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ASSESSMENT OF AORTIC STENOSIS SEVERITY USING PRESSURE DROP COEFFICIENT: A RETROSPECTIVE STUDY IN HUMANS

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ABSTRACT

Accurate assessment of the stenosis severity is critical in patients with aortic stenosis (AS). The ambiguities and reduced sensitivities of the current diagnostic parameters can result in sub-optimal clinical decision making. In this preliminary study, we investigate the functional diagnostic parameter CDP (ratio of the transvalvular pressure drop to the proximal dynamic pressure) for the assessment of AS severity by correlating with the current diagnostic parameters. CDP was calculated using diagnostic parameters obtained from retrospective chart reviews. CDP values were calculated independently from Doppler and catheterization measurements. CDP exhibited better correlation with transvalvular pressure drop and jet velocity simultaneously, than when correlated independently with the same diagnostic parameters. CDP increases with increasing AS severity, which is consistent with hydrodynamic principles. This retrospective study is a prelude to a prospective study to evaluate CDP for AS severity assessment.

INTRODUCTION

Aortic stenosis (AS) is a type of valvular heart disease that results from abnormal narrowing of the aortic valve opening. The uncertainties and discrepancies in the current diagnostic end-points determined by Doppler echocardiography and cardiac catheterization have been previously discussed [1]. Doppler calculates the transvalvular pressure drop ($\Delta p_{doppler}$) and effective orifice area (EOA) using the jet velocity (V_{jet}) measured at the vena contracta of the valve (Figure 1) [1]. Cardiac catheterization measures the pressure drop (Δp_{cath}) and cardiac output (CO) (Figure 1), while the aortic valve area (AVA) is calculated using the Gorlin equation [1].

There are significant differences between $\Delta p_{doppler}$ and Δp_{cath} due to the pressure-recovery phenomenon [1]. Another major source for error in the assessment of AS severity with the currently used end-points is its sensitivity to the CO [2]. Low transvalvular pressure gradients in subjects with low cardiac output (CO) due to LV dysfunction can be a source of error.

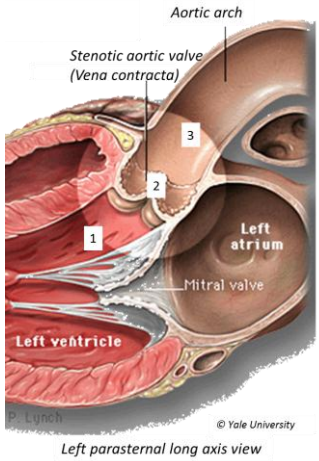

Figure 1: Anatomical location of measured parameters for AS severity assessment (CC Patrick J. Lynch and C. Carl Jaffe, Yale University, 2006)

It was proposed that the new diagnostic parameter based on fundamental fluid dynamics principles, pressure drop coefficient (CDP: ratio of the transvalvular pressure drop to the proximal dynamic pressure) will improve the sensitivity and specificity of AS severity assessment and better delineate AS severity. Moreover the proposed

diagnostic index will be less sensitive to the discrepancy between the Doppler and catheter measurements and more independent of cardiac loading conditions. CDP has been previously evaluated for assessing the severity of coronary stenosis and has been shown to be independent of the hemodynamic influence of heart rate fluctuations [3]. The aim of this preliminary retrospective study is to correlate CDP calculated from the Doppler and catheterization measurements with the existing diagnostic parameters.

METHODS

Study Patients. The study population consisted of 16 patients that were selected by a retrospective review of patient records. The selected patients were 18 years or older and were suspected to have mild to severe AS based on Doppler or catheterization measurements. Data from five patients with inconsistent pressure-flow measurements (e.g. 1 procedural error as catheterization transducer was not properly zeroed, 1 $\Delta p_{cath} = 4x\Delta p_{doppler}$) and incomplete data (e.g. 3 incomplete Doppler measurements) were excluded. Two patients with bioprosthetic aortic valves were also excluded. Thus, 9 patients were included in this initial retrospective study.

Data Analysis. The mean values of V_{jet}, LVOT velocity (V_{LVOT}), and calculated $\Delta p_{doppler}$ were obtained from the Doppler images. Similarly the mean Δp_{cath} was obtained from the catheterization reports. The hemodynamic diagnostic parameter, CDP was calculated as the ratio of the mean pressure drop to the mean proximal dynamic pressure. The CDP values were calculated independently from Doppler and catheterization measurements, where ρ is the density of blood (1.05 gm/cm^3) and V_{LVOT} is the Doppler measured mean LVOT velocity.

$$CDP_{doppler} = \frac{\Delta p_{doppler}}{0.5 \times \rho \times V_{LVOT}^{\ 2}} \qquad (1)$$

$$CDP_{cath} = \frac{\Delta p_{Cath}}{0.5 \times \rho \times V_{LVOT}^{\ 2}} \qquad (2)$$

Velocities are not measured during standard of care catheterization and hence Doppler measured V_{LVOT} was used to calculate CDP_{cath} in this retrospective study.

