Actual Orifice Area of the Porcine Heterograft: A Discussion

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The ideal orifice area of a prosthetic heart valve, whether it is of tissue or mechanical, is one which equals the area of the annulus into which it is to be implanted. Obviously, this is not possible since all valves are necessarily encumbered with such accoutrements as sewing rings, stents or housings, and valving members, all of which subtract square millimeters from the available tissue annulus area. Table 1 is a comparison between the tissue annulus size, both diameter and area, and the maximum orifice area of several popular heart valve replacements.

In the porcine valves, there must be a substantial difference between the stent orifice area as advertised by the manufacturer and the actual orifice area of the bioprosthesis. Besides the stent, which combines into one piece both the sewing ring and the framework for mounting the porcine aortic valve, there is the necessary cuff of aortic tissue as well as the inherent characteristics of the semilunar pig valve. The importance of this latter factor came to mind while reviewing Brewer's study on the dynamic valve annulus.[2]

In this paper, he speaks of the orifice of the natural human aortic valve as being more triangular in shape rather than completely circular. Therefore, the cusps do not open as fully as one would imagine. To compensate for this characteristic, the annulus expands an average of 16% during the open phase of valve function.

Brewer further develops a simple, mathematical relationship between the closed valve and the open orifice. The open valve forms a, presumably, equilateral triangle each leg of which is equal to the diameter of the closed valve. This relationship was intriguing.

TABLE 1

Tissue Annulus Diameter (mm.)	Tissue Annulus Area (mm^2)	Hancock Stent Area (mm^2)	Carpentier Stent Area (mm^2)	Angell Stent Area (mm^2)	Bjork-Shiley Orifice (mm^2)
19	284	154	164		150
21	346	201	240		200
23	415	254	324	296	250
25	491	380	419	336	320
27	573	416	434	414	380
29	661	490	511	480	460
31	755	572	593	553	460
33	855	660	680	618	
35	962	706	730		

Comparison of tissue annulus area with the stent area of porcine heterografts. The Bjork-Shiley is offered as a mechanical comparison.

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It had seemed as though it should be possible to somehow calculate more approximately the actual orifice area of the porcine bioprosthesis and the Brewer relationship offered possibilities. The actual orifice area would be a more realistic comparison to what may be seen when the effective orifice area is calculated by the formula of Gorlin and Gorlin[3] following post-implant cardiac catheterization.

Effective orifice area is determined by relating flow through the valve to the pressure gradient measured across the valve. This is based on Bernoulli's principle which states, in effect, a specific orifice area will produce a trans-orifice pressure gradient relative to the flow velocity through the orifice. The Gorlin formula is most frequently used to determine the effective orifice area of a diseased heart valve following pre-operative catheterization but is equally capable of determining the effective orifice of valvular implants. Since Brewer's relationship included an added increment corresponding to the 16% increase in diameter in the natural annulus, an adjustment was necessary to correct the leg length of the triangular orifice of the stented heterograft because this annulus will not expand. It seemed most reasonable empirically that $x \times 0.84$ would yield the correct measurement.

I opted to use the radius which was determined by dividing the stent orifice area published by the manufacturer by 3.1416 (π) and taking the square root of the result. This was a simple reversal of the formula Area = πR^2.

Trying to remember sufficient high school plane geometry, I converted the corrected triangle leg length ($2R \times 0.84$) into the area of an equilateral triangle. The area of a triangle requires the application of the formula: Area = height $\times$ $^1/_2$ base. Since an equilateral triangle is two right triangles back-to-back, I knew the hypotenuse ($2R \times 0.84$) as well as the base ($R \times 0.84$) of one right triangle. By applying the Pythagorean theorem, I could determine the height of the triangle:

$$\sqrt{(2R \times 0.84)^2 - (R \times 0.84)^2}$$

Once I had determined the height of the equilateral triangle, it was only necessary to multiply that number by one-half the length of the base ($R \times 0.84$) to find the actual area of the open porcine, stent-mounted valve. The entire two-stage process was something like this:

1. $R = \sqrt{\frac{\text{Area}}{\pi}}$
2. $AOA = (R \times 0.84) \times \sqrt{(2R \times 0.84)^2 - (R \times 0.84)^2}$

While it looks quite complex (especially to me), it was not too difficult to feed through a calculator.

