BILEAFLET MECHANICAL HEART VALVE HINGE REGION FLOWS IN THE AORTIC AND MITRAL POSITIONS

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INTRODUCTION

Bileaflet mechanical heart valves are the most commonly implanted valve design due to their unmatched durability and their good bulk flow hemodynamics. However, their implantation may cause major complications including hemolysis, platelet activation, and thromboembolic events. Clinical reports and in vitro experiments suggest that the thrombogenic potential of bileaflet valves is mainly promoted by the leakage flow through the closed valve, especially through the hinge regions. Additionally, the clinical performances of mechanical heart valves implanted in the aortic position were found to be better than those in the mitral position due to a lower rate of thrombus formation and hemolysis. *In vitro* experiments revealed that this was mainly due to a difference in hinge flow hemodynamics [1] associated with differences in bulk flow profiles in the aortic and the mitral positions.

AIM OF THE CURRENT WORK

The aim of the current study is to quantify the differences in the hemodynamic properties within the hinge for a valve in the mitral and in the aortic positions. The flow structures within the hinge are examined to provide a better understanding of the dependence of the clinical performance upon implant location.

METHODS

In order to gain optical access to the hinge regions, a reverse-engineered clear housing 23 mm CarboMedics bileaflet valve was mounted in the aortic and mitral positions of the Georgia Tech left heart simulator. The physiologic flow waveforms for both the aortic and mitral positions are shown in figure 1. Two-component velocity measurements were obtained with a fiber-optic Laser Doppler Velocimetry (LDV) system (Aerometrics Inc, Sunnyvale, CA) used in coincident backscattering mode. Each 860 ms cardiac cycle was divided into 43 time bins, 20 ms in duration, and the velocities were phase averaged within these time bins. A detailed description of the data acquisition system and the data reduction method can be found in the literature [1-3].

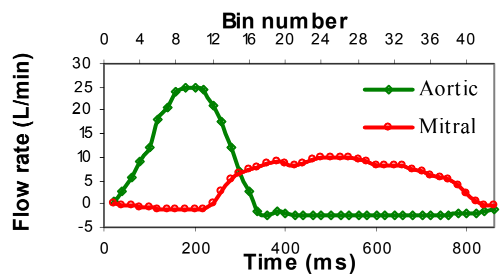

Figure 1: Flow waveform through the valve in the aortic position and mitral positions

In order to compare the dominant features for the two valve positions the cardiac cycle was divided into five characteristic phases as listed in table 1.

Phase	Aortic position	Mitral position
Acceleration	43→10 (11)	11→18 (8)
Peak	9→11 (3)	18→30 (13)
Deceleration	10→18 (9)	30→42 (13)
Forward	43→18 (19)	11→42 (32)
Closed	18→43 (26)	42→11 (13)

Table 1: Time bin ranges for the characteristic phases of the cardiac cycle, the number of bins for each phase are indicated in parenthesis.

The interpolated velocity fields, shown in figures 2 (a & c) and 3(a & c) for the peak and closed phases respectively, have been phase averaged. The contours correspond to the magnitude of the velocity vectors. The Reynolds shear stress (RSS) fields were calculated by taking the principle component of the Reynolds turbulent shear stress matrix, as described in previous literature [2]. The fields shown in figures 2 (b & d) and 3 (b & d) have been integrated over the phase period to illustrate the cumulative effect of the phases. The location of the valve leaflet in figures 2 & 3 can be inferred by the region of zero flow or RSS. During forward flow the leaflet is almost horizontal, while during closure the leaflet rotates clockwise approximately 55 degrees.

RESULTS AND DISCUSSION

The peak phase flow field in the aortic position, shown in figure 2a, has regions of high velocity both above and below the leaflet with flow orientated predominantly in the forward (leftward) direction. In contrast the peak forward flow in the mitral position, shown in figure 2c, appears to be preferentially directed above the leaflet with a recirculation region below the leaflet. The peak phase averaged velocity magnitude in the mitral position is also significantly lower which is consistent with the bulk flow through the aortic and mitral valves. The flow patterns during the peak phase are similar to those observed during the acceleration phase. During the deceleration phase there is a reversal of the flow in the bottom right hand pocket, with a more extensive region of flow reversal in the mitral position.

In the aortic position the peak flow generates regions of high RSS where the high velocity flow in the upper hinge meets the edge of the hinge, as shown in figure 2b. A second region of elevated RSS corresponds to high velocity flow between the bottom leading edge of the leaflet and the lower hinge edge. The RSS patterns during peak flow in the mitral position, shown in figure 2d, are distinctly different from those in the aortic position with high RSS levels occurring along the upper surface of the leaflet. Interestingly, the integrated RSS values in the mitral position are lower than those in the aortic position despite the fact that the integration in the mitral position occurs over 13 bins compared to only 3 bins in the aortic position. Additionally, when the RSS levels are integrated over the entire cycle the maximum shear levels in the aortic position are approximately 3 times those in the mitral position.

