Computable, Functionalized Anatomical Models for Computational Life Sciences Applications

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Multi-scale modeling in computational life sciences often requires anatomical and physiogical detailedness, especially for the simulation of interactions between devices or external physical stimuli and the human body. In most cases, the impact of these stimuli can only be thoroughly evaluated by applying a sufficient number of independent models that adequately cover the anatomical variability of the population or subpopulation, e.g., a specific patient group. Static and dynamic information about the physiological properties must also be provided. Quality measures must be applied during the segmentation, morphing, and validation of the functionalized models for specific applications to provide the necessary basis for assessing the confidence intervals of the obtained results.

The Virtual Population (ViP) addresses these requirements. This set of ten independent anatomical models (male and female, ranging from young children to the elderly) were generated by detailed segmentation of medical image data obtained from healthy volunteers and by extraction of surface and volume meshes optimized for numerical modeling. These models were parameterized to increase population coverage by using a wide range of techniques: a) biomechanics-based morphing, where high performance computing enhanced (multi-scale) mechanical simulations are performed to grow or shrink fat and muscle tissue and to change the posture; b) a multi-resolution warping approach to locally or globally adapt body and organ shapes in an interactive manner and to introduce pathological variations; and c) a volume-preserving posture modification approach derived from the field of computer graphics. Currently, the applicability of image-based morphing techniques to adapt pre-segmented models to patient-specific image data is being investigated.

Validation of the model geometries can be performed by automatically assessing organ weight and shape and by comparison with reference data. A review process involving independent experts provides further validation. Validation of simulation approaches involving the anatomical models is application-specific and is currently being performed for a range of applications, such as MRI safety-related applications.

Our anatomical models are being functionalized on multiple levels: a) by associating a comprehensive literature-derived database of tissue properties and their variation, that is further developed using input from a public online discussion forum and by monitoring newly published information; b) by integrating information about tissue inhomogeneity and anisotropy derived from medical image data (e.g., DTI); and c) by including dynamic information, e.g., related to the vascular network and neuronal activity. Computable phantoms obtained by integrating numerical solvers with these functionalized anatomical models already support the in silico development and safety assessment of medical devices, and, in the near future, they will allow in silico trials to be performed.