IN-VITRO EVALUATION OF GUIDEWIRE FLOW OBSTRUCTION IN DIAGNOSIS OF CORONARY LESION SEVERITY USING PULSATILE HEMODYNAMICS

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ABSTRACT

In interventional cardiology, measurements of mean transstenotic pressure drop ($\Delta\tilde{p}$) and blood flow ($\tilde{Q}$) at hyperemic conditions are made to evaluate the severity of coronary stenoses. These measurements are evaluated in terms of FFR (Fractional Flow Reserve) and CFR (Coronary Flow Reserve), measured with small diameter guidewires (diameter = 0.014 in. or 0.35 mm). The purpose of this *in vitro* experimental study was to investigate the guidewire flow obstruction effect in a model of moderate coronary artery stenoses (65% mean area stenosis) with a non-Newtonian liquid, similar to blood. This paper presents initial data, giving $\Delta\tilde{p}$ - $\tilde{Q}$ relationship, in moderate coronary stenosis model with pulsatile flow profile. Without the guidewire, measured $\Delta\tilde{p}$ increased from 2.27 to 15.0 mmHg as $\tilde{Q}$ increased from 58.5 to 214 ml/min. With guidewire inserted inside the stenosis, measured $\Delta\tilde{p}$ increased from 3.47 to 19.3 mmHg as $\tilde{Q}$ increased from 53.8 to 197 ml/min. Clinical measurement by Wilson [1] showed that hyperemic $\tilde{Q}$ was 172.6 and 180 ml/min with and without guidewire, respectively. By curve fitting the experimental data, the overestimation in measured $\Delta\tilde{p}$ was 28% at hyperemia. This value agreed well with our previous studies on moderate coronary artery stenoses [2,3].

INTRODUCTION

Several studies have been conducted on *in vitro* test sections to understand the hemodynamics in stenotic arteries [e.g. 4,5,7,etc]. However, clinically, $\Delta\tilde{p}$ and $\tilde{Q}$ are measured only with guidewires. Limited information exists on the extent of the resistance to flow produced by the guidewire, in addition to the restriction caused by the stenosis. The experimental study could be used to obtain baseline data pertaining to CFR and FFR, which are used during cardiac catheterization to evaluate the hemodynamic significance of a stenosis, and to determine further patient management, specifically pertaining to percutaneous coronary intervention (PCI). The study could be particularly useful for diagnosis of moderate coronary artery stenoses as measured $\Delta\tilde{p}$ are not large, and the presence of a guidewire could produce some uncertainty. The geometry for the stenotic model was based on data provided in an *in vivo* study [1].

METHODS

A non-newtonian shear thinning fluid (33% by wt. Glycerin, 67% by wt. Water, ~0.016% by wt. Xanthum gum (XG); density=1.05 gm/cm^3) was used for this experiment [6]. Viscosity was measured with LDV-II+ viscometer (Brookfield Engg., MA). The viscosity of the fluid showed a shear thinning behavior with increasing shear rate , having an infinite shear rate viscosity of 3.5 cP.

The experiment was conducted with pulsatile flow using a pulsatile blood pump (Harvard Apparatus, MA). The moderate coronary artery model was manufactured using optical grade lexan. Two pressure ports, drilled proximal and distal (~4.3 cm distal to throat) to the stenosis, were connected to a digital liquid pressure scanner (Scanivalve Corp, WA). The pressure ,in mmHg, was recorded at every 0.012 sec time interval. The flow rate was measured by an ultrasonic flow transducer (Transonic Systems Inc, NY), which sensed instantaneous volumetric flow rate at the same time interval. The flow sensor readings, which were in volts, were subsequently converted to ml/min by using a linear calibration chart. The instantaneous pressures and flow rate data were recorded simultaneously, using an external voltage trigger pulse. A data acquisition system (National Instruments, TX) was used to record the instantaeous flow rate.

Figure 1 shows schematic diagram of the flow loop. The flow rate was regulated by using a by-pass line with a variable constrictor in it. The guidewire was inserted into the test section through a rotating hemostatic valve, which prevented any leakage of the test fluid along the guidewire surface. Special care was taken to remove all air bubbles in the tubing and in the pressure ports. During the measurements, the flow loop was pressurized to maintain a physiologic condition. Table 1 shows the dimensions of test section.

