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Computational Modeling of Blood Hydrodynamics and Blockage Formation Phenomena in the Human Cardiovascular System

Adrian Tentner and Georgy Guria
National Center for Hematology

Andrey Ioilev
VNIIEF Laboratory

Simon Lo and Andros Onoufriou
CD-adapco

Maskhud Samigulin
VNIIEF Laboratory

An international collaborative effort to develop a computational fluid dynamics (CFD) model of the human cardiovascular system (HCVS) has been initiated in 2008. The HCVS model is designed to describe (a) the blood flow hydrodynamics and associated heat transport phenomena, (b) the blood flow interactions with the essential organs, and (c) the vessel blockage formation associated with atherosclerosis and thrombosis. The CFD-HCVS model is being developed as a new specialized software module using as a foundation the CFD code, STAR-CD, that is developed and distributed by CD-adapco, Ltd., a member of the project team. The CFD-HCVS module includes the following components and capabilities. (1) A simplified 3D coarse mesh CFD model of the HCVS, which allows the simulation of hemodynamic transient phenomena. The circulatory system model is closed with porous-media flow components having a hydraulic resistance equivalent to the lumped flow resistance of the smaller vessels, including microcirculation. Both hydrodynamic and thermodynamic phenomena are described, allowing the study of blood flow transients in the presence of temperature changes. (2) Simplified zero-dimensional models of the essential organs (e.g., heart, kidneys, brain, liver, etc.) describing the time-dependent consumption or production of various blood components of interest. The organ models exchange information with the CFD system model through interfaces designed to allow their replacement, in the future, with more complex 3D organ models. (3) Selected sections of the circulatory system can be replaced by realistic 3 fine mesh vessel models allowing the detailed study of the 3D blood flow field and the vascular geometry changes due to blockage formation. (4) Models of local blockage formation due to atherosclerosis and thrombosis. Three HCVS models of increasing complexity have been designed. These models contain 27 vessels, 113 vessels, and 395 vessels. The initial CFD-HCVS model development is based on the medium HCVS model with 113 vessels. A closed circuit CFD model describing the major vessels and containing 0D models of the heart and kidneys has been developed. The CFD-HCVS model includes porous-media models describing the blood flow in the smaller vessels and capillaries. Initial simulations show that the calculated blood flow rates in the vessels modeled are in reasonably good agreement with the corresponding physiological values. A simplified model of thrombosis has also been developed. Current development efforts are focused on the addition of new vessels and 0D organ models and the development of atherosclerosis models. The HCVS model provides a flexible and expandable modeling framework that will allow the researchers from universities, research hospitals and the medical industry to study the impact of a wide range of phenomena associated with diseases of the circulatory system and will help them develop new diagnostics and treatments.

Novel Design for Jaw-Thrust and Head Immobilization Device and Its Successful Testing Using Human Simulator

Girish Deshpande
University of Illinois College of Medicine

Nicholas Hand, Jesse Magnusson, Alexa Davis, Kalyani Nair, and Martin Morris
Bradley University

Jaw thrust is a common maneuver performed by medical care providers to open and maintain an airway in an unconscious patient. This essential procedure cannot only occupy significant amount of time for the health care provider, and also result in physical discomfort (low back pain) or fatigue, when it is needed for the extended period. A mechanical device can free up the care provider to perform other necessary tasks to manage critically patient and also prevent fatigue of the medical care provider. The aim of this study is to develop a novel mechanical device that can perform jaw thrust on children from 2 years old to 18 years old and maintain the airway open for extended periods of time. The designed jaw thrust device includes a base with an extension arm mounted on the base on each side of patient's head. The mandible rest is mounted on each extension arm such that it can be positioned underneath the patient's jaw. Chinstrap with rubber tubing is placed on the base on four points across the base such that, jaw thrusting pressure on the mandible rests causes rotational force on the chin straps opening patient's mouth without substantially tilting patient's head. The device maintains an airway open for extended time without any continuous attention; it also immobilizes the head in the midline thus maintaining the alignment of cervical vertebrae. Detailed finite element analyses of each of the components were done and a prototype was built for functional evaluation on a patient simulator. The device when tested and applied to a patient simulator in obstructed airway state was able to open the airway, evidenced by cough reflex elicited in response and "airway opened" timestamp noted in the computer attached to the simulator.

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