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Assessment of Coronary Status by High Accuracy Pressure Drop Measurements

Oren Rotman, Uri Zaretsky, Shmuel Einav
The Department of Biomedical Engineering, Tel Aviv University
Tel Aviv, Israel
orenrotman1@gmail.com; uriza@eng.tau.ac.il; einav@eng.tau.ac.il

Avraham Shitzer
The Faculty of Mechanical Engineering, Technion Institute of Technology,
Haifa, Israel
mersasa@technion.ac.il

Extended Abstract

Coronary artery atherosclerosis is the single largest killer of men and women in the Western World. It is the principal cause of coronary artery disease (CAD), in which atherosclerotic changes are present within the walls of the coronary arteries. In 2011, coronary atherosclerosis was one of the top ten most expensive conditions seen during inpatient hospitalizations in the U.S., with aggregate inpatient hospital costs of $10.4 billion. Yet, cardiac stress testing, traditionally the most commonly performed non-invasive testing method for blood flow limitations, in general, detects only lumen narrowing of ~75% or greater.

Arterial distensibility is a measure of the arterial ability to expand and contract with cardiac pulsation and relaxation. A decrease of arterial distensibility (increased artery wall stiffness) seems to be a common pathologic mechanism for many factors that lead to the occurrence and progression of the vascular changes associated with cardiovascular disease (CVD). Early detection of functional impairment of the arterial wall can lead to more effective strategies for the prevention of CVD.

Blood flow, pressure drop and arterial distensibility are important parameters which are indicative of the coronary arteries patency and atherosclerosis severity. While pressure drop is related to flow, and therefore serves as a functional assessment of a stenosis severity, the arterial distensibility is indicative of the arterial stiffness, and hence the arterial wall composition. In the present study we suggest that local pressure drops are affected by the arterial stiffness, and can therefore provide lesion specific bio-mechanical data on the artery, in addition to functional assessment of the flow.

The objectives of the study are (a) to investigate the correlation between the fluid pressure drop and the local arterial distensibility for different cases of stenosis severity and flow rates; (b) to introduce a new parameter for combined functional and bio-mechanical assessment of arteries, which is solely based on pressure drop measurements; and (c) to compare the new parameter to the Fractional Flow Reserve (FFR) indicator. Fractional flow reserve is defined as the pressure behind (distal to) a stenosis relative to the pressure before the stenosis. FFR expresses the maximal flow down a vessel in the presence of a stenosis compared to the maximal flow in the hypothetical absence of the stenosis. Fractional flow reserve provides a functional evaluation, by measuring the pressure decline caused by a vessel narrowing.

The investigation methods include: (a) in-vitro wet experiments on silicone mock arteries, (b) Numerical Fluid Structure Interaction (FSI) simulations. Highly accurate pressure drop measurements (accuracy: ±0.05 mmHg) were performed with fluid-filled 5F double-lumen catheter (18G/18G) using a validated signal restoration method that has been developed in our lab. Arterial models were made from Silicon with internal diameter of 4.3 mm and wall thickness of about 0.7 mm. Material properties and wall thickness were selected to provide similarity to coronary arteries distensibility. Flow conditions were

set according to dimensionless parameters (Re~115 and α~3) to fit the hemodynamic conditions of coronary arteries in-vivo. Systemic pressure was set to approximately 130/80 mmHg.

Results: Preliminary in-vitro tests indicate that our accurate pressure drop measurement method facilitates the differentiation among several levels of arterial stiffness, with distensibility ranging from 1 to 10%. Local pressure drops are markedly affected by the arterial stiffness, and these changes in pressure drop can be detected even in small to intermediate size stenoses, where the FFR values remain 0.99 and actually useless. Moreover, while maximum hyperemic flow rate is essential for FFR measurements, we were quite easily able to differentiate varying stenoses sizes at normal flow conditions.

Conclusions: Our results ascertained the measurement of pressure drop with a double lumen catheter. The results indicate the potential of a high accuracy pressure drop based parameter to be superior to FFR. Such a parameter will provide cardiovascular interventionalists with both lesion specific bio-mechanical and functional data, for improved decision making in the cath lab in real time.