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IN VITRO MEASUREMENTS OF FLOW OBSTRUCTION EFFECT DUE TO GUIDEWIRE INSERTION IN CORONARY STENOSES MODELS

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ABSTRACT

The severity of coronary stenosis is measured by FFR (the ratio of the absolute distal coronary and aortic pressures at hyperemia) and CFR (the ratio of coronary flow at hyperemia to basal), using invasive method in which small diameter guidewires (GW) (diameter = 0.014 in. or 0.35 mm) are inserted through stenotic vessel. The clinical decision making of severity for intermediate % area stenosis is critical since FFR may lie near the threshold value of 0.75. However, GW insertion obstructs the blood flow (\tilde{Q}) by increasing the transstenotic pressure drop ($\Delta\tilde{p}$) which further complicates the diagnostic process [2]. The purpose of this extensive *in vitro* experimental study was to quantify this GW flow obstruction and overestimation of $\Delta\tilde{p}$ for intermediate and severe coronary stenoses models (~81% and ~90% area stenoses, respectively) with a non-Newtonian blood model under pulsatile hemodynamics. For intermediate stenosis, before GW insertion, $\Delta\tilde{p}$ increased from 6.3 to 50.5 mmHg as \tilde{Q} increased from 49 (basal) to 172 ml/min (hyperemic) [1, 2]. With GW insertion, $\Delta\tilde{p}$ increased from 7.4 to 57.8 mmHg with corresponding flow of 45 (basal) to 160 ml/min (hyperemic). At limiting $\Delta\tilde{p}$ of 40 mmHg (assuming ostium pressure ~ 95 mmHg), hyperemic \tilde{Q} was reduced by 21 ml/min (16% flow reduction) due to GW insertion. Similarly, for severe stenosis, within flow range of 45 (basal) to 108 ml/min (hyperemic) [2], flow reduction of 19 ml/min occurred (26% reduction) at limiting $\Delta\tilde{p}$ of 40 mmHg due to GW insertion. The experimental $\Delta\tilde{p}$ well agrees with previous computational studies [2].

INTRODUCTION

Many researchers have done *in vitro* and *in vivo* studies to find $\Delta\tilde{p}$ in various stenotic models [1,3,4,5]. However, clinically $\Delta\tilde{p}$ and \tilde{Q} are measured using guidewires only [1,3]. Very few literatures [3], gave hemodynamic studies for guidewire insertion through coronary stenosis. However, experimental validation under physiological situations is still pending. Previously, such experimental study has

been done for moderate % area stenosis model, where $\Delta\tilde{p}$ vs. \tilde{Q} characteristic for with and without GW insertion was explained [7]. The present study along with previous study for moderate % area stenosis could be particularly useful for predicting reduction in \tilde{Q} due to GW insertion. The geometries for these studies are based on the data provided in an *in vivo* study [1]. Thus, clinicians can get a priori estimate of overestimated $\Delta\tilde{p}$ and reduced \tilde{Q} due to GW, knowing $\Delta\tilde{p}$ in GW inserted condition. This will help to estimate more accurate severity of coronary stenosis by finding out FFR (without GW insertion), specially in the intermediate % area blockage regime.

METHODS

The same experimental set up and procedures [7] are followed to measure $\Delta\tilde{p}$ and \tilde{Q} in present study. A non-Newtonian shear thinning fluid with carreau model coefficients: $\mu_\infty = 3.76$ cP, $\mu_0 = 50$ cP, $\lambda = 0.25$, $n = 8$ and density = 1.06 gm/cm³ was used for these experiments. The basic pulsatile flow was generated by pulsatile blood pump (Harvard Apparatus, MA) and later modified to coronary flow profile [2] by using compliance chambers. The check valve is added in flow circuit before test section to avoid excess reverse flow. The lexan test section was manufactured with dimensions as given in fig 1.

