

DEVELOPING PULSATILE FLOW THROUGH THE ENTRANCE REGION OF A DEPLOYED STENT IN A CORONARY ARTERY

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ABSTRACT

Current stent products differ significantly in terms of their design. There is a need to optimize the design of the stents such that the magnitude of positive and negative wall shear stress are reduced, thus minimizing the patho-physiological effects. The present study of developing heperemic flow through the entrance region of a deployed stent in a coronary artery segment showed a 10 fold increase in the positive values of wall shear stress at the stent wires exposed to the blood flow. Further, at the void next to the entrance, the negative wall shear stress was an order of magnitude lower than the values typically observed in similar downstream regions.

INTRODUCTION

Coronary stents are important in the treatment of atherosclerotic disease and are key to the advancement of interventional techniques. Coronary stent system is used in patients eligible for percutaneous transluminal balloon coronary angioplasty [PTCA] with symptomatic disease due to discrete *de novo* lesions in native coronary arteries [length ≤ 30 mm] with a reference vessel diameter of 3-4 mm. Essentially, stenting is intended to improve coronary luminal diameter. Current stent products, although aligned to the same goals of the mechanical enlargement of the vessel lumen, reduction in restenosis and the incidence of complications, differ significantly in terms of their design.

METHODOLOGY

A pulsatile flow analysis for hyperemic condition is performed for a freshly deployed stent in a human coronary artery having a three dimensional geometry with an axial length of 20 mm and a larger diameter (6 mm). Following the deployment of the stent, it is assumed that half of the stent is exposed to the blood flow whereas the other half is embedded in the arterial wall. Volume mesh [Figure 1A] with $\sim 650,000$ cells of hexahedral elements were generated in GambitTM (1) using the Cooper scheme. In order to mesh the deployed stent, the flow domain was sub-divided in two independent regions with non-

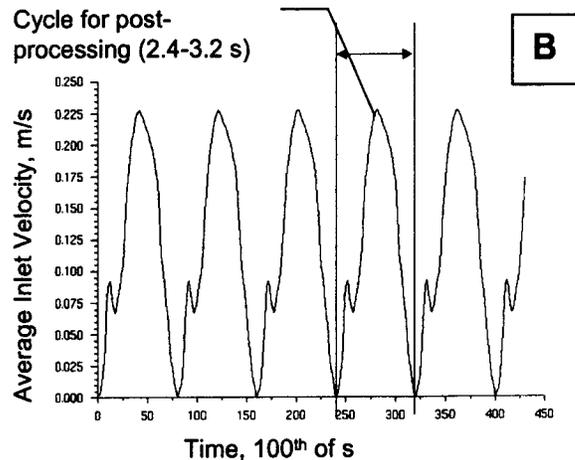
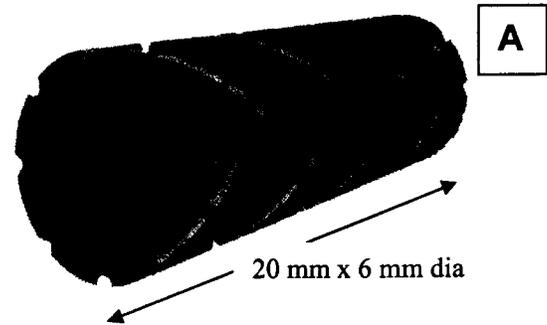


Figure 1: The mesh plot showing the flow domain of the coronary artery with deployed stent (Fig. A). Figure B shows 5 consecutive pulse cycles.

conformal interfaces between them. Computational fluid flow analysis was carried out using Fluent 6.0 (2).

For this study, a constant blood density of 1.05 gm/cc and an infinite-shear-rate viscosity of 3.45 cp were considered. Time-varying, uniform velocity boundary condition was imposed at inlet boundary with a user-defined-subroutine. The uniform velocity boundary condition simulated the worst possible location of the deployed stent in the coronary artery and thus, it provided an upper bound [maximum] of desired flow parameters [e.g. shear stress]. In other words, this model mimics the stent being placed near the entrance region of a branched coronary artery. The numerical computation was conducted for 5 consecutive pulse cycles [Figure 1B] with a pulse time period of 0.8 s. The results for the 4th cycle (2.4 s to 3.2 s) are presented here. Time at 2.5 s is the early acceleration phase, 2.8 s represents peak flow, whereas 3.14 s is the later part of the deceleration phase of the pulse. Segregated, second-order time-implicit solver with second-order discretization for pressure and momentum was used.

