# A Fiber Orientation Model of the Human Heart Using Classical Histological Methods, Magnetic Resonance Imaging and Interpolation Techniques

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## Abstract

*We present a cardiac model of post-mortem heart that can be applied to quantitative analysis of electrocardiologic problems. Two adult postmortem hearts in the systolic state were photographed and then were subjected to MRI scanning. Hence, anatomical slicing was performed using an automatic cutter that created 3mm thick sections. The first one dissected vertical to its longitudinal axis, and the second one at the sagittal plane. Each section was further diced into smaller specimens for further histological process. All the microscopic slides were digitized in order to be used for histological sections reconstructing. The need to define the fiber orientation led us to create a specific drawing package in MATLAB® called FiberCad. For each point of the extracted model, information of the electrical characteristics and the prevalent fibers' orientation can be accurately modeled.*

## 1. Introduction

The investigation of myocardial microscopic architecture springs both from the intrinsic human need to gain a better understanding of human anatomy and from the long held view that cardiac anatomy and cardiac physiology are intrinsically and uninterruptedly interacting with each other.

Recently it became evident that myocardial anatomical modeling should be included in the medical and surgical therapeutic strategies. Indeed, cardiac restoration of ventricular geometry, a modern surgical treatment for heart failure, should be carefully planned based on the analysis of the loss of optimal fiber orientation and geometry that characterizes the diseased ventricle [1].

Myocardial fiber orientation (including its variations) has a substantial impact on excitation wave front propagation on the intact heart [2] and it is implicated in the generation and maintenance of ventricular arrhythmias [3]. Furthermore, the myocardial organization is, potentially, a major factor in the electrical current distribution during defibrillation shocks, substantially affecting their therapeutic success [4].

Our reason for investigating myocardial structure initially derived from our involvement with the so-called "forward" and "inverse" problems of electrocardiography [5]. The electromagnetic field that the heart generates is the result of numerous elementary dipolar excitations corresponding to the excitation of the individual myocardial fibers. Therefore, the knowledge of cardiac microstructure (fiber density and orientation) is necessary for an accurate description of the field source and a prerequisite for any large scale simulation of the electrical and mechanical behavior of the heart [6]. The cardiac anisotropy, which is directly related to its microstructure affects the generation of body surface potentials in two respects: first, the anisotropic conduction of the cardiac action potential and second, the anisotropic distribution of the electrical conductivity of the heart tissue [7]. This leads to the hypothesis that cardiac anisotropy significantly affects the propagation of excitation wave fronts within the ventricles irrespective of the fact that its effect on the inverse solution from Body Surface Potential Mapping is tolerable [8].

In this paper we present a cardiac model of post-mortem heart that can be applied to quantitative analysis of electrocardiographic and cardiomechanical problems.

## 2. Methods and Results

Two adult postmortem hearts in the systolic state were obtained following appropriate procedures from the Department of Forensic Medicine and Toxicology of Aristotle University of Thessaloniki and filled with fixing

fluid. The post mortem heart donor personal medical history was free of cardiovascular disease. Before imaging, the hearts was photographed with a digital camera (Sony 3,2 Mpixel). MRI imaging was performed using a superconducting 1.5 T clinical scanner (Intera, Philips Medical Systems, Best, The Netherlands) with cardiac software (v.9.0.3) and a 5-element phase-array coil (Fig 1).

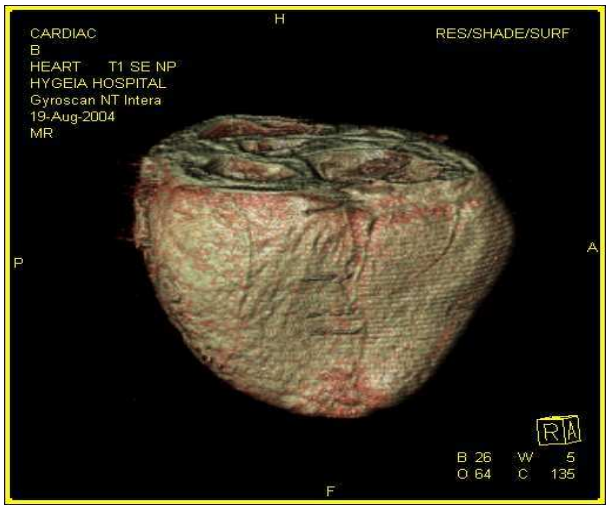


Figure 1: 3D MRI reconstruction of post-mortem heart.

Transverse, sagittal and coronal images at section thicknesses of 1 mm were obtained. Slicing was done with an automatic slicing machine with a large circular-sharp knife that automatically shaved the heart, into equal thick sections after adjustment for required dimension. We chose to section the one postmortem heart vertical to its longitudinal axis, from the apex to the base, and the other at the sagittal plane, from the right to the left ventricle, into 3 mm thick sections. All the anatomical sections were numbered (according to the order of their sectioning) and photographed (Fig 2).

