Estimation of Stress-Strain Relationships in Vascular Walls using a Multi-Layer Hyperelastic Modelling Approach

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Abstract

The World Health Organization (WHO) estimated that cardiovascular diseases were the reason behind 30% of global mortality numbers in 2005. In 2001, cardiovascular diseases caused 40% of the total deaths in the UK and led to around 10 billion dollars of productivity loss. Arteriosclerosis, atherosclerosis and hypertension are the main causes of cardiovascular diseases. Controlling blood pressure and volume could lead to saving of millions of lives and dollars.

One way of investigating and hence controlling blood pressure and volume is to use artificial mechano-sensors. These sensors would exist on molecular level to convert local stress-strain fields into electrical action potentials which can then communicate with the CNS. To understand their function in terms of measuring blood pressure, the pressure must first be transferred to a stress-strain field in the different layers -adventitia; media and intima- of the vascular wall containing mechanosentive ion channels, such that the conditions for activating mechano-sensitive ion channels in the mechano-receptors can be characterised. Previous research concluded that experimental investigations of layer characteristics have been limited to large arteries and veins , eg adult human coronary and carotid arteries, and vena cava. The mathematical model presented in this paper suggests a method of estimating the individual layer material parameters and hence stress-strain relationships for smaller vascular vessels, given only experimental data from totally intact vessels.

The model uses an existing empirically derived hyperelastic strain energy formulation to describe the individual cylindrical layer stress-strain characteristics. These are then combined assuming all the layers are thin and stress-equilibrium is conserved. Thus, an equivalent average stress, directly comparable to experimental data from an intact vessel, can be calculated. Each derived material parameter, describing the stress-strain relationship has been compared to existing experimental data from individual layers and are within previously quoted experimental error.