RESULTS

A close-up view of the velocity vector [Figure 2A] at time 3.14 s shows significant recirculation zones in the voids created by cross-links of stent wires. Temporal [at time $t = 2.5$ s {acceleration}, and 2.8 s {peak}, 3.14 s {deceleration}] and spatial distribution of the magnitude of wall shear stress is shown along the axial direction at the interface of the stent and the arterial wall [Figure 2B]. Alternate higher peaks indicate the positive wall shear stress at the stent surface that is exposed to the flow whereas the intermediate smaller peaks shows the negative wall shear stress values that exists in the void regions of the stent. Due to the developing nature of the flow, a local maximum value of (+)130 dynes/cm², about 10 times higher than the normal value and greater than the developed flow [at downstream location] wall shear stress values, is observed at the upstream locations of the exposed stent wire. At the void next to the entrance, a local minimum of (-)30 dynes/cm², which is also an order of magnitude lower than the typical values obtained in the downstream regions, is observed. Also a representative wall shear stress [Figure 2C] magnitude and pressure [Figure 2D] filled-contours at peak flow [2.8 s] are shown along the axial direction. As the flow develops along the axial direction of the exposed stent wall, sharp variations in wall shear stress magnitude and pressure values between the exposed stent wall and the adjacent void regions are gradually reduced.

Essentially, recirculation zones have low shear areas that are susceptible to the deposition of macromolecules, e.g., cholesterol, lipoproteins, and other lipid derivatives (Caro et. al., 1969; Nerem and Levesque, 1987), leading to redevelopment of atherosclerosis. In contrast to the low shear regions, it is also necessary to minimize the high shear region on the stent wire wall that is exposed to the blood flow. A high shear region due to an improper stent design may cause detrimental patho-physiological effects in the coronary artery.

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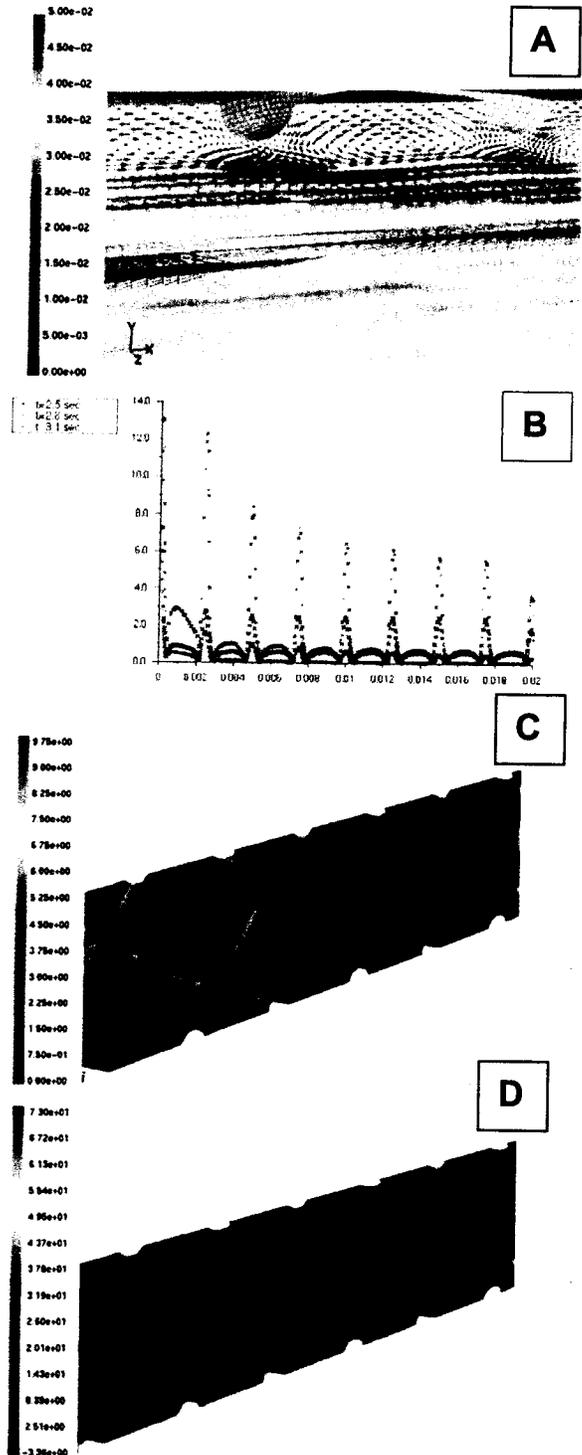


Figure 2: The velocity vector near the stent and artery interface at time $t = 3.14$ s is shown in Fig. A. Figure B shows the axial distribution of wall shear stress magnitude at time $t = 2.5$ s, 2.8 s, and 3.1 s. Figure C and D shows the filled color contour of wall shear stress and pressure at peak flow (2.8 s). All units in the figure are in SI unit.