3D Optical Coherence Tomography (OCT) – An Investigation of Intimal-Medial Thickness (IMT) and Wall Shear Stress (WSS) in a Patient's Coronary artery

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Abstract

Current OCT presents only two-dimensional (2D) slices, which limit the spatial information available. We have developed three-dimensional (3D) OCT methodology by combining OCT with biplane angiography, allowing reconstruction of a realistic lumen of coronary arteries with higher local resolution than by other methods, e.g. intravascular ultrasound (IVUS). Intimal-medial thickening (IMT) in the left anterior descending (LAD) coronary artery of a patient were investigated by OCT and IVUS. An inverse relationship between WSS obtained through computational fluid dynamics (CFD) and IMT as determined from the intravascular imaging techniques was found. The relationship is consistent with previous results from autopsy studies.

1. Introduction

OCT as well as IVUS **is** a clinical imaging technique that can visualize the inside of vessels of patients. However, OCT has higher resolution than IVUS (15 µm to 150 µm) [1,2] that offers the evaluation of wall structures in patients' coronary arteries nearly to the level of single cells. Current IVUS and OCT systems present a sequence of 2D image slices of the vessel cross-section, but the individual slices alone are inadequate for depicting the 3D spatial structure of the lumen. However, the 2D images can be combined with biplane angiography into a system that permits 3D vessel reconstruction with either OCT or IVUS data. Such a 3D system was developed in our lab and successfully used in the study of patients in Emory University Hospital [3].

An application of the technique is introduced here using data from one patient of a group which had both OCT and IVUS scanning performed in the LAD. An asymmetrical distribution of intimal-medial thickness (IMT) on the transverse sections of lumen in the curved segment was quantified through image processing of OCT slices. However, this asymmetry could not be discerned from the IVUS data. Next, the LAD geometry was reconstructed from 3D OCT data and the flow field in the lumen simulated by CFD using an inlet condition derived from Doppler velocity measurements during the procedure. The results show that the distribution of IMT has an inverse relationship with the distribution of WSS in the curved segment. The quantitative relationship is consistent with previous results obtained from the LADs of autopsied human subjects [4].

2. Data and methods

LightLab Imaging's C7-XR OCT imaging system was used in the OCT scans. The system can provide a 54 mm scanning distance along the wire and produce 271 frames through this distance in one operation. The lumen boundary is more clearly discerned by OCT than by IVUS, as Figure 1 shows.

Biplane angiography images of the left coronary artery were obtained with a Toshiba X-ray machine using two cameras simultaneously. A calibrator has been used in our process that provides markers for image registration. Programs developed from direct linear transformation (DLT) methods have been developed in our lab that solve the 3D reconstruction problem of an object from two viewing images.

Doppler velocity measurements were performed during the IVUS scan at two points, one in the middle of the left main (LM) coronary and the other in the distal segment of the LAD, providing local velocity waveforms of blood flow during the cardiac cycle. The waveforms were used as inlet and outlet velocity conditions for CFD simulation. The CFD calculation was performed in the reconstructed model employing CFD-ACE software. Blood was assumed to be an incompressible Newtonian fluid and in a laminar flow state. The pulsatile velocity field was computed, and WSS was derived.

The IMT was defined as the radial distance from the lumen boundary to the external elastic membrane (EEM) as shown in Figure 1.

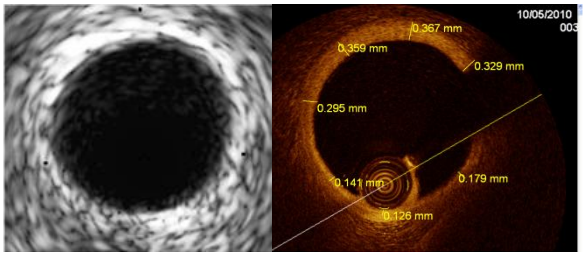

Figure 1. The left image is one of the IVUS slices in the curved LAD segment; the right image is the OCT slice at the same section. IMT was measured at 7 points.