Each anatomical section was further cut into smaller specimens that could be enclosed within histology cassettes so that would be ready for further processing. Each specimen was numbered as follows: the first capital (A or B) corresponded to first or second heart respectively, the first number to anatomical section and the second number to each specimen (in proportion to the sequence of its dissection that made by clockwise direction).

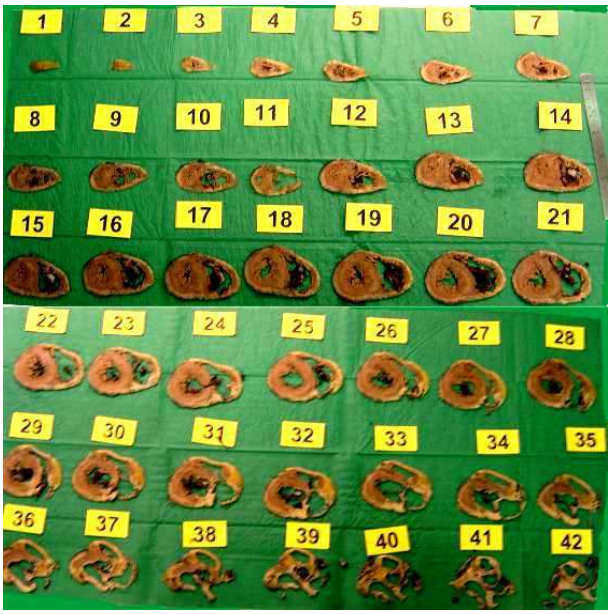


Figure 2: Histological sections of the second heart (from apex to base).

Therefore, the specimen numbered A3-5 corresponds to the specimen of the first heart, of the third section and it was the fifth specimen that sectioned at the clockwise direction. During the dissection we drew on paper the outline of anatomical sections and the position of specimens on them, so that reconstruction of histological sections could be possible at a following stage. All specimens were subjected to the following preparation in order to be ready for light microscopy: fixation (using 10% neutral buffered formalin), dehydration (was done with a series of alcohols $70^0$- $80^0$- $90^0$ and $100^0$), clearing (as clearing agent used xylene), embedding (in paraffin, using TBS88 MEDITE tissue embedding system), sectioning (tissue paraffin blocks was cut with a MICROM 340E microtome in sections of 3 μm and then mounted onto microscopic slides) and staining (hematoxylin eosin stain, using MEDITE COT 204 slide stainer). Dehydration and clearing were done simultaneously using a BAVMED 2050 tissue processor.

Following this proceeding, all the microscopic slides were digitized using a Microtek 9800 XL with TMA scanner which offers a transparency media adapter for scanning film. Each microscopic slide was scanned as a film and high quality scans at 1200 dpi optical resolution and 48-bit color were obtained. The digitization of microscopic slides was essential prerequisite for the following histological section reconstruction that was achieved using Adobe Photoshop CS2®, with the guidance of the anatomical sections sketch and their photos (Fig 3).

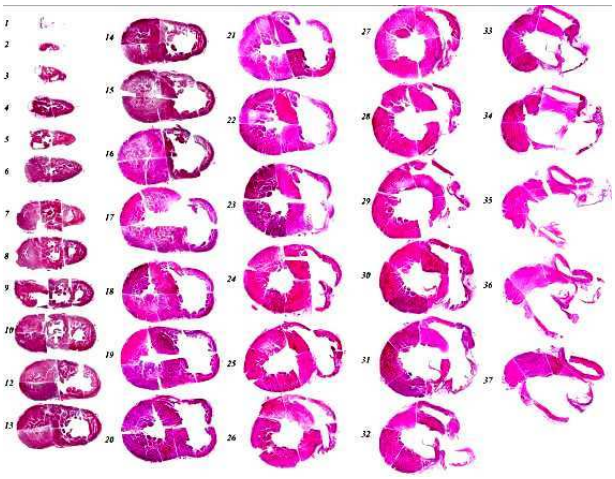

Figure 3: The histological sections reconstruction using Adobe Photoshop CS2®.

The need to define the fiber orientation led us to create specific software in MATLAB® called FiberCad. FiberCad is a drawing package especially designed for our needs. In this software the user has to load a single high resolution image of the elaborated histological sections. In each single histological slice, the boundaries of the tissue have to be determinated and then the program allocates, with a random algorithm, dotes (their number are predetermined by the user) within the bounded area. Finally, the user can define and draw (with the assistance of optical microscope when necessary) the parallel and vertical fibers with respect to this plane, starting from an existing randomly placed point.

We estimated myocardial fiber orientation, with the method mentioned above, using FiberCad. A very good estimation of fibers orientation in most regions of each slice was achieved (Fig 4). The circled dots correspond to the fibers that are vertical to the sectioning plane (transverse for the first post-mortem heart and sagittal for the second one). The drawing vectors correspond to the fibers with orientation on the sectioning plane. Therefore a 3D interpolation has been performed and the fiber orientation has been defined in the whole structure.