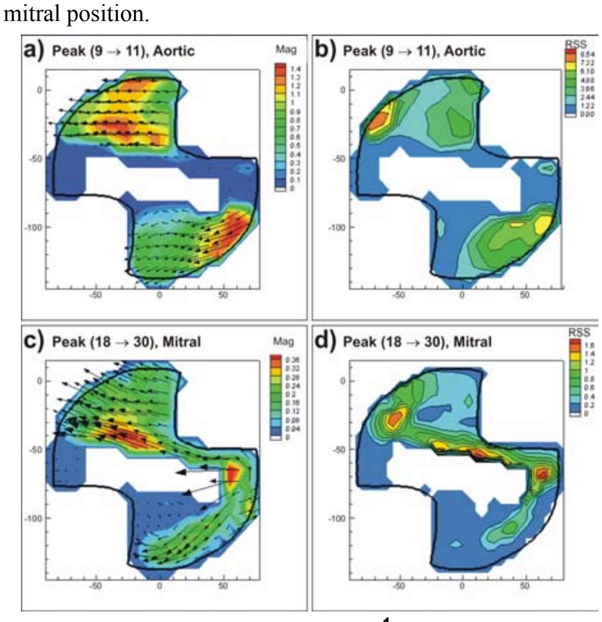

Figure 2: Peak phase velocity (ms^{-1}) and integrated RSS (Nsm^{-2}) for the mitral and aortic positions

The flow and RSS fields occurring when the leaflet is closed are shown in figure 3. Although the overall bulk flow rates during valve closure, shown in figure 1, are relatively low, a large percentage of this leakage flow passes through the small hinge area generating large flow velocities. The RSS patterns averaged over the entire cardiac cycle are remarkably similar to those obtained by averaging only over the closed phase of the cycle, indicating that the generation of RSS occurs predominantly during the closed phase.

The closed phase aortic flow field, shown in figure 3a, is characterized by two high velocity jets on the right hand side of the hinge region. The two-dimensional velocity of the leakage flow coming into the hinge region is relatively low compared to the very high velocity jets exiting the hinge indicating that the flow is three-dimensional. This is further confirmed by the velocity vector direction. The flow patterns for the closed valve in the mitral position are similar to the aortic case but the lower jet is more centralised and the flow velocities are lower. The duration of the closed phase in the aortic position is twice that of the mitral and thus the relative velocity magnitudes indicate that the volume of leakage flow passing through the investigated level is significantly greater in the aortic position. Both the integrated and average maximum RSS levels in the closed mitral valve are less than those in the aortic position. The region of high RSS occurs in the upper section of the closed aortic valve, while high RSS values occur in the lower portion of the closed mitral valve.

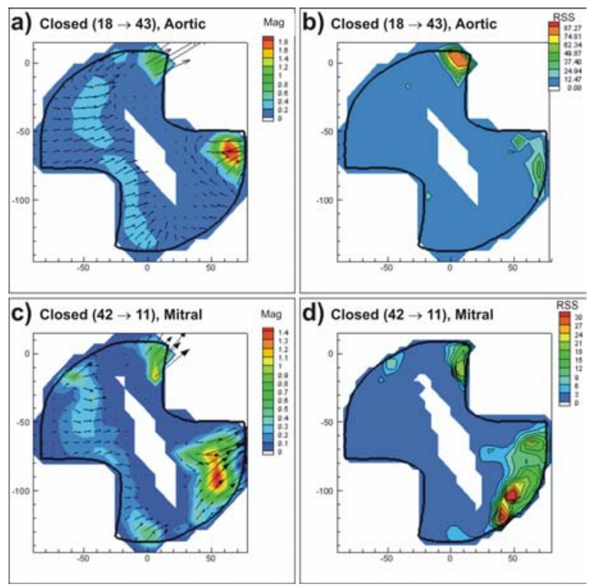

Figure 3: Closed phase level velocity (ms^{-1}) and integrated RSS (Nsm^{-2}) for the mitral and aortic positions

CONCLUSIONS

These results show the flow structures and corresponding flow induced Reynolds shear stresses are significantly different when the same valve is implanted in different positions and thus subjected to different flow conditions. This indicates that optimisation of valve hemodynamics and clinical performance may require implantation location specific valve designs.

REFERENCES

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