PERCUTANEOUS AORTIC VALVE REPLACEMENT

This proposal for a project to develop a percutaneous aortic valve replacement is divided into seven sections. The section on anatomy describes the native aortic valve and its function. The following section on the valve's dynamics and physics discusses the implications of the anatomy for the valve's successful function. The sections on aortic stenosis and regurgitation describes valve dysfunction and the section on surgical therapy discusses current surgical replacement therapy and its problems. The final two sections outline the study objectives and stages. The purpose of the study is to develop a percutaneous placement technique and prosthetic valve that would mimic the function of the native valve and avoid problems associated with current methods for surgical replacement.

I. Aortic Valve Anatomy

The aortic valve directs the flow of blood from the left ventricle into the systemic circulation through the aortic artery. It accomplishes this function by opening during the contraction of the left ventricle and closing when the left ventricle relaxes.

In a normally functioning valve, three leaflet-shaped cusps open widely to allow the unimpeded transference of blood, and then close tightly, not allowing any blood back into the left ventricle. Significant restriction to blood flow is called stenosis, and blood leakage back into the left ventricle is called regurgitation.

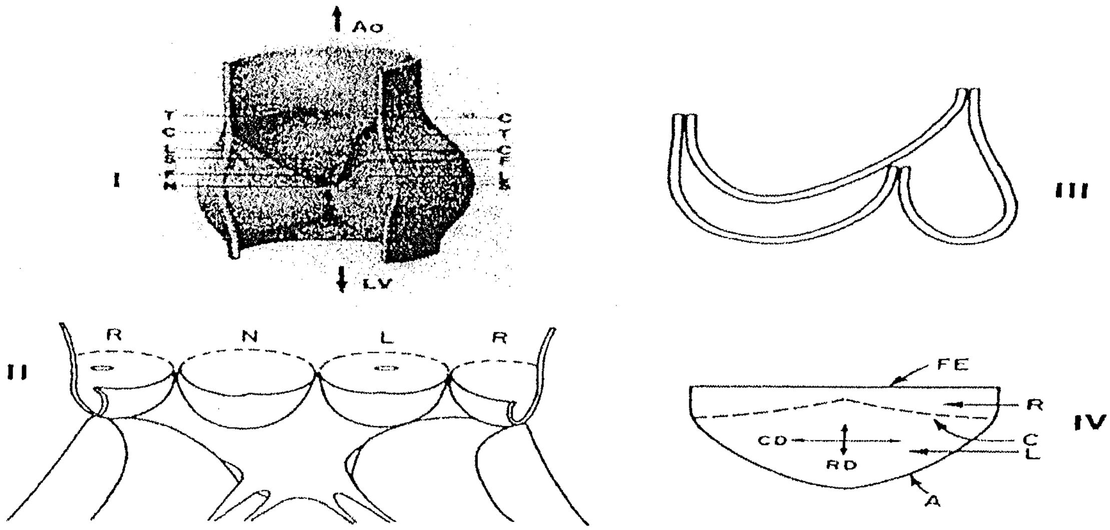

Figure 1

The aortic valve is a tricuspid structure. Each cusp folds up toward the aorta during the contraction phase and then folds back against the others in the relaxation phase. [Figure 1] However, it is important to understand that the structure of the aortic valve is complex, with integral relationships beyond its three-leaflet valve structure. For instance, each leaflet sits directly opposite an out pouching of the proximal aorta. This dilated segment, called the sinus of valsalva, is part of an anatomic relationship that assists the repetitive opening and closing of the valve while minimizing the stress on any point within this valvular apparatus. Further, the proximal portion of the aortic valve is highly elastic, which allows it to dilate during the contraction phase of the left ventricle.

Moreover, these valvular structures are integrally related to the coronary arteries, which supply blood to the heart. These arteries, as represented in Figure 2, are located within 2 of the three sinuses. Thus, each component plays a vital role in the function and durability of the valve.

The first components of the aortic valve I would like to discuss are the leaflets.

As stated, the number of leaflets within a normal aortic valve is three. Any congenital variation in the number of leaflets causes significant problems with function. When there are less than three valves, the valve undergoes rapid stenosis and restriction. An individual with a unicusped valve rarely survives beyond the first year of life. Among individuals with congenital alterations in the valve number, the most frequently encountered is a bicuspid aortic valve. Individuals with this variation in valve number can survive into adulthood. However, this valve combination becomes more and more stenotic and regurgitant by the 4th and 5th decade, which usually results in the need for surgical replacement. (See figures 3 and 4). Rarely, an individual with a quadricusped valve will survive into adulthood. This alteration in design also results in marked stenosis.

The anatomy of a normal aortic valve (three cusps, sinuses, aortic arteries) permits the dispersion of pressure over a larger surface area in the structure.

