

DISPLAY OF ACTIVATION FRONTS ON A 3D RECONSTRUCTION OF THE LEFT ATRIUM OF A DOG HEART

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Abstract— A 3D reconstruction of a 197-lead multiterminal electrode in the shape of the left atrial cavity of a dog heart was made using a CT scan and software was designed to interactively determine local activation times and display these onto a 3D representation of the multiterminal electrode.

INTRODUCTION

Clinical studies suggest that the pulmonary veins play a key role in the genesis of atrial fibrillation in a number of patients [1], [2]. To investigate the role of the pulmonary veins in the genesis of atrial fibrillation, endocardial mapping of the electrical activity was carried out in the left atrium of a dog. An anatomically correct multiterminal electrode was designed that covers most of endocard of the left atrium and extends into the pulmonary veins, see figure 1. This multiterminal electrode with a highly curved surface can, however, not be mapped onto a 2D display without losing important information about the spatial relationship between the electrodes. An estimation of the velocity of the wavefront from a planar representation e.g. would be impossible.

METHODS

A silicone cast was made of the left atrium of a dog heart. This cast was covered with a layer of glue. After cutting the cast into two and removing the silicon, thin silver wires ($76\ \mu\text{m}$) were pulled through the cavity. The halves were pressed together and the assembly refilled with a resin. After cutting the wires at the surface a multiterminal electrode resulted, that was shaped according to the canine's left atrium and that contained 197 leads.

For this study mongrel dogs weighing 25–30 kg were used. Hearts were Langendorff perfused with a blood-Tyrode mixture. The multiterminal electrode was inserted into the left atrium through the mitral valve via an incision in the left ventricular lateral wall.

All signals were recorded with a 256-channel data-acquisition system (SVRA256, Stichting Vision Research

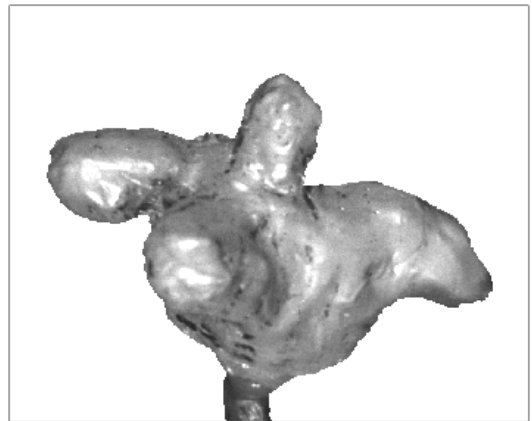


Figure 1. A photograph of the multiterminal electrode. The terminals of the electrode can not be distinguished at this magnification. The wires of the electrodes leave through the tube at the bottom.

Amsterdam, the Netherlands)[3]. This equipment has a maximum sample rate of 4 kHz and a resolution of 16 bits at $1.9\ \mu\text{V}$ per bit.

Reconstruction of the multiterminal electrode

A helical CT-scan was made of the electrode with an Elscint CT-Twin/Flash (Elscint Inc., Hackensack, NJ) CT-scanner. Reconstructions were made with a pixel-size of 0.2 by 0.2 mm and a distance between slices of also 0.2 mm. After some preprocessing the surface of the electrode was detected in the stack of slices with a deformable triangulation model. The final triangulation which optimally describes the boundary of the electrode, has an average surface of about $0.6\ \text{mm}^2$ per triangle. The surface of the electrode was detected by placing a tetraeder in the middle of the multiterminal electrode and inflating this until the border of the object was hit, see figure 2). During the inflation two neighbouring triangles were split into four smaller triangles whenever the surface of the triangles exceeded $4/3$ times $0.6\ \text{mm}^2$. Every 20th iteration the mesh was regularized by volume preserved averaging and Delaunay triangulation to enhance the uniformity of

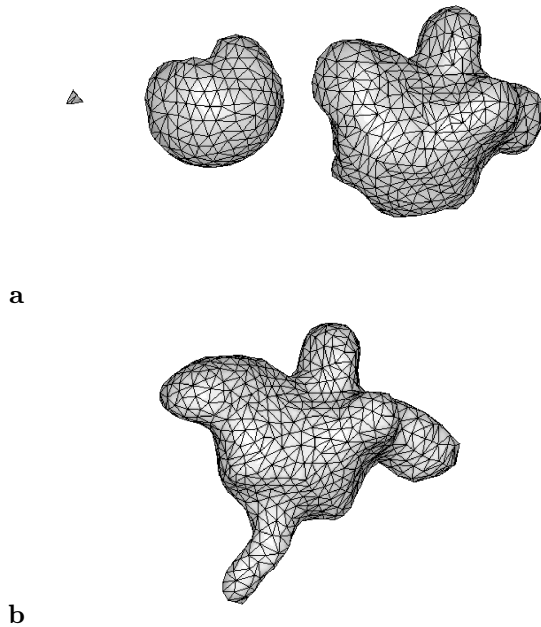


Figure 2. Partially **a** and fully **b** inflated mesh of the multiterminal electrode.

the triangles.

