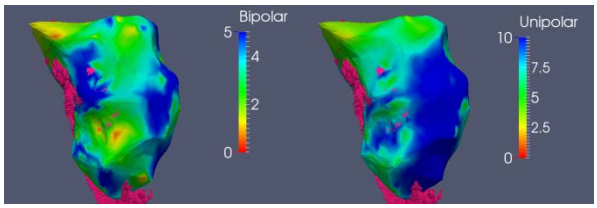

Figure 3. Bipolar and unipolar voltage color-map of an endocardial EAM, overlapped to LE-MDCT defined scar and myocardial wall thinning scar represented in pink.

In Table 1 the results of the points with low voltages present in MDCT defined scar and the mean voltage values of these areas are shown. In these results, we

compare also the union of all scar indexes, as well as each scar index separately.

Additionally, we analyzed the percentage of myocardium analyzable due to the artifacts caused by ICD, obtaining a mean percentage of myocardium analyzability value of 97,4%.

Table 1. Mean percentage and voltage measurements of EAM scar contained in MDCT defined scar.

	Union of scar	wall thick	Scar* DE	Fat** thick	Intersect ***
Bipolar < 1.5 (%)	23.0	29.7	21.1	30.3	34.5
Mean bipolar (mV)	3.0	2.8	3.1	3.2	2.4
Unipolar < 8 (%)	60.1	70.3	53.2	54.1	68.2
Mean unipolar (mV)	7.7	7.1	8.2	8.8	6.6

* only 2 patients had the DE-MDCT with scar areas (1 endo and 1 epi). ** only 2 patients had an epicardial procedure. *** 3 patients had more than one scar detection procedures.

5. Discussion

Today, DE-MRI has been widely studied as an effective way in detecting myocardial scar areas, in order to plan the strategy and to guide ventricular ablation procedures, which is universally recognized as the gold standard for this purpose. On the contrary, MDCT has been used for the definition of the anatomical landmark and for the identification of the epicardial fat, due to its higher spatial resolution during one breath-hold acquisition. In this preliminary study, we wanted to demonstrate that, besides the previously mentioned advantages, MDCT is also a good predictor of scar localization.

Being bipolar voltage a local measure, it is able to detect only superficial scared areas, on the sampled points. Since our patients have intramural and extended scars, these structures cannot be detected using bipolar voltages, and the value of 23% agreement found, reflected this. On the other hand, it was demonstrated [1] that unipolar voltage best differentiates between the absence and presence of scar, having a larger field of view, which may allow detection of scar covered by fat and intramural scar. This fact is in good agreement with our findings, where MDCT defined scar had a quite high concordance value (60.1%) with low unipolar voltage measures. Additionally, the mean unipolar value under MDCT defined scar (6.6 mV) is well in concordance with the literature, that established 8mV as the cut-off value. Moreover, we are confident that these results can be further improved, as we assumed a very low registration error. In fact, the literature has defined this range as being much larger than 5mm [1].

Thanks to these preliminary results, the proposed segmentation method and surface distance measurements could be very important for the prediction of scar localization. As a consequence, false low voltages and mapping time could be reduced in order to determine the sites to be ablated.

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Address for correspondence.
Sofia Antunes
IBFM-CNR
Via Fratelli Cervi 93,
20090 Segrate (Milano), Italy
sofigantunes@gmail.com.