Modeling the Anatomy of the Human Heart Using the Cryosection Images of the Visible Female Dataset

F. B. Sachse[1], C. D. Werner[1], M. H. Stenroos[1], R. F. Schulte[1], P. Zerfass[2], O. Dössel[1]
[1]Institut für Biomedizinische Technik, Universität Karlsruhe (TH), Karlsruhe, Germany
[2]Center of Advanced European Studies and Research, Bonn, Germany
E-mail: Frank.Sachse@ibt.etec.uni-karlsruhe.de

Abstract

Anatomical models of the human heart describe the distribution of tissue including the orientation of fibers and sheets. These models are the foundation for the simulation of the electrophysiological and mechanical cardiac behavior. These simulations help to improve diagnostic and surgical techniques as well as the medical education.

In this work the cryosection images of the Visible Female dataset and a variety of digital image processing techniques were applied to achieve a realistic, highly detailed anatomical model of the heart. The model is stored in a three dimensional data set consisting of approximately 80 million cubic voxels. Each voxel has a size of 0.33 mm x 0.33 mm x 0.33 mm and was assigned to one out of 20 different tissue classes.

The incooperation of the myocardial fiber and sheet orientation makes the model of interest for applications in the scope of numerical field calculation. The model can be applied eg in the area of elasto- and fluidmechanics as well as electrophysiology of the human heart.

Keywords Anatomical Model, Heart, Preprocessing, Segmentation, Fiber Orientation, Lamination, Visible Female

I. Introduction

Computer-based anatomical models of the human heart are the foundation for the simulation of the electrophysiological and mechanical cardiac behavior. These simulations help to improve diagnostic and surgical techniques as well as the medical education.

Anatomical models consist of information concerning the distribution of tissue including the orientation of its fibers and sheets. The inclusion of fiber and sheet orientation allows the simulation of anisotropic behavior, which is significant eg for the electrical excitation propagation and elastomechanical deformation.

Commonly, anatomical models of the heart are created outgoing from medical tomographic images applying techniques of digital image processing. In this work the photographies of the Visible Female dataset were used to derive a realistic, highly detailed heart model. A variety of digital image processing techniques were applied to achieve an anatomical model. The model includes the orientation of fibers and sheets of the myocardium.

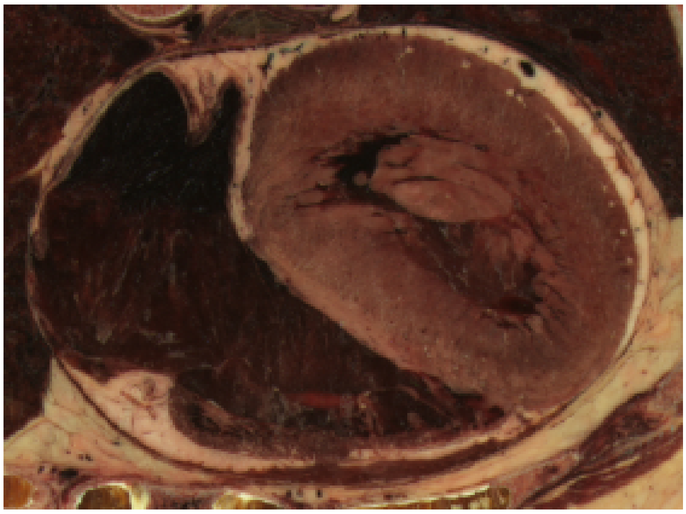


Figure 1. Exemplary cryosection of the Visible Female data set with a transversal view of the cardiac region.