After the inflation process the triangular mesh had approximately the shape of the multiterminal electrode. Starting from this mesh a closer approximation was generated by moving all vertices in the direction of the local mean surface normal such that an energy function was minimized. The energy function included both local density gradients in the CT slices to pull the surface as close as possible to the physical object and contributions of the local bending energy to smoothen out noise in the CT slices.

In the original CT slices the voxels were identified that contained the silver wires. The voxels closest to the surface were selected as the approximate position of the electrodes. These positions were projected onto the mesh. The mesh and the electrode positions were visualized with MATLAB software (The Mathworks inc, Natick MA USA). Careful comparison of rendered and actual object enabled us to identify all the electrodes with their channel number in the amplifier. The next step was to generate a new mesh that contained all the vertices of the original mesh and all the electrodes, see figure 3a. The area with electrodes does not cover the entire left atrium. The area in the vicinity of the valves is not sampled nor is the auricle. Electrodes are present up to a few millimeter into the pulmonary veins. To allow interpolation within the area covered by the electrode terminals but no extrapolation outside this area, another set of points was added to the mesh. These points were chosen along the border with a distance of approximately $1/\sqrt{3}$ times the mean area of

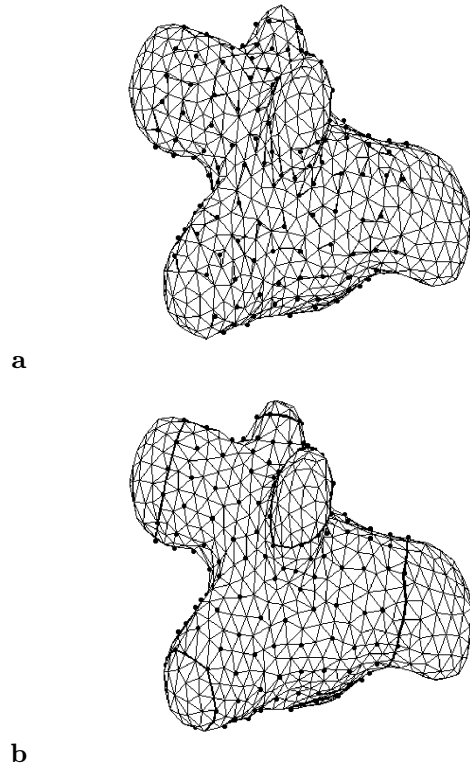


Figure 3. Mesh and electrodes before **(a)** and after **(b)** regularization of the mesh. Dots indicate the positions of the electrodes. The thick lines in the mesh after regularization indicate the border inside which interpolation is possible.

the triangles. This new mesh was regularized by Delaunay triangulation and volume preserved averaging under the restriction that none of the newly added points was allowed to change. The result was a new mesh with triangles that are as equilateral as possible and have all nearly the same size. Moreover all electrodes are part of it and also the choice of the border points forced the border to be well defined, see figure 3b.

Regularization of the mesh

Many operations on a mesh, such as interpolation of a function over the vertices, are best performed if the triangles in the mesh have approximately the same size and are more or less equilateral. Moreover when displaying the grid the 3D impression is enhanced. When adding points during the inflation to keep the average surface of the triangles constant, the mesh can evolve into an object with triangles that deviate much from the target equilateral triangles. To regularize the mesh every point is moved in such a way that all triangles connected to the point have as equal an area as possible. Because moving points unrestrictedly in 3D space can distort the image another restriction is that the total volume of the pyramid made

of the triangles connected to the point may not change. While moving the points around, at the same time it was made sure that the mesh continued to be a Delaunay triangulation.

MAP_LAB

Display and analysis of the recorded ECGs was done using MATLAB software. A program was written that could display information such as potentials and isochrones on the 3D surface. An interface to an existing multichannel ECG analysis program, MAP_LAB[4], that also used MATLAB as a basis, was constructed. This package provides standard tools for displaying scalar signals, automatic activation detection and facilities to edit the timing on a lead by lead basis. It also allows the selection of a lead from the 3D representation by double clicking on a displayed electrode. The 3D representation of the data can be rotated in all directions to get a good view of the data. Changes in e.g. the timing of an activation are immediately reflected on the 3D surface using pseudocolormaps for isochrone display.

MATLAB also allows the batch generation of stills, that can later be combined to movies. This could be used to generate a movie of a rotating object to quickly familiarize people with the display format. We did also generate a movies of atrial fibrillation, which gives a good and illuminating overview of what atrial fibrillation is.

CONCLUSIONS

MATLAB and our own toolbox MAP_LAB proved to be an ideal environment to process the electrophysiologic data and to visualize the results on irregular surfaces.

To be able to display isochrones on an anatomically correct atrium requires a combined effort by a large group. Necessary contributions come from the mechanical engineers for making the multiterminal electrode, electrical engineers that make excellent hardware for very large number of channels, computer scientists to generate the required meshes, and to make the visualization programs and analysis software, and the physicians that process the data.

ACKNOWLEDGEMENT

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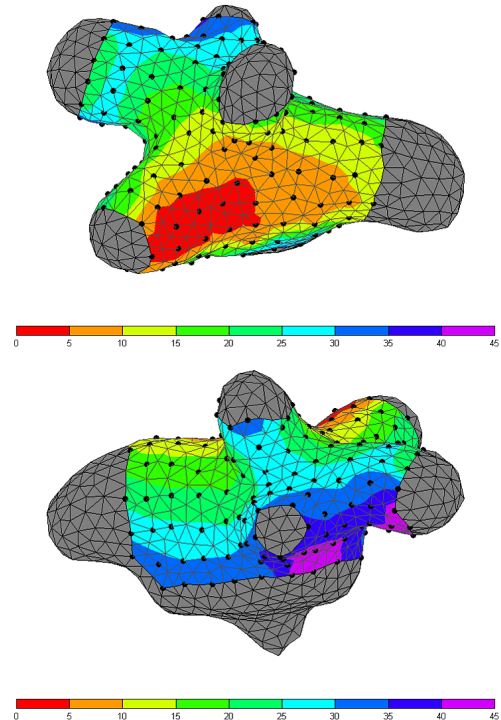


Figure 4. Two views of multiterminal electrode with superimposed isochrones. Times of the isochrones are in milliseconds.

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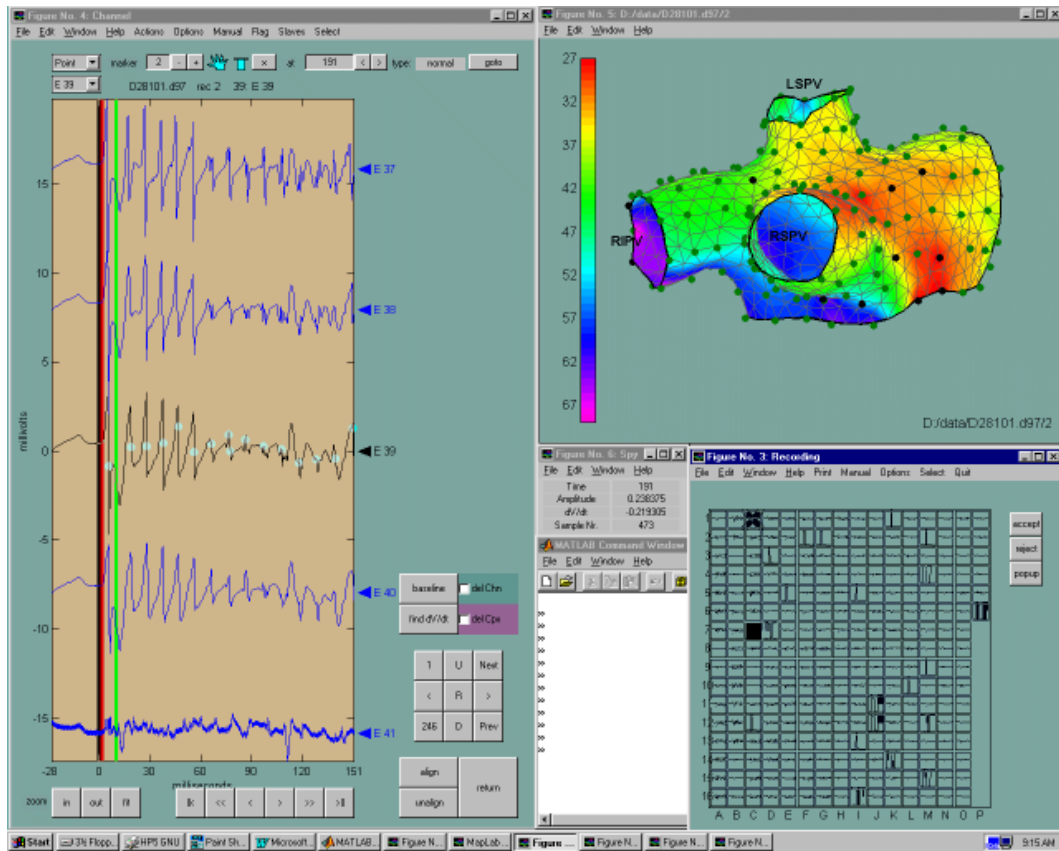


Figure 5. The MATLAB screens that allow editing of activation times and simultaneous display of pseudocolor isochrones onto the 3D surface. The window on the left contains 5 channels, the middle is used for designating the activation times, indicated by the dots. The other four serve as a reference to help distinguish real activation from remote activation. The window at the top right shows the pseudocolor isochrones in 3D, this shows only the area inside the borders as indicated by the lower part of figure 3. The dots indicate the electrode positions, double clicking will change the current channel to that electrode. The 3D figure can be grabbed with the mouse and rotated by hand to get the best possible view on the region of interest. In the middle is a small window that displays information (amplitude, derivative and distance to a zero reference) about the current sample in the current channel. The window in the lower right displays all channels with the current channel in reverse. Clicking on any channel in this window will make this the current channel. Also in view (partly obscured at the bottom, middle) is the MATLAB command window that can be used to type commands.