3. Results

The 3D LAD model reconstructed from OCT slices is shown in Figure 2. The longitudinal length of the model is 36 mm and includes 180 OCT frames. The primary morphological feature is a vessel with a smooth lumen and large curvature in the distal LAD. Although the OCT catheter traverses only the main vessel and not the side branches, locations for branches are easily seen and outflow into these is modeled in the calculations. The WSS analysis focuses on the curved segment as defined by the two arrows in Figure 2. The time-averaged WSS was computed from the pulsatile velocity field at each location on the vessel wall. The WSS distribution could be divided into regions: low WSS, less than 15 dynes/cm^2, located on the myocardial side and high WSS, more than 25 dynes/cm^2, located on the epicardial side.

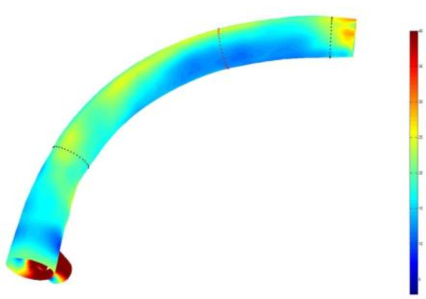

Figure 2. Time mean WSS distribution averaged over one cardiac cycle where color scale is limited to 30 dynes/cm^2. Color becomes crimson when WSS>30 dynes/cm^2.

In order to compare measured and computed variables, all data for WSS and IMT obtained from the curved segment were unwrapped into two Cartesian coordinate planes as Figure 3 shows. The right panel is IMT distribution illustrated by a color map where the maximum thickness is 0.37 millimeters and the minimum is 0.075 millimeters. The left panel is the WSS distribution where the scale range is 10.4 to 30 dynes/cm^2. The color maps present an inverse relationship between WSS and IMT where higher WSS (> 25±5 dynes/cm^2) favors thinner IMT (< 0.12±0.05 millimeters) and lower WSS (< 12±5 dynes/cm^2) favorites thicker IMT (> 0.33±0.05 millimeters).

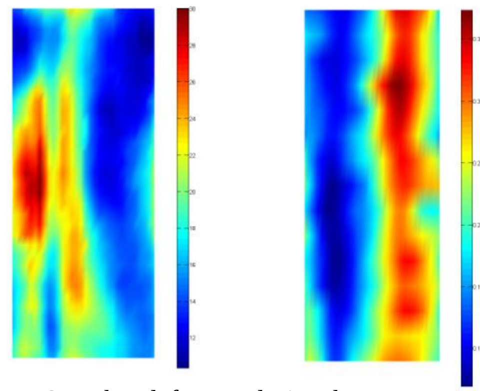

Figure 3. The left panel is the unwrapped WSS distribution in the curved segment where the color scale is 10.4 to 30 dynes/cm^2. The right is the unwrapped IMT distribution in the segment where the color scale is from 0.075 to 0.37 millimeters.

A correlation between WSS and IMT in the segment was performed (r = -0.68796 and P < 0.0001). WSS and IMT present a linear inverse relationship as Figure 4 shows. The relationship is consistent with previous results from an autopsy study [4].

4. Conclusion

The improved resolution of OCT allows accurate representation of coronary artery luminal cross-sections and IMT under *in vivo* conditions, within the limits of optical depth penetration. This yields improved accuracy and resolution of computed WSS, and the results presented here are perhaps the first *in vivo* demonstration in a coronary artery of a specific subject of the hypothesized inverse relationship between WSS and IMT.

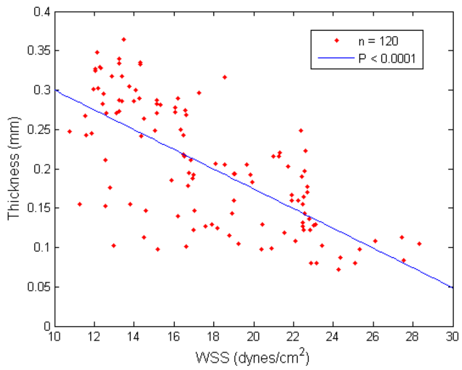

Figure 4. The linear coefficients were estimated from two groups of data using a least squares method. The data were obtained at the same points distributed uniformly over the curved segment.

Acknowledgements

Data in this study were derived from an IRB approved protocol of the Emory University Hospital. Research was partially supported through funds from the Wallace H. Coulter Foundation, the Georgia Research Alliance and National Heart, Lung, and Blood Institute, National Institutes of Health, as a Program of Excellence in Nanotechnology Award, N01 HV-08234 to DPG.

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