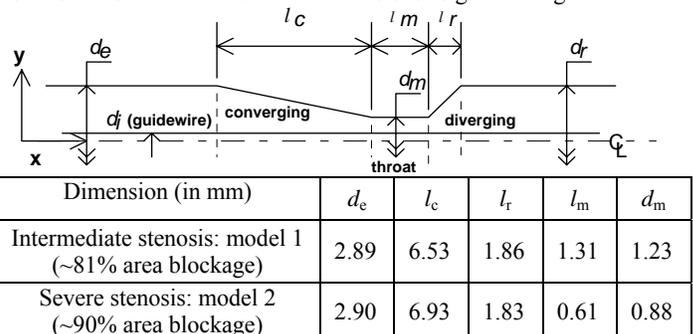


Figure 1: Stenotic model geometry and dimensions.

The pressure ports were drilled in axial direction in such a way that individual $\Delta\tilde{p}$ in each section (converging, throat and diverging) can be measured. The digital pressure scanner (Scanivalve Corp, WA) was used to measure pulsatile pressure at every 12 ms. Pulsatile flow was also measured with ultrasonic flow transducer (Transonic Systems Inc, NY). The pressure and flow readings were recorded simultaneously with SC-2070 data acquisition card and Virtual bench software (National Instruments, TX). To quantify the guidewire flow obstruction effect under clinical settings, the pressure measuring guidewire and FFR/CFR measuring system (SmartWire and Combomap system, Volcano Therapeutics, CA) were used. Later on, reduction in flow and overestimation of $\Delta\tilde{p}$ were calculated.

RESULTS AND DISCUSSION

Three sets of experiments were conducted for each % area blockage model. Without GW insertion pressure was measured with pressure scanner and after inserting GW, pressure was measured with GW and FFR/CFR system as well as with pressure scanner. A typical pressure pulse is shown in the Fig 2. For intermediate stenosis, flow was increased from 49 (basal) to 172 ml/min (hyperemic) and for severe stenosis model, from 45 to 108 ml/min [2] (Fig 3). Before increasing flow to the next step, GW was inserted to delineate GW flow obstruction effect for same flow. For intermediate stenosis, without GW, $\Delta\tilde{p} - \tilde{Q}$ relation was $\Delta\tilde{p} = 0.0015\tilde{Q}^2 + 0.05\tilde{Q}$. After inserting GW, this relation was changed to $\Delta\tilde{p} = 0.002\tilde{Q}^2 + 0.075\tilde{Q}$. For severe stenosis, the corresponding relations were $\Delta\tilde{p} = 0.0035\tilde{Q}^2 + 0.12\tilde{Q}$ (without GW) and $\Delta\tilde{p} = 0.005\tilde{Q}^2 + 0.18\tilde{Q}$ (with GW). The reduction in \tilde{Q} at given $\Delta\tilde{p}$ for various stenotic geometries are shown in fig 4. The ischemic condition was detected when distal coronary pressure falls below 55 mmHg (i.e. $\Delta\tilde{p} \sim 40$ mmHg assuming ostium pressure ~ 95 mmHg) [6]. Hence, at this $\Delta\tilde{p}$, flow reduction was estimated for stenoses models. These flow reductions were 16% (21 ml/min out of 127 ml/min) and 26% (19 ml/min out of 73 ml/min) for intermediate and severe blockages, respectively. Further, GW insertion in intermediate stenosis increases both viscous and momentum change related losses but in severe stenosis model, GW insertion appreciably increases pressure losses associated with momentum change only. These two facts prove dominance of momentum change related $\Delta\tilde{p}$ over viscous $\Delta\tilde{p}$, in intermediate to severe stenosis. The same trend of overestimation of $\Delta\tilde{p}$ from intermediate to severe stenosis was found previously [3]. Further experiments are needed to find out better correlation between $\Delta\tilde{p}_{\text{without GW}}$ and $\Delta\tilde{p}_{\text{with GW}}$ for various lesion lengths.

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REFERENCES

(1) Wilson, R.F., Johnson, M.R., et al., 1988, "The effect of coronary angioplasty on coronary flow reserve." *Circ.* Vol. 77, pp.873-885.
 (2) Banerjee, R.K., Back, L.H., et al. 2003, "Physiological flow simulation in significant human coronary artery stenoses." *Biorheology.* Vol. 40, pp. 451-476 and 613-635.
 (3) De Bruyne et al., 1993, "Transtenotic coronary pressure gradient measurement in Humans: In vitro and In vivo evaluation of a new pressure monitoring angioplasty guidewire *J. American College of cardiology* Vol. 22 (1) pp. 119-126.
 (4) Young, D.F., Tsai, F.Y., 1973, "Flow characteristics in models of

arterial stenosis-I steady flow and- II unsteady flow." *J. Biomech.* Vol.6, pp. 395-410 and pp. 547-559.