II. Material

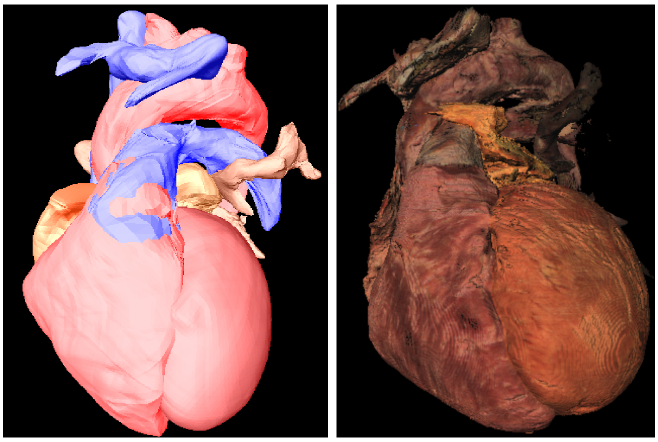
The foundation of this work are the cryosection images of the Visible Female dataset provided by the National Library of Medicine, Bethesda, Maryland (USA) [1]. The images are part of the Visible Human Project and show transversal views of the cadaver of a 59 year old woman. Each image consists of 2048 x 1280 pixels with 24 bit color information (see figure 1).

III. Preprocessing, Segmentation and Classification

The stack of 2D cryosection images was preprocessed to obtain 3D-data sets. Therefore, the images were converted and combined with techniques also used for the preprocessing of the Visible Man data set [2]. Missing areas in the Visible Female data are interpolated with usage of radial basis functions.

The 3D-data set was segmented and classified using different techniques of digital image processing, eg interactively deformable contours, thresholding, region growing, and morphological operators [3][4]. The boundaries of the atria, ventricles and pericardium were constructed using interactively deformable contours [5]. The initial contours were manually placed, oriented and scaled.

The boundaries of the atria and ventricles serve as a mask for thresholding in the 3D-data sets to classify blood,



(a) (b)

Figure 2. Frontal view on the heart of the Visible Female. (a) Interactively deformed contours are used to construct boundaries. The boundaries serve for the further processing of the cryosection images. (b) Result of segmentation and tissue classification.

myocardium and other tissue. Further anatomical structures, eg the aorta, the truncus pulmonalis and coronary vessels, are segmented with region growing techniques. Minor fail assignments were eliminated with morphological operators. Therefore, sequences of median filtering as well as opening and closing operators were executed.

IV. Rulebased Assignment of Orientation

In this work the orientation and lamination of myocardial fibers is defined in a macroscopic sense. The determined fiber orientation can be viewed as the averaged macroscopic orientation of the principal axis of myocytes. The lamination is described by the averaged macroscopic orientation of fiber sheets in conjunction with the fiber orientation. Hereby, the region of averaging is the cubic voxel of the anatomical volume dataset.

The orientation of myocardial fibers and sheets was interpolated based on sets of restrictions. The sets of restrictions were determined with automatic methods inside and on the surface of myocardial structures. For each structure an individual rulebased method was chosen. For the atria the method delivered fiber orientations, for the ventricles the method delivered orientations of fibers and sheets.

The rules were derived from anatomical studies [6][7][8][9][10][11][12], which examine the fiber and sheet orientation for the different anatomical structures in the heart. Two types of restrictions were used:

- points and their associated orientation
- points and an associated normal of orientation

Methods to adapt restrictions to anatomical variations were developed [13].

Information from the anatomical model was used for the interpolation of orientations. The interpolation was limited to areas of myocardial structures. The interpolation of the atria and ventricles was performed sequentially [14].

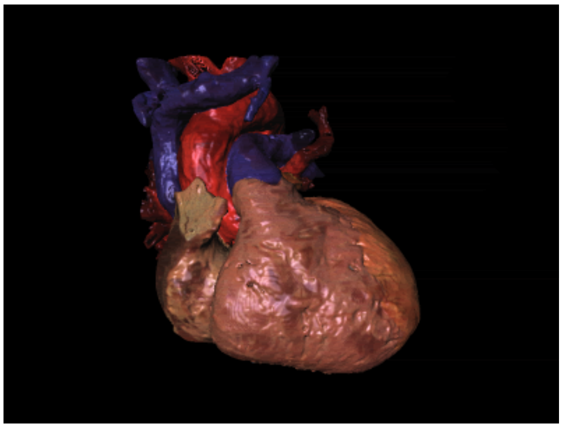


Figure 3. Anatomy of the heart from lateral. The atria and ventricles are colored stemming from the Visible Female dataset. Venous and arterial vessels are colored in blue and red, respectively.