To test the accuracy of numbers derived from this formula, a search of the recent literature was made to find papers concerning post-implant hemodynamic studies on porcine valves. The main criterion was that effective orifice areas had to have been presented. Two were found; one by Jones and his colleagues,[5] another by Johnson and colleagues.[4] Table 2 is a comparison of the stent orifice area, the actual orifice area, and the effective orifice areas seen by Johnson and Jones. For further comparison, the orifice areas of some pivotal disc valves are included.

While the formula takes into account neither anatomical differences among porcine aortic valves nor variations in cusp flexibility, it does yield a more workable measurement

TABLE 2

Tissue Annulus Diameter (mm)	Hancock Stent Area (mm^2)	"Actual" Orifice Area (mm^2)	Effective Area (Jones)[5] (mm^2)	Effective Area (Johnson)[4] (mm^2)	
19	284	60	98		Range
21	346	78	103		
23	415	99	129	106	60–145
25	491	121	144	150	80–300
27	573	162	161	147	90–210

Comparison of actual orifice area with the effective orifice area of the Hancock aortic bioprosthesis.

of the potential effective area that might be measured *in vivo* by the application of the Aaslid[1] or Gorlin formulas.

Porcine valve orifices are shaped more like a rounded trapezoid than a perfect circle. Stent designs vary to support in different ways the natural anatomy of the pig aortic valve and the muscular septal shelf of its right coronary cusp. The difference between the calculated actual orifice area and the calculated effective orifice area is greatest in the small sizes where the asymmetrical variations are most pronounced.

To give an efficiency index so that valves of different sizes might be compared with each other, in 1975, Aaslid[1] in Oslo, Norway, proposed the effective area index. This simple formula equates effective orifice area to tissue annulus area, the former being divided by the latter. An index of 1.0 is the impossible ideal while 0.5 is considered good by today's standards. Probably 0.7 or 0.75 is the best index that might be technologically feasible in the future. Certainly no valve of any type or design has ever reached it yet. Table 3 is a comparison of Aaslid's effective area index utilizing the effective orifice areas found in Johnson and Jones and the calculated actual orifice area.

Most of the Hancock bioprostheses are around 0.3 in the aortic position, a most disheartening discovery. According to Aaslid, the Bjork-Shiley and Lillehei-Kaster pivotal disc prostheses range between 0.4 and 0.5. Again, the use of the actual orifice area calculation is least accurate in the smaller size but approximates rather well the larger size for which we have effective orifice areas.

TABLE 3

Tissue Annulus Diameter	"Actual" Orifice Index	Effective Index (Jones)	Effective Index (Johnson)
19	0.211	0.345	
21	0.225	0.298	
23	0.239	0.310	0.255
25	0.246	0.293	0.305
27	0.283	0.281	0.257

The Aaslid index is the orifice area divided by the tissue annulus area. A "good" index is about 0.50 while 0.75 is a theoretical maximum.

This technique for determining actual orifice area does not allow hair-splitting accuracy but it does allow a reasonable, approximate number to be derived. The actual orifice area bears a reasonable resemblance to the effective orifice area. This determination, however crude, allows a more realistic impression of the post-implant effectiveness of a porcine bioprosthesis.

The reporting of effective orifice area and, possibly, the use of the Aaslid effective area index will increase in the literature. Once an Aaslid index number becomes relatively standard for a valve design, such as 0.3 for the Hancock and 0.5 for the Bjork-Shiley, it is a simple matter to multiply the tissue annulus area by this index to determine more accurately the actual orifice or anticipated effective orifice area of a given prosthesis or bioprosthesis.

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