(5) Lipscomb, K., Hooten, S. 1978, "Effect of stenosis dimensions and blood flow on the hemodynamic significance of model coronary artery stenoses." *Am. J. Cardiology,* Vol. 42, pp. 781-792.

(6) Brown B.G. et al, 1984, "Dynamic mechanisms in human coronary stenosis". *Circ.* Vol. 70 (6), pp. 917-922.

(7) Ashtekar, K.D., Sinha Roy, A., et al. 2005, "In-vitro evaluation of guidewire flow obstruction in diagnosis of coronary lesion severity using pulsatile hemodynamics" *Summer Bioengg. Conf.* (B0164982).

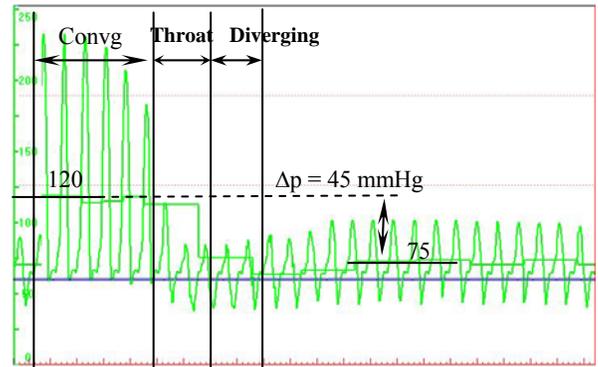


Figure 2: Instantaneous pressures in axial length (measured by advancing guidewire in test section and FFR system)

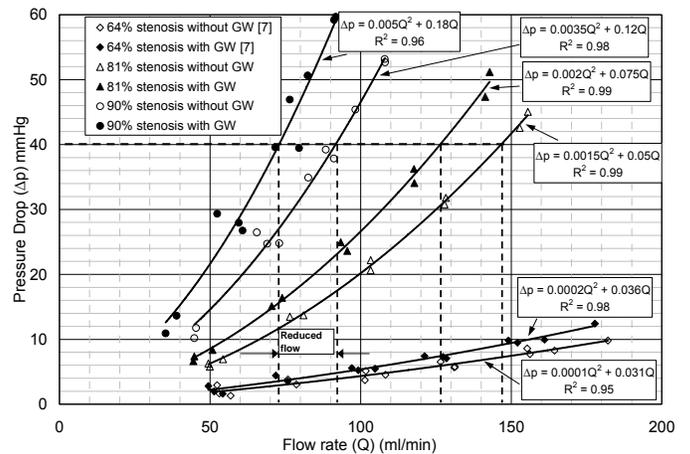


Figure 3: $\Delta\tilde{p}$ Vs \tilde{Q} : with and without guidewire. (n=3)

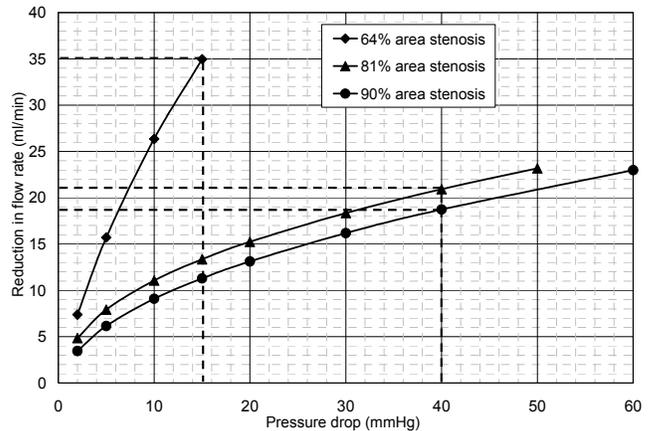


Figure 4: Flow reduction due to guidewire insertion