Chapter 16
Modelling and Simulation in Biomedical Research

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ABSTRACT

In the following chapter, the authors will discuss the development of medical imaging and, through specific case studies, its application in elucidating the role of fluid mechanical forces in cardiovascular disease development and therapy (namely the connection between flow patterns and circulatory system disease - atherosclerosis and aneurysms) by means of computational fluid dynamics (CFD). The research carried in the Biomedical Simulation Laboratory can be described as a multi-step process through which, from the reality of the human body through the generation of a mathematical model that is then translated into a visual representation, a refined visual representation easily understandable and used in the clinic is generated. Thus, the authors' daily research generates virtual representations of blood flow that can serve two purposes: a) that of a model for a phenomenon or disease or b) that of a model for an experiment (non-invasive way of determining the best treatment option).

INTRODUCTION

Over the last century society in general and the medical profession in particular has witnessed unimaginable and unprecedented growth, progress, expansion and advances in the technological field, particularly in the area of medical imaging. As we become more intimate with technology we realize how much the understanding of our lives has changed for the better, while at the same time new questions and issues that need addressing where brought to into light. Our particular work relies on the use of medical imaging and computer simulation technologies to visualize a phenomenon otherwise not accessible to the naked eye: blood flow. The following chapter will look at the ways in which these virtual images enable the scientist and the physician to better the understanding of the human body and the ways it functions.

Mirroring society at large, in the medical world technology is a ubiquitous and versatile presence allowing the real and the virtual merging and blending almost seamlessly. In the following chapter we will also present aspects of this merging encountered in our own research laboratory, as well as briefly reflecting upon the changes in our perception of medical imaging, the developments of the technology over the last half century, but most importantly the major steps forward in terms of its use as a didactic tool as well as aid in both defining a diagnosis and in deciding upon optimal treatment strategies.

BRIEF OVERVIEW OF THE FIELD

The search for the best way of understanding and then explaining motion in general and flow in particular has preoccupied the human mind for centuries. The focus of our research program is blood flow. In itself and in the context of the whole human body function, blood flow is one of the hidden-to-the-naked-eye phenomena, difficult to visualize, expose and explain. The need for a thorough examination lies in the tight connection between arteries, their vessel walls and the blood flowing through. The goal of our research is elucidating the role of fluid mechanic forces in cardiovascular disease and treatment. Arteries adjust their caliber to maintain the level of wall shear stress, the frictional force exerted by flowing blood against the vessel wall. The endothelial cells that line the wall, cells which also respond to and express various molecular factors, mediate this behaviour. Atherosclerosis (fatty deposits in the artery wall) and aneurysms (ballooning of the artery wall) tend to develop at sites of complicated blood flow patterns. Their rupture, the event that precipitates many heart attacks and strokes, is determined in large part by the mechanical forces exerted on them. The success of vascular surgeries or minimally invasive procedures depends on the skill of the surgeon or interventionalist as much

as it depends on the type of intervention or the design of the medical device chosen. The right strategy is crucial in avoiding the induction of further blood-flow-induced complications. With the discovery of the connection between flow patterns and circulatory system disease, the value and significance of computational fluid dynamics (CFD) was acknowledged, and CFD experts have been since involved in the designing and developing of the techniques and devices used in various vascular interventions (such as bypass grafts, stents or coils).

The need for exploring unseen areas of the body is not new: it has been preoccupying anatomists and clinicians since the dawn of medical science, but became the driving force behind perfecting the medical visualization techniques and technology over the last century. It all appears to have begun with Roentgen's discovery of X-rays, which initiated the modern age of medical imaging and set in motion a series of developments and applications that lead to previously unthinkable discoveries in the field. The initial accidental discovery was almost immediately followed by well-designed experiments that helped calibrate and adjust the apparatus and, subsequently, angiography was born from the idea of replacing blood with a radio-opaque dye.[1]

The development of both apparatus and skill enabling direct visual representations of blood opened new paths to a more thorough and detailed study of blood flow in its complexity. Our own work in the Biomedical Simulation Laboratory can be described as a multi-step process whereby from the reality of the human body an easily readable visual model is generated by the computer. To be more precise, data is collected from the patient/subject, and from corroborating information obtained from the medical images (MRI, CT) of the blood vessel, along with the Navier-Stokes equations, we generate a mathematical model for the physiological phenomenon of blood flow; this model is then translated into a visual representation of the phenomenon observed; the last step is the

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