EFFECT OF AORTIC VALVE GEOMETRY ON LEAFLET STRAIN WITHIN A PHANTOM SILICONE AORTIC HEART VALVE DURING CLOSING

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Introduction

This paper characterises the changes in strain profiles of the tricuspid aortic valve leaflets while closing in variable valve geometries, along with measuring free edge twist. The aim is to firstly demonstrate a workflow for assessing the mechanical behaviour of such valves to enable optimised designs and, secondly, to demonstrate the role of geometric parameters on valve performance.

Methods

Using a similar method to Van Loon [1], an stl file of the tricuspid aortic valve was produced with initial dimensions defined by De Hart [2] (Valve 1). The values of the commissure height and the leaflet tilt angle were then varied to produce a further two models (Valves 2 and 3 respectively). These stl models were converted to mould designs to cast the valves in silicone.

Valves were mounted in a viewing tank incorporated into a flow system analogous to the human circulatory system. This was used to open and close the valve at a rate of 80 bpm with a pressure range of 80-120mmHg. Highspeed stereo-digital image correlation (6000fps) was performed on the upper valve leaflet during closing while simultaneous pressure readings were taken at the points shown in Figure 1. Readings for each valve were repeated four times.

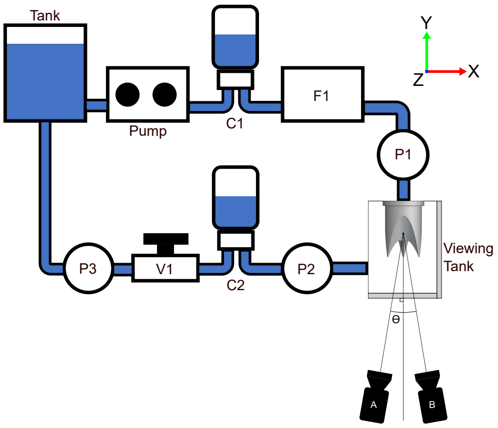

Figure 1: The flow and imaging setup including pressure sensors at P1, P2 and P3. Θ= 19.2° and the cameras are elevated at 5.7° to view the upper leaflet.

Results

Displacement and mean maximum principle strain were recorded at 5 points on the top valve leaflet, then plotted against the mean transvalvular pressure drop. Figure 2 shows an example result. All valves showed discontinuous softening behaviour, which can be split into two stages. Stage 1 showed asymptotic softening to a critical value (Stage 2). Here it becomes much stiffer before softening again. The magnitude of displacement within Stage 1 varies significantly both between valves and between the locations on the leaflet. Stage 2 is more consistent between valves, with the magnitude and shape of the pressure drop curves being similar.

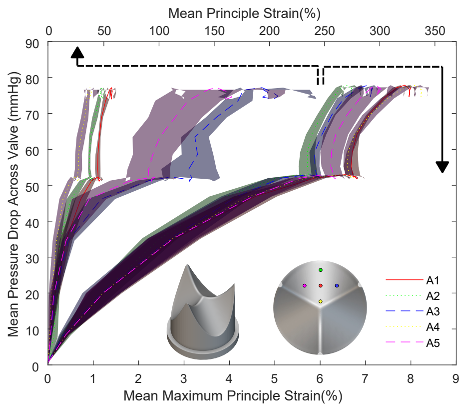

Figure 2: The mean maximum principle strain and displacement across repeat cycles versus pressure drop.

Discussion

Stage 1 behaviour is produced through the combination of geometry and material properties. The former causes significant differences in the profiles. Stage 2 is controlled predominantly by the latter, leading to similar looking Stage 2 curves across valve geometries. During Stage 1 the orifice of the valve has closed, and the leaflets fill under increasing downstream pressure. Here, twisting and locking of the free edge is observed. The critical value where Stage 1 ends and Stage 2 begins marks the end of the geometry defined displacement. Further deformation is caused by the sinking of the valve leaflets, the resistance to which, is determined by the material properties of the silicone. Within the leaflets themselves there is also significant differences in readings. Asymmetries lead to anticlockwise twisting regardless of valve geometry.

References

1. Van Loon, Int J Numer Method Biomed Eng. 26(3–4):405–20, 2010
2. De Hart et al, J Biomech. 36(1):103-12, 2003

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