Statistical Analysis. A linear regression analysis was performed on data from the 9 patients to assess any significant linear correlations between CDP and the existing diagnostic parameters. Data from one patient was identified as an influential outlier based on Cook's Distance and excluded from the regression analysis. A probability value of $p<0.05$ was considered statistically significant.

RESULTS

The mean values of $\Delta p_{doppler}$, V_{jet}, Δp_{cath}, $CDP_{doppler}$ and CDP_{cath} for the 8 patients (excluding the outlier) are reported in Table 1.

Table 1: Mean values of Δp, V_{jet}, and CDP

	Mean	Range
$\Delta p_{doppler}$ [mm Hg]	31.5 ± 8.2	20-42
V_{jet} [cm/s]	263.5 ± 40.4	200-314
Δp_{cath} [mm Hg]	35.1 ± 14.5	12-59
$CDP_{doppler}$	25.3 ± 16.75	9.2-57.4
CDP_{cath}	26 ± 17.1	10.5-54

The correlation of the functional index, CDP with the current diagnostic parameters Δp and V_{jet} is described in Table 2. $CDP_{doppler}$ exhibited better correlation with $\Delta p_{doppler}$ and V_{jet} simultaneously (r=0.7), than when correlated independently with the same variables (r=0.55 & r=0.5 respectively). Similarly the simultaneous correlation of CDP_{cath} with Δp_{cath} and V_{jet} (r=0.76) was better than the individual correlations with the same diagnostic parameters (r=0.52 & r=0.74 respectively). This is consistent with the definition of CDP, which is function of both pressure (Δp) and flow (velocity). The correlations reported are moderately significant.

The regression equations described in Table 2 show that CDP increases with increasing AS severity, i.e. with increasing Δp and V_{jet}. This is consistent with hydrodynamic principle of flow through stenotic orifices, which indicates progressive acceleration and convergence of flow field proximal to and through the stenosis with subsequent divergence and deceleration downstream from the stenosis (Figure 1).

Table 2: Correlation of CDP, Δp and V_{jet}

Dependent vs. Independent variable	Regression equation	Correlation coefficient	p-value
$CDP_{doppler}$ vs. $\Delta p_{doppler}$	1.12 x($\Delta p_{doppler}$) - 10.0	r=0.55	p=0.16
$CDP_{doppler}$ vs. V_{jet}	0.21x(V_{jet}) - 29.15	r=0.5	p=0.21
$CDP_{doppler}$ vs. $\Delta p_{doppler}$ and V_{jet}	9.26 x($\Delta p_{doppler}$) - 1.66x(V_{jet}) + 172.0	r=0.7	p=0.18
CDP_{cath} vs. Δp_{cath}	0.61 x(Δp_{cath}) + 4.5	r=0.52	p=0.19
CDP_{cath} vs. V_{jet}	0.31x(V_{jet}) - 56.5	r=0.74	p<0.05
CDP_{cath} vs. Δp_{cath} and V_{jet}	-0.44 x(Δp_{cath}) + 0.45x(V_{jet}) - 75.9	r=0.76	p=0.11

CONCLUSION AND DISCUSSION

This preliminary retrospective study has confirmed the feasibility of using both pressure drop and flow in a single diagnostic index, CDP for assessment of AS severity. With the advent of less invasive techniques for treatment of AS, it is imperative that more accurate diagnostic end-points be pursued. Using a wide range of values, it is expected that CDP will be able to better delineate different grades of AS severity. It is anticipated that with the inclusion of more patients in this retrospective study, significant correlations between CDP and the existing diagnostic parameters will be obtained. In the future, it is of interest to conduct a prospective study to evaluate CDP for diagnosing AS severity.

REFERENCES

1. Scherrer-Crosbie et al. Aortic Stenosis: Physics and Physiology - What Do the Numbers Really Mean. Reviews in Cardiovascular Medicine, 2005. 6(1): p. 23-32.
2. Zile MR et al. Heart failure in aortic stenosis - improving diagnosis and treatment. The New England journal of medicine, 2003. 348(18): p. 1735.
3. Kolli KK et al. Influence of heart rate on fractional flow reserve, pressure drop coefficient and lesion flow coefficient for epicardial coronary stenosis in a porcine model. Am J Physiol Heart Circ Physiol. 2010.