FINITE ELEMENT ANALYSIS OF BLOOD FLOW AND HEAT TRANSPORT IN THE HUMAN FINGER

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Introduction

- Blood dynamics is of multi-scale physical phenomena and multi-scale computational method can predict flow , pressure, and temperature in systematic vessels and different organs
- Measuring finger skin temperature and blood flow is important for Diagnosing blood circulation illness and be helpful for noninvasive measurement of blood glucose

Objectives

- To develop a computational model for the analysis of blood flow and temperature distribution in large blood vessels and biological tissues.
- To simulate the thermal function in the human finger

Modeling the Blood Flow and Heat Transfer

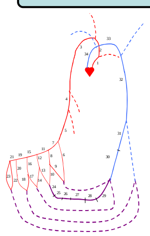
Simulation of Blood flow dynamics in large vessels ⇒ one-dimensional equations for pulsatile flow

$$\frac{\partial A}{\partial t}+\frac{\partial q}{\partial x}=0$$

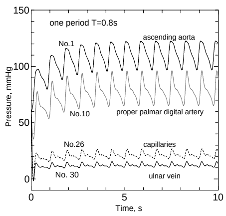
$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{q^2}{A}\right)+\frac{A}{\rho}\frac{\partial P}{\partial x}=-\frac{2\pi \nu r}{\delta}\frac{q}{A}$$

$$P(x,t)-P_0=\frac{4}{3}\frac{Eh}{r_0}\left(1-\sqrt{\frac{A_0}{A}}\right)$$

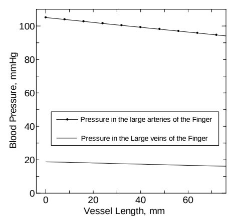
Two-step Lax-Wendroff Method



Schematic diagram of the circulation system in the upper limb



Computed Pressure signals in different vessels



Pressure distribution in the direction of the blood flow in large arteries and veins of the finger

Heat transfer in living tissues ⇒ The theory of porous media for heat transfer

Blood flow in microvessels ⇒ The fluid phase in porous media

Living tissues ⇒ The solid phase in porous media

Boundary conditions

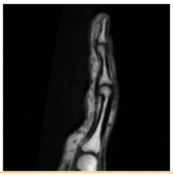
$$\frac{\partial^2 P^*}{\partial x^{*2}}+\frac{\partial^2 P^*}{\partial y^{*2}}=0$$

$$u^*=-Da\,\mathrm{Re}\frac{\partial P^*}{\partial x^*} \qquad v^*=-Da\,\mathrm{Re}\frac{\partial P^*}{\partial y^*}$$

$$\frac{\partial T^*}{\partial t^*}+\varepsilon\left[u^*\frac{\partial T^*}{\partial x^*}+v^*\frac{\partial T^*}{\partial y^*}\right]=\frac{1}{Pe_m}\left[\frac{\partial^2 T^*}{\partial x^{*2}}+\frac{\partial^2 T^*}{\partial y^{*2}}\right]+\frac{1}{Pe_m}q_m^*$$

Finite Element Analysis

Geometric modeling ⇒ MR image-based modeling and mesh generation



Original MR image

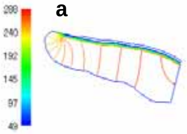
128×128 pixels

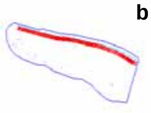
Processed Image

Original mesh

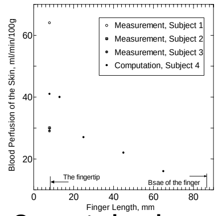
FE model for Computation

Results

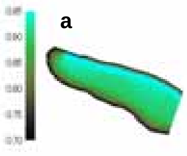


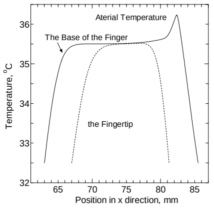


The Computed Capillary Pressure (a), Velocity (b) in an image-based model of the human finger



Computed and measured blood perfusion in the skin



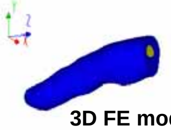


b

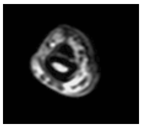
Computed temperature distribution (a) and temperature profile in different positions (b)

Current Work

Three-dimensional modeling of the human finger



3D FE model



One cross sectional image of the finger, 256 ×256 pixels

CONCLUSIONS

One-dimensional blood flow and porous media coupling model can be applied to predict local capillary pressure, blood perfussion, and temperature by using fewer assumptions as compared to other bioheat models.