Geometrical Modelling of the Fibre Organization in the Human Left Ventricle

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Abstract. The aim of the present study is to check, by means of elementary mathematical tools, a conjecture according to which myocardial fibres are geodesic curves running on some surfaces. This conjecture was first stated and experimentally checked by Streeter (1979) for the equatorial part of the left ventricle free wall. Quantitative polarized light microscopy provides measurements on fibre orientation that could lead to evidence that the conjecture remains true for the whole of the left ventricle. Study of the right ventricle is under progress.

1 Introduction

It is commonly believed [3] that the myocardium design and structure allow maximal mechanical efficiency in the systole and diastole processes. The long-term purpose of our multi-disciplinary approach is to try and propose a model for the mechanical behaviour of the myocardium. In the long run, performance of the complete electro-mechanical system could be analyzed. For related works, see [1], [7]. It is well known that usual mechanical models for skeletal muscles are of no help for the myocardium. Obviously, the myocardium is not, as ordinary muscles, linked at both ends to a bone. Fibre micro-structure and fibre geometrical organization are quite different as well. We believe that the specific fibre organization in the myocardium should be taken into account in a complete model. Numerous anatomical studies, see *e.g.* [8], [9], have been devoted along the years to a description of the fibres arrangement and we refer to [5] for an extensive bibliography. What will be sufficient to recall here is that the dissection or peeling techniques are not precise enough, since apparently preferred fibre directions can be inferred by the experimental process. Data have been improved by means of several techniques in microscopy, such as photonic or electronic microscopy. In the present work, we use the data provided by the polarized light microscopy devices developed by some of the authors [4], [5].

More precisely, we intend to check the geometrical description proposed by Streeter [9] who introduced a topological representation of the left ventricle

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as a “nested set of toroidal bodies of revolution” on which myocardial fibres run as geodesics. This information would increase our understanding of the biomechanical properties and propagation of electrical stimuli in the heart.

The experimental technique, which is valid for both ventricles and for the septum, measures for a set of points located on several myocardial sections two angles from which the fibre orientation can be deduced. In other terms, the output of the experimental work is a discrete three-dimensional vector field. Assuming that the left ventricle has a structure of revolution, we use the invariance of Clairaut’s constant along geodesics as a first hint that the conjecture might be true.

Work under progress is devoted to a similar description of the right ventricle. Note however that the simple structure of revolution of the left ventricle is no longer true for the right ventricle.

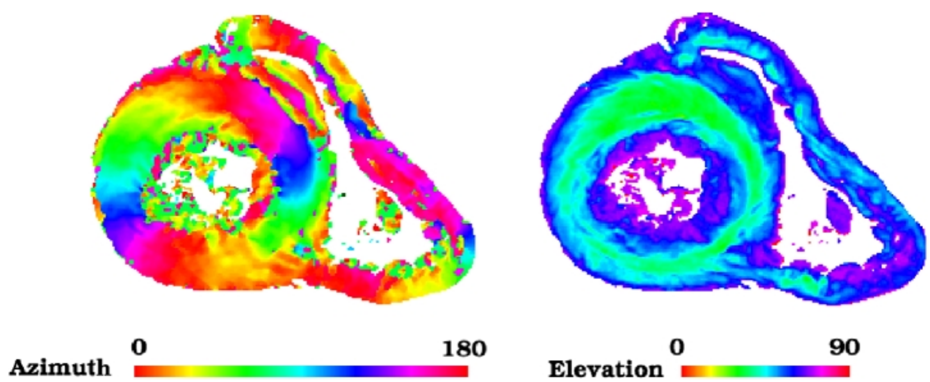

Fig. 1. Maps of the azimuth and elevation angles obtained by means of polarized light microscopy in a coronal section.

2 Data

The data are obtained on fetal hearts. We refer to [4] and [5] for a complete description of the protocol. Let us just recall that the ventricles are embedded in a transparent resin in which they can be clearly seen after polymerization. Sections that can be transversal, sagittal or coronal can then be cut. A section thickness is $500\mu m$, and, because of the thickness of the saw, adjacent sections are separated by a $250\mu m$ gap. The measurement technique relies on the birefringence properties of myocardial cells: in short, the velocity of the light is slower when travelling along the long axis than along the short axis of the fibre. Results are given pointwise: each section is dicretized in $130\mu m \times 130\mu m$ squares, and a mean angular information is collected for each of these elementary squares. For each voxel, the acquisition and representation processes result in two angles: