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CATHETER OBSTRUCTION EFFECT ON PULSATILE FLOW RATE - PRESSURE DROP DURING CORONARY ANGIOPLASTY

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ABSTRACT

Quantitative methods to measure the hemodynamic consequences of various endovascular intervention including balloon angioplasty are limited. Catheters measuring translesional pressure drops during balloon angioplasty procedures can cause flow blockage and thus inaccurate estimates of pre-and post-intervention flow rates. The purpose of this investigation is to examine the influence of the presence and size of an angioplasty catheter on measured pulse pressure gradients across human coronary artery stenoses.

Imaging methods (e.g., contrast angiography, intravascular ultrasound, angioscopy) may document anatomic changes at a vessel stenosis before and after balloon angioplasty or other endovascular procedure. Long term success of the angioplasty intervention in terms of vessel patency and function of the perfused distal organ or tissue ultimately relies on restoration of near normal hemodynamic conditions across the stenotic lesion.

The ability to measure flow rate to assess tissue perfusion distal to vascular obstructions in coronary and many peripheral arteries is lacking however. While in principle the pulsed Doppler ultrasound tip catheter can be used to measure coronary artery velocity (Cole and Hartley, 1977) absolute measurement of pulsed and mean flow rate is more difficult to make accurately because of the velocity distribution across the lumen, transducer positioning and sample volume, blockage and disturbance effects of the catheter, determination of vessel cross-sectional area, in vivo calibration, etc. Therefore, these catheters have been used in patients to measure changes in flow velocities such as to estimate coronary flow reserve before and after angioplasty (e.g., Wilson et al., 1988).

Measurement of the mean pressure gradient across a stenosis has been used during angioplasty procedures as a hemodynamic endpoint in gauging the severity of the lesion and the effectiveness of the intervention.

In percutaneous transluminal balloon coronary angioplasty (PTCA) the guiding catheter tip is positioned in the coronary ostium and the angioplasty catheter is advanced through it over the small guide wire to the stenosis site. The mean translesional pressure gradient (Δp) is the mean pressure difference between the coronary ostium as measured through the guiding catheter and just distal to the stenosis as measured near the tip of the angioplasty catheter (Wilson et al., 1988). Thus, this measurement of Δp includes that across the proximal vessel or vessels where bifurcations are present as well as the stenosis and distal region. Various authors have described use of catheters to measure translesional pressure gradients including Gruentzig et al. (1979), Ganz et al. (1983 and 1985), Leimgruber et al. (1985), Anderson et al. (1986) and Redd et al. (1987). Relatively large mean translesional pressure gradients have been reported on the order of Δp = 50 mm Hg at basal flow before angioplasty (Leimgruber et al., 1985; Wilson et al., 1988). This value is about 50% of the ~100 mm Hg mean overall pressure drop across the coronary vascular bed. After increasing the minimal lesion cross-sectional area by balloon angioplasty, the mean translesional pressure gradients were reduced to the range of 10-15 mm Hg. Whereas clinical investigators have acknowledged the limitations of the translesional pressure gradient measurements because of the obstruction by the angioplasty catheter (e.g., Anderson et al. (1986), Wilson et al. (1988), there is not much information on flow blockage with the catheter present.

This study presents a new pulsed flow rate - pressure drop relation across vascular stenoses that is easily applicable *in-vivo* and considers the presence of catheters, thereby extending the earlier work of Young and Tsai (1973) and Back et al. (1994) for various stenosis models without catheters present. We use numerical and analytical flow modeling and *in-vitro* experimental evidence, coupled with angiographic data on the dimensions and shape of stenotic vessel segments before and after angioplasty, to estimate the flow blockage effect with the catheter present (by using the measured pressure gradients) including a "tight fit" condition between the stenotic vessel and catheter before balloon inflation.

The numerical study is conducted to obtain the time-dependent solution of an incompressible, non-Newtonian fluid representing blood viscosity for the selected artery with and without catheters. The flow is described by the conservation equations of fluid mass and momentum. Galerkin finite element method (FEM) is used to solve the two conservation equations and thus to obtain the temporal and spatial distribution of velocity, wall shear rate and stress, and pressure. The numerical calculations are performed for the center line instantaneous velocity and with uniform/parabolic spatial inlet flow conditions. Siegel et.al. (1993) shows the *in-vivo* velocity profile at the core region of coronary artery, as measured by an ultrasound Doppler flow cuff. The Carreau model is used to represent the shear rate dependent non-Newtonian blood viscosity whose mode constants are obtained by curve-fitting of available shear-rate dependent blood viscosity date in the literature (Cho and Kensey, 1991).

$$\eta = \eta_\infty + (\eta_o - \eta_\infty)\left[1 + (\lambda\dot{\gamma})^2\right]^{\frac{n-1}{2}} \qquad (1)$$

where λ (characteristics time) = 3.313 s, n = 0.3568. ηo = 0.56 poise.ηoo = 0.0345 poise.

Relatively large mean translesional pressure gradients have been observed, but they may be due to obstruction effects. To evaluate this hypothesis, numerical flow modeling coupled with *in-vitro* experimental evidence was used to estimate pulsed and mean flow resistance increases due to the presence of a catheter in a proximal vessel for concentric and eccentric catheter configurations. For an angioplasty catheter, over the relative range of catheter size to coronary vessel size (d_i/d_o) from 0.3 to 0.7 (which is currently being used clinically), the flow resistance increased by a large factor of 3-33 for concentric configuration. For smaller infusion catheters, the flow resistance increase was less, although still appreciable. Very small angioplasty guidewire increases in flow resistance, although the magnitude was less. These initial results might be used by clinicians to obtain rough estimates of actual mean pressure gradients *in-vivo* in relatively straight proximal segments of artery from values measured with catheters. Since catheters are used so widely clinically, these initial results may be useful also for other vessels in the vascular system where the mean flow is describable by the Poiseuille relation. Whereas there is reasonable confidence in the flow modeling methodology, hemodynamic data are needed to evaluate the actual magnitude of the effects of obstruction *in-vivo*.