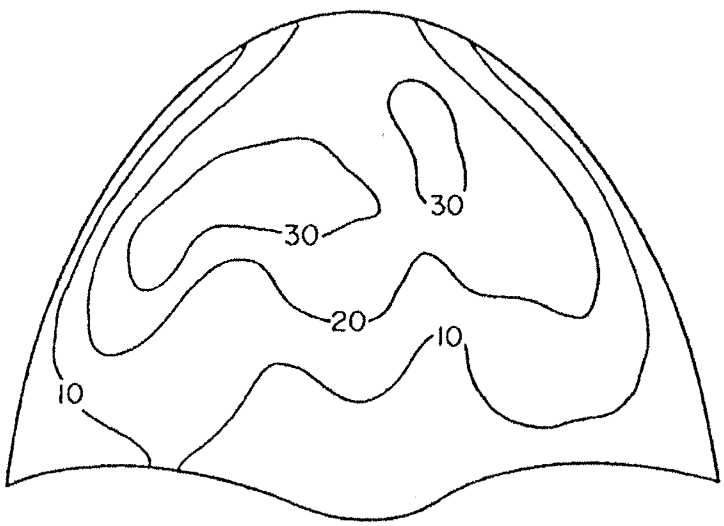

Figure 4.1

This dispersion resists the exhaustion of any one component of the valve. Moreover, the curvature of the cusp structure allows the leaflet to reverse curvature, an ability needed in order to fold and allow the maximum opening diameter during contraction. Finally, a curved design allows a redundancy in the coaptation area of the leaflets. The area of coaptation is the valve edge that must meet and close in order to prevent regurgitation. Hence, both the number of leaflets and their overall shape is important in the function and durability of the valve.

As mentioned earlier, the valve leaflets have a direct relationship to the sinuses of valsalva. The sinus diameter is almost twice that of the aorta.

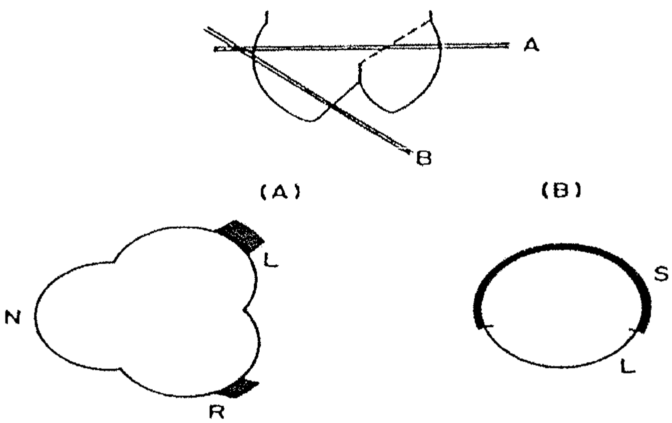

Figure4.2

This cavity plays an important role in the mechanism of valve closure.

[referenced Mano Thubrikar] An oblique section through the leaflet-sinus assembly shows this remarkable relationship (see Figure 4). This section reveals that the sinus and leaflet form a circle when the valve is in a closed position. Furthermore, it is angulated to a degree as to allow pressure transduction along the entire surface of this unit. All this suggests that the shape of the leaflet-sinus assembly is important in determining how stresses are developed within the valve. This relationship also allows the valve leaflets to close without straining the aortic valve. Finally, this relationship of the sinuses and valve allows for the efficient flow of blood in the coronary ostia.

Another structure, the aortic root, has been observed to expand during ventricular contraction. The dilatation of this structure reduces tension, which in turn reduces resistance to flow, as predicted by Poisselles' law, which describes the relationship of resistance to vessel diameter, length of tube and fluid viscosity. This phenomenon also allows for complete opening of the aortic valve. Interestingly, when the cusps open, a circular dimension is maintained that is at least the same diameter as before contraction(Medical Engineering & Physics 19(8): 696-710,1997). This behavior reduces circumferential stress on the valve and generates a reduced Reynolds shear stress number (the number used to evaluate the amount of stress in a confined fluid system). In a similar manner, the inner lining of the cusp of the valve, the lamina ventricularis, extends into the ventricular myocardium when the valve is in an open position. A confluence of fibers at the base, called the fibrous coronet, is a distinct structure separating the elastic fibers above and the myocardium below. However, this structure is not static. It is a very dynamic structure, which bends and molds to the forces exerted from the ventricular myocardium (Cardiovascular Research, 22,7,1988)(Journal of Biomechanics33 (6): 653-658, 2000 June). In a fashion similar to the aortic root, this structure allows the valvular apparatus to open with the least amount of strain.

The coronary arteries arise within or above the sinuses of valsalva. The blood flow to the heart occurs during ventricular diastole. At this time, the cusps of the aortic valve are closed, and as mentioned, the diastolic forces of the blood against the valve are dispersed along the valve and adjacent sinus. The opening, or ostia, of the coronary arteries, when located near the apex and middle of the sinuses, allows for least turbulent, most laminar flow characteristics.

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