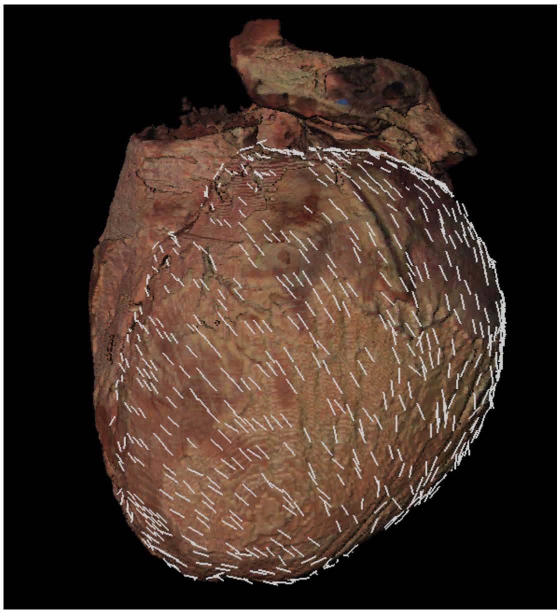


Figure 4. 3D visualization of heart with left ventricular fiber orientation from anterior lateralis. The white lines depict the macroscopic averaged orientation of the ventricular myocytes.

V. Results and Conclusions

The anatomical model is illustrated in figure 2. It was stored in a three dimensional data set, which consists of approximately 80 million cubic voxels. Each voxel has a size of 0.33 mm x 0.33 mm x 0.33 mm and was assigned to one out of 20 different tissue classes, eg left and right ventricle, left and right atrium, arterial and venous blood, and fat as well as different kinds of vessels.

The fiber and sheet orientations were stored in a three dimensional data set, with the same dimensions as the dataset of the anatomical model. For each voxel three angles are stored ranging from 0 to 180 degrees.

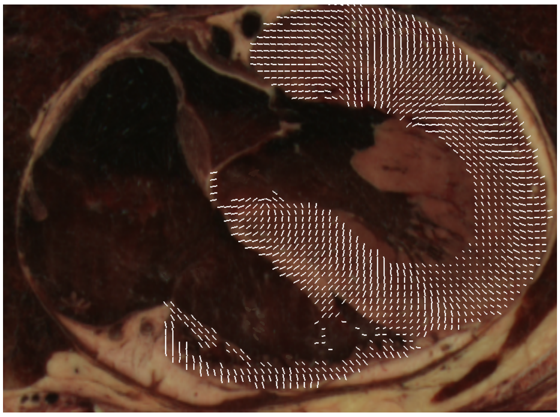


Figure 5. Sheet orientation of the left ventricle. A transversal slice is shown from superior.

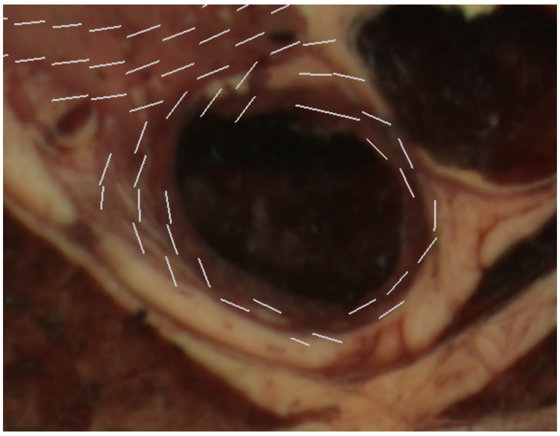


Figure 6. Truncus pulmonalis with fiber orientation. A transversal slice is shown from superior.

