Chapter III

Analysis and Quantification of Motion within the Cardiovascular System: Implications for the Mechanical Strain of Cardiovascular Structures

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ABSTRACT

The estimation of motion of the myocardial and arterial wall is important for the quantification of tissue elasticity and contractility and has gained attention as a determinant of cardiovascular disease. In this chapter, a review is attempted regarding the analysis and quantification of motion within the cardiovascular system from sequences of images. The main sources of cardiovascular wall motion include blood pressure, blood flow and tethering to surrounding tissue. The most commonly applied techniques for cardiovascular motion analysis include feature-based and pixel-based methodologies; the latter further include block matching, optical flow and registration techniques. Two distinct paradigms based on these methodologies are highlighted, namely myocardium and carotid artery wall motion. The current status of research in these areas is reviewed and future research directions are indicated.
INTRODUCTION

Cardiovascular disease (CVD) is caused by disorders of the heart and blood vessels, and includes coronary heart disease (heart attacks), cerebrovascular disease (stroke), raised blood pressure (hypertension), peripheral artery disease, rheumatic heart disease, congenital heart disease and heart failure. According to the World Health Organization (World Health Organization website), CVD is the number one cause of death globally and is projected to remain the leading cause of death. An estimated 17.5 million people died from cardiovascular disease in 2005, representing 30% of all global deaths. Of these deaths, 7.6 million were due to heart attacks and 5.7 million were due to stroke. Around 80% of these deaths occurred in low- and middle-income countries. If appropriate action is not taken, by 2015, an estimated 20 million people will die from cardiovascular disease every year, mainly from heart attacks and strokes.

Clinical diagnosis, treatment and follow-up of cardiovascular disease are greatly aided by a number of imaging techniques which provide qualitative and quantitative information about morphology and function of the heart and the blood vessels. Furthermore, advanced image processing methods can be used to extract features from digitized images and facilitate image interpretation and subsequent decisions on disease management. Among such features, the estimation of motion of the myocardial and arterial wall is important for the quantification of tissue elasticity and contractility and has gained attention as a determinant of cardiovascular disease. Myocardial and arterial wall elasticity is altered with age as well as in the presence of pathology (e.g., myocardial infarction, atherosclerosis) mainly due to altered wall composition.

In this chapter, a review is attempted regarding the analysis and quantification of motion within the cardiovascular system from sequences of images. The main sources of cardiovascular wall motion are described, techniques for imaging tissue motion are reported and the most commonly applied methodologies for motion estimation based on temporal image sequences are discussed. Specific clinical applications of these methodologies for the analysis and quantification of motion of the myocardium and the carotid artery wall are also presented within this chapter.

BACKGROUND

Motion of the Myocardial and Arterial Wall

Throughout the cardiovascular system, tissue motion is caused by blood pressure, blood flow and tethering to surrounding tissue. Blood pressure, commonly expressed in terms of the transmural pressure (intramural minus extramural), causes tensile stress in the wall. As the transmural pressure rises, mechanical stresses are induced in all directions within the wall. Compressive stress may occur and is enhanced when the less compliant deeper wall layers prevent the surface layers from expanding, resulting in further compression. Stresses in the longitudinal and circumferential directions, on the other hand, are generally tensile in nature, leading to tissue lengthening.

Unlike orthogonal forces such as those induced by transmural pressure, fluid shear generated by friction or viscous drag due to blood flow acts tangentially upon the cardiovascular wall and endothelium. The magnitude of fluid shear depends on factors such as local geometry, local velocity of blood flow and the viscosity of blood as largely related to the haematocrit. In the heart, shear strain may be developed between the endocardium, the myocardium and the pericardium, whereas in arteries between neighboring arterial layers (intima, media, adventitia) and between arterial wall and surrounding tissue. In arteries, atherosclerotic plaques tend to occur where flow velocity and shear stress are reduced and flow
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