VASCULAR BIOMECHANICS AND HEMODYNAMICS

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1. Introduction

The basis of modern cardiovascular hemodynamics has been established in the 1960^{ies} and 1970^{ies}. Invasive measurements of aortic pressure and flow in mammals and humans demonstrated that the cardiac pulsation generates pressure and flow waves, traveling along the arterial tree. Arterial pressure and flow were studied as wave phenomena and it was realized that relevant, quantitative hemodynamic assessment of the cardiovascular system required measurement of both pressure and flow. The concept of arterial impedance was introduced. Wave reflection was found to be an important determinant of the pressure and flow wave contours, altering with age, in cardiovascular disease or in response to drugs.

In spite of these fundamental physical insights, the interpretation of arterial blood pressure in daily clinical practice is still too often restricted only to systolic and diastolic blood pressure measured with cuff sphygmomanometry. Blood flow, if even measured, is usually limited to an estimate of cardiac output. With the availability of new pressure (arterial tonometry) and flow (ultrasound technology, magnetic resonance imaging) measuring techniques, it is however possible to apply the hemodynamic concepts, developed in the invasive pioneer studies, on larger patient populations in a non-invasive way. The main objective of this chapter is to familiarize the reader with these fundamental concepts and to give an accessible outline of how they can be applied in clinical practice.

Firstly, some basic knowledge on the arterial system is provided, as well as the general basis of hemodynamics. It is explained how measured pressure and flow waves relate to arterial impedance and wave reflection. We will introduce simple models of the arterial system, i.e., tube models and lumped parameter models, to help to explain and to understand arterial impedance. Next, it is shown how impedance, wave reflection and arterial (mechanical) properties can be estimated from (non-invasively) measured pressure, flow and arterial dimensions. We hereby discuss the assessment of global arterial parameters (total arterial compliance) as well as regional (pulse wave velocity) and local mechanical properties (elasticity and distensibility).

2. The arterial system

In this chapter, we will focus on the *systemic* arterial tree, which distributes oxygenated blood from the heart (left ventricle) to the organs (excl. the lungs), muscles and tissues. We will not consider the *pulmonary* arterial system, leading deoxygenated blood from the heart (right ventricle) to the lungs , neither do we consider the systemic (pulmonary) venous system, draining deoxygenated (oxygenated) blood from the systemic organs, muscles, tissues (lungs) towards the right atrium (left atrium).

The largest and main artery of the arterial tree is the aorta, which directly originates from the heart (Figure 1). In a normal healthy adult, it has a diameter of 2-3 cm, tapering to a diameter of about 1 cm at the level of the aorto-iliac bifurcation. Distinction is made between the aortic root, ascending aorta, aortic arch, descending aorta, thoracic (above diaphragm) and abdominal aorta (below diaphragm).

Major arteries are the coronary arteries supplying blood to the heart muscle itself (about 400 ml/min), the carotid arteries (in the neck; the common carotid artery bifurcates into the internal and external carotid artery) supplying blood to the brain and face, the arteries towards the internal organs (renal arteries, celiac tree, …), the iliac and femoral arteries supplying blood to the pelvic region and legs, and the brachial and radial/ ulnar arteries, being the arteries in the upper- and lower arm.

We further refer to the chapter “Measuring arterial stiffness in vivo” where the composition and mechanical behavior of arteries is discussed.