SIMULATION OF THE HUMAN ARTERIAL SYSTEM – STATIC AND DYNAMIC

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ABSTRACT

This paper introduces and compares two new models for the blood flow in the human arterial system. The first one is a hydrostatic model for the average flow and pressure values within the network. It is capable of being identified individually for each patient with a minimum amount of work. The second one is a hydrodynamic model for the pulse wave propagation within the arterial network. Due to the complexity of this one, it is a difficult task to obtain individual patient data, but it is designed for principal investigations of pathological pulse forms.

INTRODUCTION

Under normal circumstances modeling and simulation in human medicine is limited by the complexity of the investigated biological processes and by the difficulties of gaining data for an individual patient. So there is a thin line between complex models, which represent the structural information but need too many parameters for identification, and simplified models, which can be identified using easy available data at the cost of structural information.

METHODS

Both models are using a pipe network consisting of cylindrical tubes to identify the arterial system. These networks have the following properties:

- There is only one node with a given inflow.
- The outflows of all nodes are collected through fictitious arteries of the same length but with variable diameters.
- Blood is a Newtonian fluid.
- The arteries are hydraulic smooth.

For the static model the inflow at the starting node is constant in time, therefore the mean flow velocities can be calculated by solving a nonlinear equation system, which can be obtained by fundamental laws [1].

For calculating the pulse wave propagation in the hydrodynamic model the shock wave equations for elastic tubes

$$gH_x + V_t + VV_x + \frac{V|V|}{2D}\lambda(V) = 0 \quad \text{(eq. of motion)}$$

$$H_t + \frac{a_0^2 F(H)}{g} V_x + VH_x - V\sin(\alpha) = 0 \quad \text{(eq. of continuity)}$$

are solved using the methods of characteristics [2].

A common problem of blood flow models is how to deal with those small arteries which could not be included in the model network by their size or unimportance for the certain investigation. Instead of the usual situation of lumping and setting boundary conditions for each outflow node separately [3], in the presented models the outflows are collected in one node with a constant output. From another point of view these collecting arteries represent a combined boundary condition for all end nodes.

RESULTS

The static model is implemented as a MATLAB function as well as a C++ module in a software package for preoperative predictions in order to forecast hydraulic effects of different vessel operations [1]. Validations with different data records have shown that this model can be easily identified for specific patients.

The dynamic model (network with about 200 vessels), implemented in C++ with a MATLAB interface, is capable to perform detailed surveys for different conditions. Because of the large amounts of data necessary to identify the parameters and the structure of the blood vessel system of an individual patient, it is not possible to obtain a specific simulation model right now.

DISCUSSION

The two models show clearly the limitations of modeling and simulation in the fields of biomedicine caused by the difficulties of gaining individual data. Therefore the use of complex medical simulation for assisting physicians in their daily work depends very much on the further development of measuring instruments and diagnostic tools [4].

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