RESULTS AND DISCUSSION

The experiment was conducted at different physiological $\tilde{Q}$ with and without the insertion of the guidewire. Transient pressure for proximal and distal ports and flow profiles are shown in Figure 2 for $\tilde{Q}$ of 178 ml/min without guidewire. In Figure 2, the peak to peak phase difference between Δp(t) and Q(t) was 37°. Figure 3 shows $\Delta\tilde{p}$ - $\tilde{Q}$ relation for all $\tilde{Q}$ with and without guidewire. Without the guidewire, the measured $\Delta\tilde{p}$ was 2.27, 4.63, 6.60, 6.74, 9.08, 12.2 and 15.0 mmHg at $\tilde{Q}$ of 58.5, 84.9, 113, 131, 159, 178 and 214 ml/min, respectively. With guidewire inserted inside the stenosis, the measured $\Delta\tilde{p}$ was 3.47, 5.54, 7.78, 8.93, 12.4, 14.6, 19.3 mmHg at $\tilde{Q}$ of 53.8, 81.1, 108, 124, 153, 174, and 197 ml/min, respectively. Clinical measurement by Wilson [1] showed that hyperemic $\tilde{Q}$ was 172.6 and 180 ml/min with and without guidewire, respectively. The regressed power law fit for the data were $\Delta\tilde{p} = 0.0003\times\tilde{Q}^2 + 0.0428\times\tilde{Q}$ and $\Delta\tilde{p} = 0.0002\times\tilde{Q}^2 + 0.0346\times\tilde{Q}$ with and without guidewire. Thus, the overestimation in measured $\Delta\tilde{p}$ was about 28% at hyperemia. This value agreed well with our previous studies on moderate coronary stenoses [2,3]. Further experiments are needed with flow profile more representative of patho-physiological coronary flow, and to compare with measured values of FFR and CFR with guidewire.

ACKNOWLEDGEMENT

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Table 1: *In vitro* test section dimensions

Proximal Vessel dia.	2.95 mm	%mean area stenoses= $(1-(1.75/2.95)^2)\times100$= 64.8%
Distal Vessel dia.	2.95 mm	
Length of converging section	6.96 mm	
Length of diverging section	1.79 mm	%mean area stenoses With guidewire= $(1-\frac{1.75^2-0.35^2}{2.95^2-0.35^2})\times100$= 65.7%
Length of throat	3.15 mm	
Throat dia.	1.75 mm	

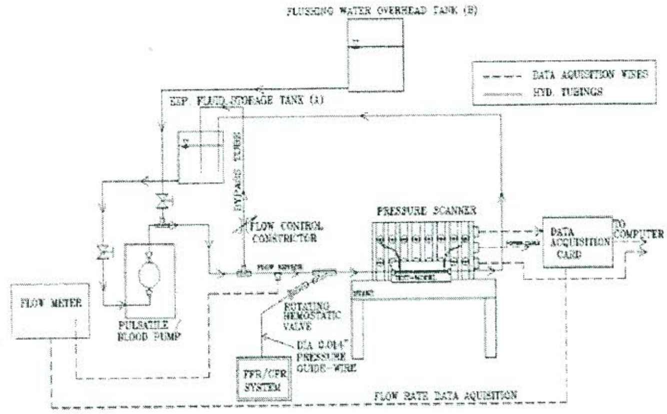

Figure 1: Experimental flow loop.

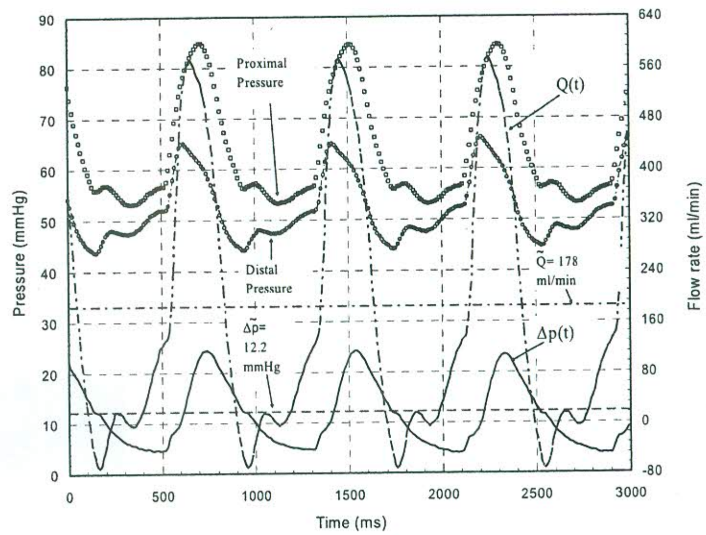

Figure 2: p(t) (proximal and distal ports), Δp(t) and Q(t) at $\tilde{Q}$ =178 ml/min without guidewire.

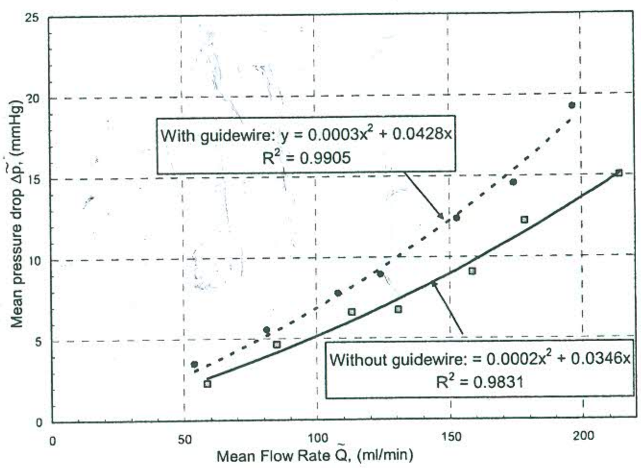

Figure 3: $\Delta\tilde{p}$ Vs $\tilde{Q}$ with and without guidewire.