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Non-Invasive Characterization of the Mechanical Properties of Arterial Walls

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Abstract : No routine technique currently exists for clinicians to measure the mechanical properties of vascular walls non-invasively. Most of the data available in the literature come from traction or dilatation tests conducted ex vivo on native blood vessels. The objective of the study is to develop a non-invasive characterization technique based on Magnetic Resonance Imaging (MRI) measurements of the deformation of vascular walls under pulsating blood flow conditions. The goal is to determine the mechanical properties of the vessels by inverse analysis, coupling imaging measurements and numerical simulations of the fluid-structure interactions. The hyperelastic properties are identified using Solidworks and Ansys workbench (ANSYS Inc.) solving an optimization technique. The vessel of interest targeted in the study is the common carotid artery. In vivo MRI measurements of the vessel anatomy and inlet velocity profiles was acquired along the facial vascular network on a cohort of 30 healthy volunteers: - The time-evolution of the blood vessel contours and, thus, of the cross-section surface area was measured by 3D imaging angiography sequences of phase-contrast MRI. - The blood flow velocity was measured using a 2D CINE MRI phase contrast (PC-MRI) method. Reference arterial pressure waveforms were simultaneously measured in the brachial artery using a sphygmomanometer. The three-dimensional (3D) geometry of the arterial network was reconstructed by first creating an STL file from the raw MRI data using the open source imaging software ITK-SNAP. The resulting geometry was then transformed with Solidworks into volumes that are compatible with Ansys softwares. Tetrahedral meshes of the wall and fluid domains were built using the ANSYS Meshing software, with a near-wall mesh refinement method in the case of the fluid domain to improve the accuracy of the fluid flow calculations. Ansys Structural was used for the numerical simulation of the vessel deformation and Ansys CFX for the simulation of the blood flow. The fluid structure interaction simulations showed that the systolic and diastolic blood pressures of the common carotid artery could be taken as reference pressures to identify the mechanical properties of the different arteries of the network. The coefficients of the hyperelastic law were identified using Ansys Design model for the common carotid. Under large deformations, a stiffness of 800 kPa is measured, which is of the same order of magnitude as the Young modulus of collagen fibers. Areas of maximum deformations were highlighted near bifurcations. This study is a first step towards patient-specific characterization of the mechanical properties of the facial vessels. The method is currently applied on patients suffering from facial vascular malformations and on patients scheduled for facial reconstruction. Information on the blood flow velocity as well as on the vessel anatomy and deformability will be key to improve surgical planning in the case of such vascular pathologies.

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