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Computation of hemodynamics in the left coronary artery with variable angulations

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ABSTRACT

The purpose of this study was to investigate the hemodynamic effect of variations in the angulations of the left coronary artery, based on simulated and realistic coronary artery models. Twelve models consisting of four realistic and eight simulated coronary artery geometries were generated with the inclusion of left main stem, left anterior descending and left circumflex branches. The simulated models included various coronary artery angulations, namely, 15°, 30°, 45°, 60°, 75°, 90°, 105° and 120°. The realistic coronary angulations were based on selected patient's data with angles ranging from narrow angles of 58° and 73° to wide angles of 110° and 120°. Computational fluid dynamics analysis was performed to simulate realistic physiological conditions that reflect the *in vivo* cardiac hemodynamics. The wall shear stress, wall shear stress gradient, velocity flow patterns and wall pressure were measured in simulated and realistic models during the cardiac cycle. Our results showed that a disturbed flow pattern was observed in models with wider angulations, and wall pressure was found to reduce when the flow changed from the left main stem to the bifurcated regions, based on simulated and realistic models. A low wall shear stress gradient was demonstrated at left bifurcations with wide angles. There is a direct correlation between coronary angulations and subsequent hemodynamic changes, based on realistic and simulated models. Further studies based on patients with different severities of coronary artery disease are required to verify our results.

1. Introduction

Atherosclerosis is the leading cause of morbidity and mortality in the advanced countries. The causes of atherosclerosis are multifactorial and identification of these factors could allow earlier detection and prevention of the disease. Hemodynamics and vessel geometry may play an important role in the cause of plaque formation, since atherosclerotic plaques occur frequently in well-recognized arterial regions of curvature, bifurcated area and vessel branches (Zarins et al., 1983; Asakura and Karino, 1990; Conner, 1994). Blood flow variations, particularly those related to the rate of change of stream-wise velocity perpendicular to the blood vessel wall (known as the wall shear stress), have been reported to be related to the pathogenesis of atherosclerosis (Lehoux, 2006; Sabbah et al., 1986).

Early hemodynamic analysis of coronary artery disease performed using computational fluid dynamic (CFD) techniques has been typically performed using one of two approaches, they were based on either simulated models or realistic coronary artery geometry simulations (Lim and Kern, 2005; Katritsis et al., 2007; Shanmugavelayudam et al., 2010; Wellnhofer et al., 2010; Nordgaard et al., 2010). As far as we know, no systematic studies have been performed hitherto that relate bifurcation angles to flow instabilities predisposing to the formation of atherosclerotic lesions. The left coronary artery differs from the right coronary artery in terms of geometric appearance as the left side has a very short main stem, which quickly divides into left anterior descending and left circumflex with an angle formed between these two branches. Thus the angulation between these two coronary branches induces local hemodynamic changes, which may pose a potential risk for development of atherosclerosis. The aim of this study was to investigate the relationship between hemodynamics and angulations at the left coronary artery, based on simulated models and realistic patients' data. Various angles were simulated at the left coronary artery with the aim of identifying the effect of angulation on the subsequent hemodynamic changes to the left coronary artery.

2. Materials and Methods

2.1. Measurement of left coronary artery anatomical details

Four patients suspected of coronary artery disease underwent multislice CT angiography and were included in the patient datasets. This original DICOM

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