Computational Analysis of the Effect of Cardiac Motion on Left Main Coronary Artery Hemodynamics

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Abstract

Cardiac muscle health is dependent on the ample supply of oxygenated blood to ensure optimal cardiac function. The continuous supply of oxygenated blood occurs through coronary arteries embedded within the muscle. Cardiac motions involve contracting and expanding giving rise to the biomechanical behavior of the arteries. This work studies the impact of cardiac motion on the coronary flow using a two-way fluid-structure interaction. Blood flow was modelled within an idealized 3D coronary arterial structure using incompressible laminar Navier-Stokes equations. The vessel walls of left main artery were represented using an isotropic five-parameter Mooney-Rivlin hyperelastic material which deformed dynamically with prescribed displacement boundary conditions to simulate ventricular torsional and expansion motions. Our results showed higher blood velocities at the bifurcation region in the moving artery than in the non-moving case, particularly during systolic torsional motion. During systole, the wall shear stress near the bifurcation was found to be lower in the non-moving case relative to the moving one. In the non-moving model, a helical-shaped pattern of secondary flow was observed as the blood flowed through the curved vessel, however this pattern diminished in the moving model, where the arterial curvature dynamically changed throughout cardiac cycle.

1. Introduction

Coronary artery disease (CAD) is the most common cardiac disease and the leading cause of death globally. An estimated nearly 18 million people died from CAD in 2019 [1]. Since coronary arteries are attached to the cardiac epicardial surface, any abnormal motion of cardiac muscle can potentially affect the vascular hemodynamics including blood emptying and filling. Studies on the mechanical interaction between the myocardium and coronary arteries are well-documented [2-4]. Large torsional motion, wall thickening and contraction dynamics of the ventricles are expected to alter the hemodynamic environment within the coronary arteries.

Arterial motion has been shown to function as a pump that drives blood into the artery [4]. These works studied the effect of myocardial motion on coronary blood flow [5,6] and revealed that the impact of cardiac motion on time-averaged wall shear stress (WSS) was insignificant compared to oscillatory hemodynamic parameters such as temporal variation of WSS and oscillatory shear index. Gholipour et al. [7] observed a significant effect of cardiac motion on the von-Misses stress of the coronary artery which leads to a 265% increase in radial stress. Other studies [8,9] concluded that the effect of dynamic vessel motion was only secondary to the pulsatile flow effects on the coronary arteries.

Most of these studies have only considered a small section of a coronary artery with no branching and have not investigated in depth the combination of ventricular torsion and expansion on the coronary hemodynamics. In reality, cardiac motion is likely to be spatially inhomogeneous and therefore the embedded arteries are subject to deformations in the radial, circumferential and longitudinal directions [10]. Moreover, the role of secondary flow patterns in moving coronary vessels has not yet been investigated. The present study simulated a physiologically deforming motion in an idealized arterial geometry and compared the hemodynamic effects against the non-moving case.

2. Methods

An idealized model of left main coronary artery bifurcated 45º into the left anterior descending and left circumflex arteries has been adopted [11], as in Figure 1.

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