6.4. FLUID MECHANICS OF THE AORTIC VALVE

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1. INTRODUCTION

The aortic valve consists of three thin (0.1 mm) cusps and three matching sinuses. The cusps are reinforced with collagen strands running from commissure to commissure. Under no load the cusps furl up in the axial direction. When closed, the cusps are stretched out and are supported by the underslung loops of collagen. A photograph of a human aortic root is shown in Figure 1 of chapter 6.1. The left ventricle is marked \( V \), the aorta \( A \), a cusp \( C \) and its corresponding sinus \( S \). The diameter of the aorta is approximately 25 mm. In measurements of instantaneous velocity in the ascending aortas of dogs, using heated thin-film gauges (1), it was shown that aortic blood-flow was laminar, that there was no central jet and that reversed flow at the end of systole was very small. These measurements showed, however, that velocity was not uniform across the aorta. These results were surprising, because they implied that the valve was open wide at mid-systole, otherwise the flow would have been turbulent (since the peak Reynolds number was 10,000), but that the valve closed, or nearly closed, during systole with flow still going forwards through the valve. Since the thin-film gauge responds to velocity fluctuations of frequencies well in excess of 10kHz, turbulence would certainly have been detected had it existed.

Anatomists have long been aware of the existence of the aortic sinuses, and Leonardo da Vinci (2) postulated (in 1513) that vortices were generated within them and that these vortices urged the cusps towards closure. The existence of the vortices, and the rapid clearance of radiopaque dye within them is readily apparent from cineangiograms of the aortic root.

In 1912, an alternative explanation of valve closure was given by Henderson and Johnson (3). They gave it the quaint title “the breaking of the jet,” an effect depending on deceleration of the aortic flow.

Based on model experiments a fluid mechanic explanation of aortic valve closure was postulated (4). In the model valve, which had three natural rubber cusps (0.1 mm thick) and a rigid aortic root and sinuses, the cusps opened wide early in systole, vortices formed in the sinuses, and the cusps moved towards closure, under the action of the vortices together with the
adverse pressure gradient associated with decelerating aortic flow, in the latter part of systole. A small amount of reversed flow (2%-5% of stroke volume) was required to seal the valve.

The relative importance of the sinus vortices and the adverse axial pressure-gradient in effecting valve closure has been difficult to determine, because they are so closely interrelated. The purpose of the work reported here was to attempt to separate the two hydraulic effects by varying the geometry of the aortic sinuses.

2. METHODS

A model of the aortic root was made (Figure 1), which consisted of a rigid perspex case into which the cusps were glued. The sinuses were made of perspex also, and were detachable. The cusps were made of uniform sheets of natural rubber 0.1 mm thick, and were glued with silicone rubber adhesive into the aortic root. The model valve was placed in a pulsatile flow rig (4) which could produce sinusoidal pulses, of frequencies up to 10 Hz, superimposed on a steady flow. A viewer was placed downstream of the valve so that the cusps could be photographed with a cine camera at 50 frames per second.

*Figure 1. Scale drawing of a model of the aortic root with interchangeable sinuses of various geometries (side view on the left and end view on the right). Both sinus length (A) and sinus depth (B) were varied.*