FLOW DEPENDENT CHANGES IN AORTIC VALVE EFFECTIVE ORIFICE AREA: THE ROLE OF UNSTEADY FLOW EFFECTS

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Introduction

Aortic valve stenosis is defined as an incomplete opening of the aortic valve. When the ventricular outflow crosses the aortic stenosis, it first converges leading to an area smaller than the geometric area of the valvular orifice. This area is usually called the Effective Orifice Area (EOA). The EOA is one of the most important parameter used to evaluate aortic stenosis severity. However, the EOA may vary with transvalvular flow and the explanation of this flow dependence remains controversial. Some studies have suggested that EOA estimated by Doppler-echocardiography (EOA_{Dop}) may underestimate the actual EOA at low flow rates[1]. The objective of this in vitro study was to elucidate the mechanism of the flow dependence of the EOA.

Methods

One bioprosthetic valve and three sharp-edged orifices of 0.5; 1.0 and 1.5 cm^2 were tested in a mock flow model[2] under pulsatile flow conditions at 4 stroke volumes (SV): 20, 30, 50, and 70 mL. The EOA_{Dop} was compared to the reference EOA (EOA_{PIV}) measured by Particle Image Velocimetry using a new technique based on an acoustical term source[2].

Results

There was an excellent correlation and agreement between EOA_{Dop} and EOA_{PIV} (R^2=0.94; difference: 0.003±0.103 cm^2). For the sharp-edged orifices of 0.5 cm^2 and 1.0 cm^2, no significant change in the EOA was observed with increasing flow rate. For the sharp-edged orifice of 1.5 cm^2 and the bioprosthetic valve, a substantial increase in both EOA_{Dop} and EOA_{PIV} was observed when SV increased from 20 to 70 mL (orifice 1.5cm^2: EOA_{Dop}:+52%, EOA_{PIV}:+54% and bioprosthetic valve: EOA_{Dop}:+62%,; EOA_{PIV}:+63%).
In the case of the sharp-edged orifice of 1.5 cm^2, the variation of EOA with flow could be predicted by taken into account the preponderance of unsteady effects at low flow (Figure.1), using the equation:

$$EOA_L = EOA_N \left(\frac{St_N}{St_L} \right)^{\frac{1}{3.5}} = EOA_N \left(\frac{SV_N}{SV_L} \right)^{\frac{1}{3.5}} \quad (1)$$

where, St is the Strouhal number and L and N indices refer to normal and low flow conditions respectively. This equation also successfully predicted the EOA flow dependence in sharp-edged orifices of 1.5 and 2.0 cm^2 tested by Voelker and al.[3] (mean error: orifice 1.5 cm^2: 0.02±0.005 cm^2; orifice 2.0 cm^2: 0.03±0.03 cm^2 In the bioprosthetic valve, the variation in EOA predicted by equation 1 underestimated the variation in EOA measured by Doppler or PIV. This was likely due to the fact that, as opposed to sharp-edged rigid orifices, the bioprosthetic valve is flexible and, as a consequence, its geometric orifice area may also vary with flow rate.

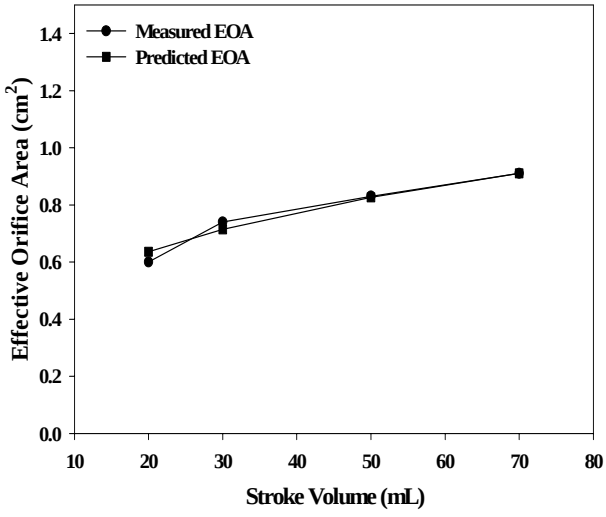

Figure.1: Measured and predicted EOA (using equation 1) for a sharp-edged orifice of 1.5 cm^2.

Conclusion

Using the PIV method as a reference, the present study shows that Doppler derived EOAs provide accurate estimates of actual EOAs over a wide range of valve orifice sizes and flow rates. The EOA flow dependence is not due to measurement artifacts and can

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be accurately predicted by taking into account unsteady effects at low flow rates.

References

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