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Towards predictive cardiovascular modeling: Simulation of short-term arterial adaptations in 3D subject-specific models

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Advances in numerical methods and three-dimensional imaging techniques have enabled the quantification of cardiovascular mechanics in subject specific anatomic and physiologic models. The computer modeling effort has been focused on three main applications areas: i) cardiovascular disease research, ii) medical device design and performance evaluation and iii) virtual surgical planning [1]. The focus of this work is on the latter.

A key objective in surgical planning modeling should be the appropriate representation of the transitional stages experienced by the subject due to anesthesia, stress, blood loss, and the various regional auto-regulations mechanisms of the arterial system that seek to maintain baseline conditions of flow and pressure. Under this light, one could cast the problem of modeling the function of the cardiovascular system under transitional stages as a control system problem.

In this work we will present the key components of a computational framework that enables the simulation of cardiovascular dynamics under transitional stages. A key component of the framework is a model of the baroreflex mechanism [2]. This mechanism couples cardiovascular and nervous systems and is responsible for dynamic adaptations of parameters such as vascular resistance and compliance, unstressed volume, heart rate, and cardiac contractility. We will demonstrate this framework under a specific transitional stage induced in the clinic known as "tilt test".

The second part of this work focuses on another task of critical importance towards facilitating the translation of computational modeling in the clinic, namely the automatic estimation of material and boundary condition parameters used in the computer model. Currently, this task is by far the most time consuming of the modeling effort and it requires a high degree of expertise from the user. We will demonstrate a Kalman-filtering based framework for automatic estimation of cardiovascular modeling parameters [3].

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