The anatomy of the heart is visualized including the fiber and sheet orientation. The movie 3 shows the created anatomical model. The figure 4 shows the anatomy of the heart and the orientation of left ventricular fibers. The figure 5 shows a transversal view of the orientation of sheets in the ventricular myocardium. Figure 6 shows a transversal view of the orientation of the fibers in the truncus pulmonalis.

The high resolution and the derived detailed description of the anatomy enhances the repertoire of anatomical models of the human heart. Particularly, the incooperation of the myocardial fiber and sheet orientation makes the model of interest for applications in the scope of numerical field calculation. The model can be applied in the area of elasto- and fluidmechanics as well as electrophysiology of the human heart. Therefore, a change of the model representation might be necessary, eg to surface and irregular volume meshes.

VI. Acknowledgments

The presented work is supported in parts by the SFB 414 "Information Technology in Medicine: Computer- and Sensor-based Surgery".

References

[1] M. J. Ackerman, "Viewpoint: The Visible Human Project," *Journal Biocommunication*, 18, 2, 1991, 14.

[2] F. B. Sachse, C. D. Werner, M. Müller, and K. Meyer-Waarden, "Preprocessing of the Visible Man dataset for the generation of macroscopic anatomical models," in *Proc. First Users Conference of the National Library of Medicine's Visible Human Project*, 123–124, 1996.

[3] R. C. Gonzalez and R. E. Woods, *Digital Image Processing*. Reading, Massachusetts; Menlo Park, California: Addison-Wesley, 1992.

[4] F. B. Sachse, M. Glas, M. Müller, and K. Meyer-Waarden, "Segmentation and tissue-classification of the Visible Man dataset using the computertomographic scans and the thin-section photos," in *Proc. First Users Conference of the National Library of Medicine's Visible Human Project*, 125–126, 1996.

[5] P. Zerfass, F. B. Sachse, C. D. Werner, and O. Dössel, "Deformation of surface nets for interactive segmentation of tomographic data," in *Biomedizinische Technik*, 45-1, 483–484, September 2000.

[6] W. A. McAlpine, *Heart and Coronary Arteries.* Berlin: Springer, 1976.

[7] R. H. Anderson and A. E. Becker, *Anatomie des Herzens.* Stuttgart: Georg Thieme Verlag, 1982.

[8] P. Nielsen, I. LeGrice, P. Hunter, and B. Smaill, "Mathematical model of geometry and fibrous structure of the heart," *American Journal of Physiology*, 260, 1991, H1365–H1378. Heart Circ Physiol. 29.

[9] I. J. LeGrice, B. H. Smaill, L. Z. Chai, S. G. Edgar, J. B. Gavin, and P. J. Hunter, "Laminar structure of the heart: Ventricular myocyte arrangement and connective tissue architecture in the dog," *Am J Physiol*, 269, 1995, H571–H582.

[10] I. J. LeGrice, P. J. Hunter, and B. H. Smaill, "Laminar structure of the heart: A mathematical model," *Am J Physiol*, 272, 1997, H2466–H2476.

[11] K. Wang, S. Y. Ho, D. G. Gibson, and R. H. Anderson, "Architecture of atrial musculature in humans," *British Heart Journal*, 73, 1995, 559–565.

[12] R. H. Anderson and S. Y. Ho, "The architecture of the sinus node, the atrioventricular conduction axis, and the internodal atrial myocardium," *Journal Cardiovasular Electrophysiology*, 9, 1998, 1233–1248.

[13] F. B. Sachse, R. Frech, C. D. Werner, and O. Dössel, "A model based approach to assignment of myocardial fibre orientation," in *Proc. Computers in Cardiology*, 145–148, 1999.

[14] F. B. Sachse, M. Wolf, C. D. Werner, and K. Meyer-Waarden, "Extension of anatomical models of the human body: Three dimensional interpolation of muscle fiber orientation based on restrictions," *Journal of Computing and Information Technology*, 6, 1, 1998, 95–101.