Review on CFD simulation in heart with dilated cardiomyopathy and myocardial infarction

Bee Ting Chan, Einly Lim, Kok Han Chee, Noor Azuan Abu Osman

Heart failure is characterized by the inability of the heart to supply adequate blood flow and therefore deliver oxygen to tissues and organs in the body. It is usually induced by cardiovascular diseases such as coronary artery disease, arrhythmias, congenital heart disease, heart valve disease, congestive heart disease, rheumatic heart disease, stroke and high blood pressure. Cardiovascular disease is the most commonly reported cause of mortality and it contributes to approximately 30% of deaths worldwide. When an individual suffers from cardiovascular disease a number of compensatory mechanisms take place in order to maintain cardiac output and these include geometrical modifications of the heart. The heart is stretched to hold more blood in the diastole so that it is able to generate stronger force of contraction during systole, following Frank-Starling’s law [2–4]. Furthermore, to overcome the high afterload pressure that is normally experienced by patients that are suffering from heart disease, yet with reasonable wall stress, the muscle wall thickens. Over a long period the gradual declination of cardiac performance is no longer compensable. At this stage, clinical symptoms such as fatigue, dizziness, diminished exercise capacity, shortness of breath and edema are observed.

Heart failure patients may experience systolic dysfunction, diastolic dysfunction, or both. Systolic dysfunction refers to the abnormal performance of the heart caused by insufficient con- traction, while diastolic dysfunction refers to abnormalities that are caused by the insufficient relaxation of the heart. Systolic dysfunction involves a progressive condition which leads to cardiac remodeling, which is characterized by dilatation, changes in sphericity, wall thinning, decreased cardiac reserve, impaired exercise tolerance, increased wall stress [5] and thus increased myocardial oxygen demand [6]. DCM is one of the most common cardiac diseases which exhibits systolic dysfunction. Diastolic dysfunction, on the other hand, is characterized by slow relaxation of the heart and abnormal filling patterns, most often caused by increased stiffness of the cardiac muscle [7–8]. Diastolic heart failure is shown in hypertrophy cardiomyopathy where the heart develops thicker and stiffer heart muscles that show signs of impaired relaxation.

Numerous methods have been used to diagnose and differentiate various types of heart failure conditions in order to devise the best treatment strategies for the patients involved. These involve examining the heart’s morphology [9–11], electrical activity [12–13], mechanics [11,14–15] and hemodynamics [16–17]. Invasive diagnostic methods, such as blood test and coronary catheterization procedures, are routinely used in a clinical setting. With the advancement of medical technologies, noninvasive imaging modalities, such as chest X-rays, electro- cardiograms (ECG), computed tomography (CT) and magnetic resonance imaging (MRI) are gradually becoming more popular. Among these, MRI and echocardiography are the most commonly used diagnostic tools that are used to assess cardiac function through geometric and flow measurements, such as left ventricle (LV) volume, wall mass, stroke volume, ejection fraction (EF), wall motion and wall thickness. However, differentiated velocity vector and pressure field, as well as the local hemodynamics indices such as mass transport, wall shear and boundary flow layer [18], which are important parameters for early diagnosis of heart failure, are not able to quantitatively evaluate the effects of individual parameters to the disease conditions through imaging modalities.

The CFD method involves the study of cardiovascular blood flow patterns and it has emerged as a reliable tool that can be used to enhance our understanding of the pathophysiology and progression of heart disease by providing the means through which reproducible numerical experiments can be produced under identical conditions. Global and regional hemodynamics variables, such as intraventricular blood flow dynamics, ventricular wall motion, spatial and temporal distributions of pressure and myocardial strains and stresses, can be obtained through the simulations. Information about these parameters provides opportunities for the early diagnosis of certain heart diseases while sensitivity analysis performed through the CFD method is able to demonstrate the correlation between individual parameter to the disease...
condition. Early CFD techniques for hemodynamics simulations were mostly carried out on simplified geometries [19–21]. With the development of cardiac imaging techniques, patient-specific morphology and flow have been progressively used [22–25], and this provides valuable clinical information. In the recent decade, FSI models that take into account the interaction between the blood and the cardiac wall have been developed [26–30]

The present paper provides a comprehensive overview of the existing diagnostic methods, including CFD simulations, in terms of their ability to identify the presence of the two most common myocardial diseases, i.e. DCM and MI during filling phase. Currently available and commonly used diagnostic tools are presented, with an emphasis on the various information or parameters they provide, as well as their limitations on global variables. This is followed by a review of the existing CFD models of the diseases, focusing on their methods, findings (the global and regional hemodynamic variables), as well as validations of the results.

Full text available at:

www.sciencedirect.com/science/article/pii/S0010482513000279