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Assessment of the Orifice Area of Bioprosthetic Valves by Orifice-View Roentgenography

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Orifice-view angiography permits us to visualize en face the orifice of the aortic or mitral valve. The radiopaque annulus of bioprosthetic valves assists in permitting the angiographer to position the patient exactly, so that the valve can be seen as if looking directly into the orifice. Orifice-view angiography of porcine bioprosthetic valves has been useful in assessing the size and configuration of the valve orifice. It can reveal a failure of leaflet opening that would indicate degeneration, even when hemodynamic measurements remain equivocal.

To evaluate the possibility of stenosis or incomplete opening of a prosthetic valve, quantitative assessment of the valve orifice is useful. The effective size of the orifice can be measured by angiograms obtained at a projection which shows the orifice en face, a technique termed orifice-view angiography (1-3). The configuration of the orifice shown by orifice-view angiography provides a qualitative as well as a quantitative assessment of the functional valve area.

Two-dimensional echocardiography, although potentially ideal for this purpose because it is noninvasive, does not show the orifice area of porcine bioprosthetic valves with sufficient detail to measure the area of the orifice. Echocardiography is useful, however, for assessing thickening, fluttering, or abnormal motion of the leaflets (4). Calculation of the orifice area of prosthetic valves from hemodynamic data utilizes the hemodynamic calculations of the Gorlin equation (5) or its modifications. Although this technique is a cornerstone for hemodynamic evaluation, its limitations include the necessity of crossing the valve, the requirement for accurate measurement of the pressure gradient (which in mildly stenotic valves may be small and difficult to measure), and the simultaneous accurate measurement of cardiac output. Also, stiffening of the leaflets, which usually occurs with valvular degeneration and can result in incomplete opening of the leaflets, may not cause clinical manifestations of valvular stenosis and may not be clearly detectable by hemodynamic studies. However, it may be possible to detect abnormalities by orifice-view angiography and to identify them before overt regurgitation occurs.

To date, we have evaluated 12 valves by orifice-view angiography. All were of the unmodified porcine bioprosthetic type, that is, all the valves had a muscular shelf beneath the right coronary cusp, which is the normal porcine configuration and is used in Hancock models 242 and 342. In six patients, the valves were in the aortic position, and in six in the mitral position.

For visualization of the aortic valve, a catheter is placed in the aorta with the tip just distal to the valve. As contrast material opacifies the root of the aorta, nonopacified blood from the ventricle creates a jet, the perimeter

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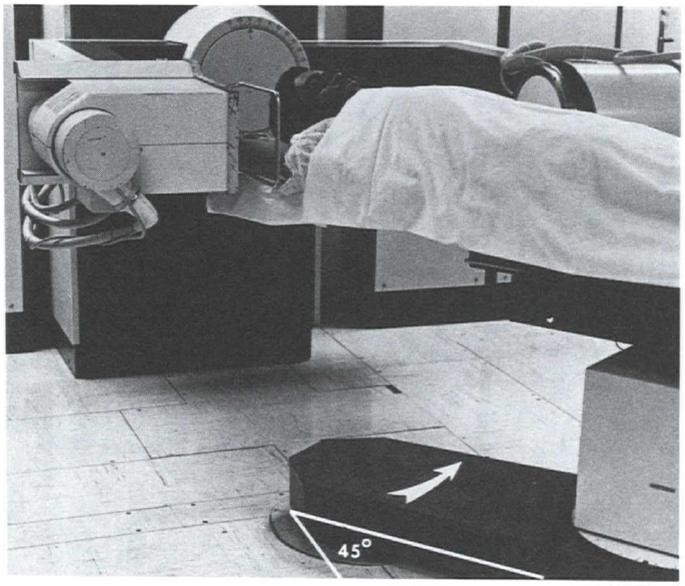

Fig. 1

Position for visualization of the orifice of the aortic valve. Typically, the table should be rotated 40° counter-clockwise (see arrow), although the limitations of the equipment may make it impossible to achieve this rotation. The orifice can be adequately seen in most patients if the table is rotated somewhat less than 45°.

of which defines the orifice of the aortic valve. To show the mitral valve, the tip of the catheter is placed in the left ventricle. Nonopacified blood, as it passes through the mitral valve, creates a jet, the perimeter of which defines the orifice of the mitral valve.

