Designing valves: An art or science?

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Designing and reconstructing semilunar valves for use in children has been the focus of research and clinical practice of both clinicians and engineers in recent years. Surgeons have traditionally used an experimental approach that is based primarily on clinical experience and intuition. Analytic approaches that are based on engineering principles have also been proposed,^{1,2} promising a more precision-based individual approach.³

The article in this issue of the *Journal* by Kan and colleagues⁴ describes a handmade expanded polytetrafluoroethylene valved conduit for right ventricular outflow tract reconstruction and reports acceptable in vitro and in vivo performance. Although others have presented similar expanded polytetrafluoroethylene valved conduits,⁵ an important contribution of Kan and colleagues⁴ is the quantitative description that allows others to recreate their design. This requires math to define conduit diameter, leaflet width, leaflet height, and the curves describing the leaflet attachment edge and free edge given the size of a patient's pulmonary artery. The equations that the authors present do not show why the particular form for the leaflet edges (parabolas) was chosen or how their choice of leaflet size relates to features of the closed, loaded valve. The latter relationship deserves a closer look.

In the normal, closed semilunar valve, the leaflet free edges angle downward, with angle Φ , toward the point of central coaptation (Figure 1). The length of the leaflet free edge in this state is approximately as follows:

$$W = \frac{D}{\lambda \cos \phi}$$

where D is the diameter of the valve root and λ is the degree of stretch of the leaflet width under load.⁶ This angle, Φ , is typically 30° to 35° degrees.⁷ A material like expanded polytetrafluoroethylene does not stretch appreciably under load ($\lambda = 1$), so the equation predicts that the leaflets in the closed and loaded state must have width 15% to 20% greater than the vessel diameter to meet at the valve center in the presence of this downward excursion. Kan and colleagues,⁴ however,

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Central Message

An analytic approach to surgical valve reconstruction guided by anatomic measurements and quantitative principles of valve mechanics may offer precision personalized valve reconstruction.

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chose leaflet width equal to one-third of the vessel (conduit) perimeter, or $\pi D/3$, so we would expect the width of their leaflets in the valved conduit to be inadequate. They oversized the valved conduit by 10% to 20%, however, so that it is not fully opened in the pulmonary artery, and this provides the requisite amount of slack to allow the downward

FIGURE 1. Relationship of leaflet free edge (dashed line) to diameter (D) of valve root at tops of commissures in diastole. Φ , Angle of the leaflet free edges downward toward the point of central coaptation.

excursion of the closed leaflets. This may explain the competence of their valve as reported in their study.

Although a surgical journal is not the right forum for detailed mathematical analyses, a simple equation or two may occasionally be necessary to adequately describe a surgical reconstruction method. In addition, simple equations that approximate complex physical behaviors—such as the one accounting for the excursion and stretch of a valve leaflet in the closed state—may provide quantitative guidance for challenging aspects of valve reconstruction.

Surgical valve reconstruction may still seem an art in the hands of gifted surgeons. Precision personalized valve reconstruction, however—guided by anatomic measurements and quantitative principles of valve mechanics—may make such procedures available to more patients and improve reliability of outcomes.

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