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IN VITRO PRESSURE FLOW RELATIONSHIP IN MODEL OF SIGNIFICANT CORONARY ARTERY STENOSIS

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ABSTRACT

Simultaneous measurement of pressure and flow rate has been found to be helpful in evaluating the physiologic significance of obstructive coronary artery disease and in the diagnosis of microvascular disease. This experimental study seeks to find important pressure-flow relationship in an *in-vitro* model of significant coronary artery stenoses using a non-Newtonian liquid ,similar to blood showing a shear thinning behavior, using significant stenotic *in-vitro* model (minimal area stenosis = 90%). The geometry for the stenotic model is based on data provided in an *in vivo* study by Wilson et al., (1988). For 90% area stenosis, the maximum recorded pressure drop for steady flow rate of 55, 79 and 89 are 14, ~24 and ~32 mmHg respectively. The maximum pressure drop at flow rate of 115 ml/min (the physiological limit) is 50.3 mmHg respectively. Using a power law curve fit, the maximum pressure drop (in mmHg) related with flow rate (in ml/min) provided a power law index of 1.72. Shorter distal length than required in the *in-vitro* model did not allow the recording of complete pressure recovery. This preliminary data provides reference values for further experimentation both *in vitro* with pulsatile flow as in physiological conditions, and *in vivo*.

INTRODUCTION

The morbidity and mortality associated with PCI are less than 5%. The restenosis rate of the balloon angioplasty is in the range of 40%, and this usually becomes manifest within 4-6 months. Several studies have been conducted on stenotic models to understand the hemodynamics in stenotic arteries (Cho et al., 1983; Young et al., 1973, Berger et al., 2000, etc.). This study seeks to further understand the hemodynamics of blood flow through stenotic coronary arteries and quantify physiological parameters such as estimation of Fractional Flow Reserve (FFR). In this study, the dimensional data for the test section (having minimal area blockage 90%) was obtained (Wilson et.al., 1988, Banerjee et al., 2003) from a group of 32 patients who had single-vessel, single-lesion coronary artery disease with unstable or stable angina pectoris. The experimental data could be used to obtain important values pertaining to Coronary Flow Reserve (CFR) and Fractional Flow Reserve (FFR), which are used during cardiac catheterization to evaluate the hemodynamic significance of a stenosis and to determine further management, specifically pertaining to future percutaneous coronary intervention (PCI).

METHODS

Experimental Procedure

A non-newtonian shear thinning fluid (33% by wt. Glycerin, 67% by wt. Water, 0.02% by wt. Xanthum gum (XG); density=1.1 gm/cm^3) is used for this experiment (Brookshier et al., 1993). To get viscosity variation with shear rate, measurements were made with AR2000 Rheometer (TA Instruments, DE). The viscosity of the fluid showed a shear thinning behavior with increasing shear rate. The viscosity data of the fluid gave the following constants for the Carreau Model: $\mu_\infty = 0.032P, \mu_0 = 0.56P, T = 3.424\sec$ and $n = 0.424$.

The experiment is conducted at steady flow. *In-vitro* model of the different stenosis severity were manufactured using optical grade lexan. For pressure measurements, ports were drilled along the length of the test-section which were sequentially connected to a pressure transducer (Validyne Inc., CA) to measure the pressure along the axial direction. Before each experiment, the transducer was calibrated by an in-line water manometer so that any errors due to zero shift of the transducer are removed or minimized. The pressure drop (Δp) is recorded through a data acquisition system (National Instruments) in units of Volts and subsequently converted to mmHg by using the linear calibration curve. For steady flow, a PULSAFEEDER pump was used to supply the solution to an overflow-overhead tank so as to maintain a constant supply head. Flow rate was calculated by weighing a sample of the fluid coming out of the test section for 4 mins divided by the density of the fluid.

