Quantitative Analysis of Circumferential Plaque Distribution in Human Coronary Arteries in Relation to Local Vessel Curvature

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Background
• Symptomatic coronary artery disease and atherosclerosis are among the leading causes of death in many countries.
• Inter-relationships between vessel geometry, hemodynamics, and plaque development need to be understood.
• 3-D Fusion of x-ray coronary angiography and intravascular ultrasound (IVUS) data allows a geometrically correct representation of coronary geometry and cross-sectional morphology.
• Computational fluid dynamics (CFD) methods are well established to determine shear-stress patterns along the lumen/plaque boundaries.

Motivation
• It has been observed that plaque tends to accumulate on the inner curvature rather than on the outer curvature of a vessel (Figure 1).• Simulations in idealized tubular phantoms of constant curvature indicate lower wall shear stress on the inner curvature (Figure 2).• Given that low wall shear stress is associated with plaque accumulation on the inner curvature rather than on the outer curvature of a vessel (Figure 2).• Inter-relationships between vessel geometry, hemodynamics, and plaque development need to be understood.

Methods
(a) 3-D Fusion
• Lumen/plaque and media/adventitia contours are segmented semi-automatically from the IVUS data, as acquired with end-diastolic gating.
• The IVUS catheter path is determined from the angiograms and reconstructed into 3-D space.
• Fusion yields the final 3-D model (Figure 4).

(b) Plaque Thickness
• Contours resulting from 3-D fusion are initially oriented relative to the catheter.
• Thus, contours are resampled with respect to the vessel centroid, forming a reliable centerline over all frames.
• Plaque thickness is measured along 72 radial lines originating from each centroid as the 3-D Euclidean distance between the contours.

(c) Curvature Index
• The local curvature index combines two parameters for each contour point:
  1. The magnitude of the local vessel curvature.
  2. The circumferential position of the contour point relative to the curvature direction.
• Directly derived from curvature as defined in differential geometry (Frenet-Serret formulas; Figure 5, next column).

Results
• A total of 39 in-vivo pullbacks acquired in 37 segments.
• 12 different curvature thresholds were applied.
• Ratios and linear fits for 29 segments.
• An average r increases with threshold T, indicating the relationship increases with curvature.

Conclusions
• 3-D fusion methodology based on x-ray angiography and IVUS can be used to quantitatively analyze circumferential plaque distribution and local vessel curvature.
• In vessels with non-trivial geometry or which are located in lower branching levels, the resulting complex flow and plaque-accumulation patterns require more detailed CFD analyses.

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