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The Integrated Heart - a progress report on the Cardiome project.

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Abstract **- The Physiome Project, which aims to use anatomically and biophysically based modelling as a basis for physiological understanding, is gaining momentum in several areas. The cardiac physiome project - the *Cardiome Project* - involving a number of research groups around the world, is an attempt to provide an integrated model of the heart, incorporating electrical activation, mechanical contraction, energy supply and utilisation, cell signalling and many other biochemical processes. This talk will describe current progress on the following aspects of the cardiome project: database developments, model developments and visualisation.**

I. DATABASE DEVELOPMENTS

An important aspect of the Physiome Project is the development of standards and tools for handling web accessible data. The decision has been made to base all data storage on the newly approved XML standard (Xtensible Markup Language - see http://www.w3c.org/). XML files contain tags identifying the names, values and other related information of model parameters whose type is declared in associated DTD (Data Type Definition) files. A set of tools called XQL is designed to issue queries to database search engines to extract relevant information from XML documents (which can reside anywhere on the world wide web). The display of information in web browsers is controlled by XSL (XML Style Language) files. Our initial focus has been on two types of XML documents - 'CellML' contains the parameters for models defining cell function (electrophysiology, mechanics, energetics, etc) and 'FieldML' contains the spatial (and, if necessary, temporal) variation of model parameters. The mathematical models of cell function which use these parameters are defined by the existing 'MathML' standard (see http://www.w3c.org/MathML/).

II. WHOLE HEART MODELS

The anatomically based whole heart model currently includes the following aspects of heart function:

♦ Heart structure, incorporating the 3D geometry and fibrous-sheet structure of ventricular myocardium is modelled using a finite element mesh with cubic Hermite basis functions.

♦ Ventricular mechanics is solved with a large deformation Galerkin finite element method which includes an anisotropic material constitutive law based on the fibrous-sheet structure and the spatial distribution of extracellular matrix collagen density.

♦ Myocardial activation is computed using the anisotropic and spatially inhomogeneous conductivity tensor (also based on the fibrous-sheet structure) and the His/Purkinje fibre network. The ionic current based equations are solved on a finite difference grid defined at material points of the deforming myocardial finite element mesh.

♦ Coronary perfusion is modelled by solving the 1D flow equations with a two-step Lax Wendroff finite difference technique through the anatomically based model of the largest six generations of the coronary tree (both arteries and veins) and a lumped parameter model for vessels below 100μm.

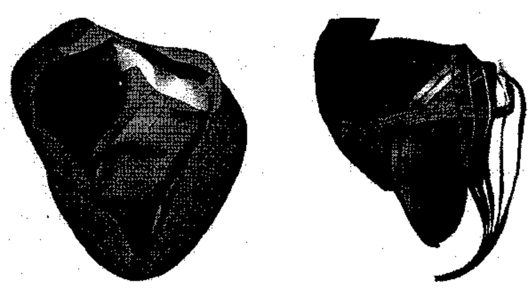
♦ Ventricular fluid flow is modelled by solving the 3D Navier-Stokes equations with a finite volume technique in which remeshing is used to accommodate the moving endocardial boundaries.

♦ A model of atrial anatomy is being developed which incorporates the regional variation of electrical properties (SA node, specialised conducting tracts and AV node).

♦ A model of the human torso has been developed which includes the heart, lungs and the layers of skeletal muscle, fat and skin. Current flow from the heart into the torso is computed in order to predict the body surface potentials arising from activation of the myocardium. An inverse procedure is being developed to predict myocardial activation from measurements of body surface potentials.

III. VISUALISATION

Software based on an X/Motif user interface and OpenGL graphics libraries has been developed for graphical display and user interaction with the 3D models, as shown in Fig.1.



(a) (b)

Fig.1 Finite element model of the ventricular myocardium. (a) Shaded endocardial surfaces of the right and left ventricles and the epicardium. (b) Ribbons following fibre paths and showing the orientation of the fibrous-sheet planes in the myocardium.