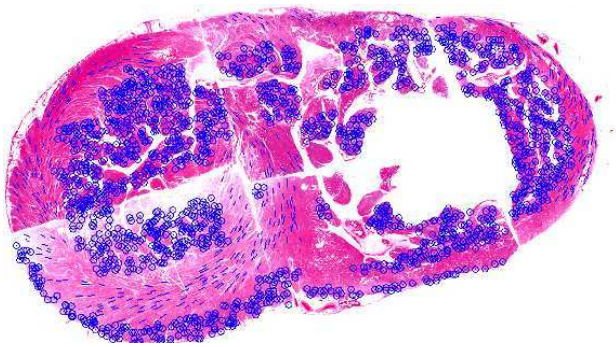

Figure 4: Example of fiber orientation estimation achieved using FiberCad.

The interpolation procedure that was used in order to define the fiber orientation in a level among histological slices is described in Fig 5. First the cuts of two successive slices with a predefined anatomical axis of the heart have been defined. Then starting with this cut-point each slice is separated every N (0.5) degrees and in M (40) zones creating totally 360/N * M (720*40=28800) nodes. For each slice, the nodes are counted in same manner and while the discretization is very dense we can assume that fiber on node *in* in slice 1 is the continuation of fiber on node *in* in slice 2. Finally starting from the fiber on slice1 we move – rotate and scale the fiber until it matches with the one in slice 2. In this way we can define all the fibers at any interstage slice.

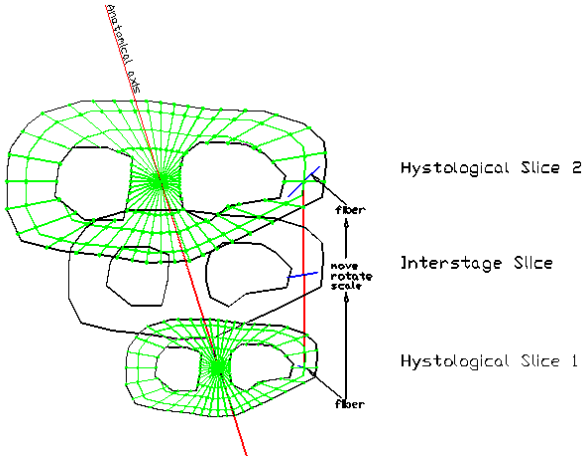


Figure 5: The interpolation procedure.

Unfortunately, the tissue in the scanned images derived from histological slices is arbitrarily located and the 3d reconstruction can not be directly achieved. This problem can be solved by means of the MRI data. Selecting three characteristic points on the tissue, in a histological image, and the respective MRI slice, the program rotates and moves the first image so that it coincides with the second one. Hence, the histological slices have now been appropriately located in space.

In order to complete our work another program called MRIcad has been designed. MRIcad is a semi-automatic (semi since edge detection techniques like canny can be applied) program in which each slice of the heart can be separated in several regions. Then after the completion of this procedure for all the slices a 3D high quality tetrahedral mesh (high quality: means that the ratio of edges for each tetrahedral is near to 1) can be exported. In this way for each tetrahedron the nearest fiber to its barycenter can be easily defined since the fiber orientation at any location in known.

## 3. Conclusions

We have designed a full software package in order to create an advanced 3d reconstruction of a heart. For each point of the extracted 3D model, information of the electrical characteristics and prevalent fiber orientation was defined (Fig 6).

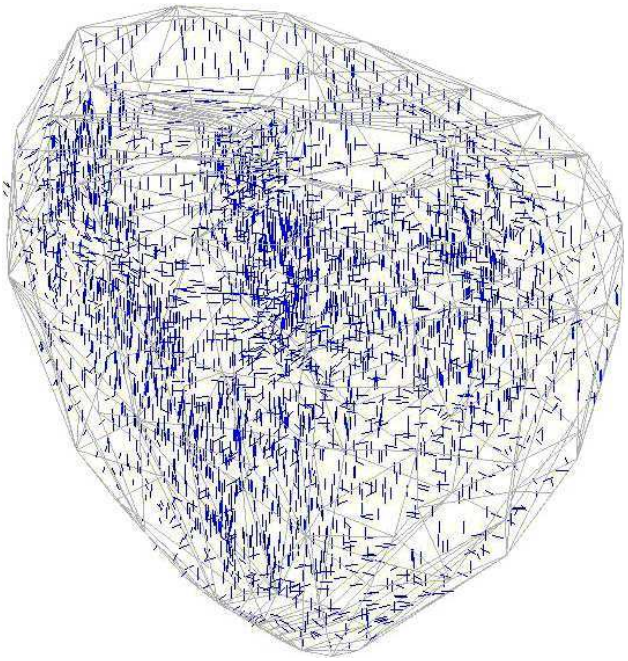

Figure 6: The 3D fiber orientation model: each tetrahedron of the high-quality mesh (that was created in MRICAD) contains one only vector. This model is ready to be implemented in forward and inverse problems of electrocardiography.


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