RESULTS AND DISCUSSION

Figure 1 shows the photograph of the 90% stenosed test section with the pressure ports along the length of the test section. Figure 2 shows the preliminary results of pressure drop measured along the length of the 90% area blockage test section at different distances for different flow rates. In the figure, the pressure at third port from the left is taken as reference port to calculate and plot the pressure drop. Due to ports being limited to a distal length of ~2.5 cm in the 90% stenosed test section, the complete pressure recovery distal to the stenosis could not be recorded. Figure 3 shows the maximum pressure drops recorded for different flow rates. For 90% area stenosis, the maximum recorded pressure drop for flow rate of 55, 79 and 89 are 14, ~24 and ~32 mmHg respectively. The maximum pressure drop at flow rate of 115 ml/min is 50.3 mmHg. The physiological limit for 90% area stenosis above which the mean distal pressure can go below 55 mmHg (known to cause ischemia) is ~115 ml/min. While the non-linear nature of the pressure drop Vs flow rate is evident (quadratic curve fit), the absence of shear layer wave instabilities in the experimental data (Fig. 1) is consistent with findings of Banerjee et al. (2003). Using a power law curve fit, the maximum pressure drop (in mmHg) provided the following relation with flow rate (in ml/min): $\Delta p = 0.0143xQ^{1.72}$. The presence of these instabilities in pulsatile blood flow can enhance the pressure recovery, thus giving shorter distal recovery lengths as compared to relatively longer lengths observed in steady flow.

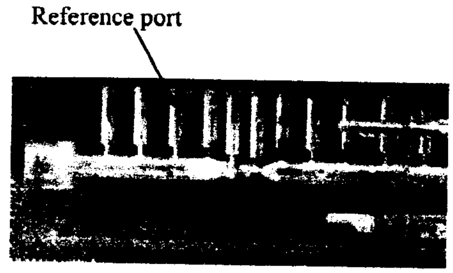

Figure 1: 90% stenosed test section. Figure shows the stenosis with pressure ports along the length of the test section. There are additional ports in the plane normal to the plane of the paper which are not seen in this photograph.

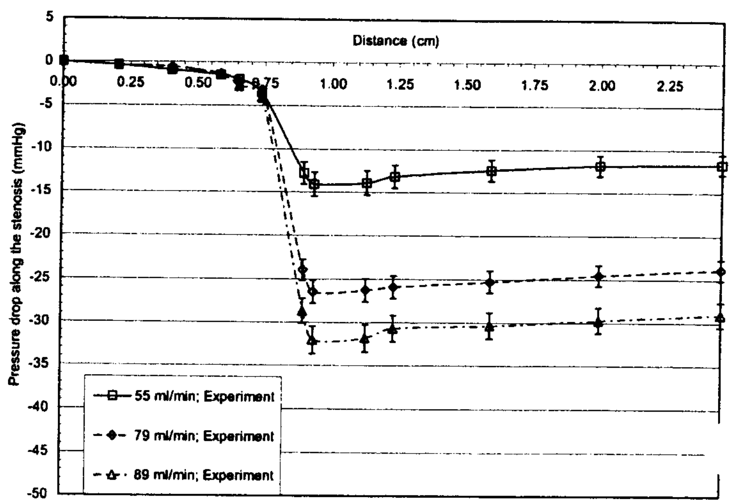

Figure 2: Pressure drop measured along the length of the 90% area blockage test section. Experimental values measured at different flow rates are indicated by symbols.

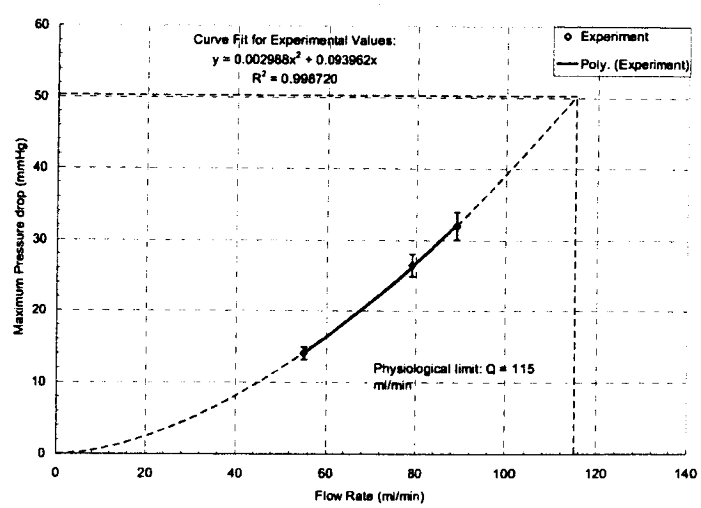

Figure 3: Maximum recorded pressure drop at different flow rates: Experimental curve fit is provided.

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