The technique for orifice-view angiography requires careful positioning of the patient (Fig. 1). The aortic valve usually tilts toward the right and somewhat anteriorly (1,2) although it is usually unnecessary to attempt to compensate for the anterior tilt (Fig. 2). The table is turned counter-clockwise 40° to give a caudal angulation, with the x-ray tube image intensifier oriented in a straight lateral projection (Fig. 1). In this position, the x-ray beam travels approximately from the right axilla to the left iliac crest. In most patients, the table should be angulated 45° (1,2), but some equipment (e.g., the Siemens "U" arm and table) may be limited to a smaller angle. Because the valve ring is radiopaque, the projection can be modified in a patient to show the ring as a perfect circle. This eliminates any error due to distortion of the projected image which might occur from a projection not perpendicular to the orifice.

The mitral valve usually tilts toward the right shoulder and anteriorly (Fig. 3). To show the mitral valve en face in most patients, the table should be positioned to produce a 25° caudal angulation by turning it 25° in a counter-clockwise direction. The U arm should be rotated 30°

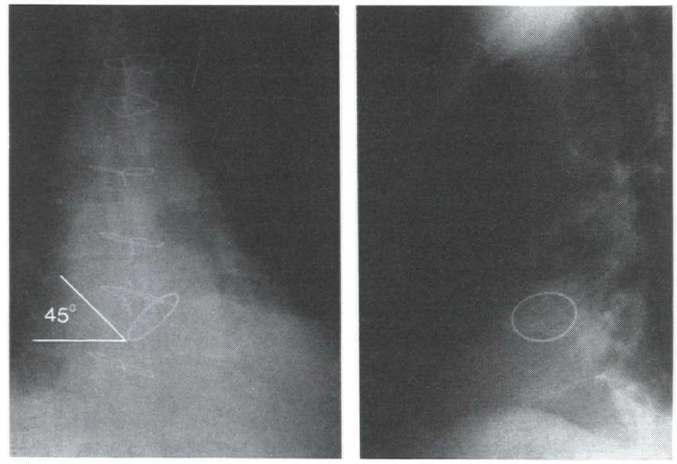

Fig. 2

Patient with porcine bioprosthetic valve in the aortic position. Left: Posterior-anterior view. The x-ray beam should be elevated 45° obliquely from a true lateral position to show the orifice en face. Right: Lateral view. The valve tilts only slightly anteriorly, approximately 15°.

from the vertical in a clockwise direction (toward the patient's left side) to produce a left anterior oblique projection (Fig. 4). In 80% of patients, this projection permits us to measure the cross-sectional area of the mitral valve with less than 10% error due to distortion of the projected image (3). As with the aortic valve, modification of this projection can be made to show the ring of the prosthetic valve as a perfect circle, thus eliminating any error due to distortion. The orifice of the mitral valve is seen as unopacified blood flows through the valve into the opacified left ventricle. Planimetry can be used to measure the orifice area of the valve from the angiogram. The image is corrected for magnification on the basis of the known outside diameter of the annulus of the valve, which is clearly visible on the film. If the diameter of the annulus is not known, a calibrated grid can be positioned perpendicular to the x-ray beam at the level of the valve. Large amounts of prosthetic regurgitation may make it difficult to see the valve orifice satisfactorily.

Among the 12 patients we evaluated, the areas of the valve orifices measured from the orifice-view roentgenograms corresponded to values predicted by the Gorlin hydraulic equation (Table I).

An example of an orifice-view aortogram of a normal aortic bioprosthetic valve is shown in Fig. 5. Among the five patients with bioprosthetic valves in the aortic position who had normally functioning valves, the orifice areas ranged from 1.4 to 2.3 cm^2. The orifice area thus shown was only 29% of the area inscribed by the outer

TABLE I

Hemodynamic and Roentgenographic Measures

Patient	Valve Position	Tissue Annulus Diameter (mm)	Valve Area by Orifice View (cm^2)	Valve Area by Gorlin Equation (cm^2)	Pressure Gradient* (mmHg)
1	Aortic	29	2.3	-	2
2	Aortic	25	1.4	1.7	30
3	Aortic	29	1.6	-	-
4	Aortic	25	1.5	1.8	18
5	Aortic	27	1.6	2.6	14
6	Aortic**	25	1.1	0.8	46
7	Mitral	29	1.3	-	-
8	Mitral	29	1.4	1.7	9
9	Mitral	35	2.0	1.5	10
10	Mitral	31	2.8	-	0
11	Mitral	27	1.2	-	0
12	Mitral	31	1.7	-	5

**Peak systolic pressure gradient for the aortic valve and mean diastolic pressure gradient for the mitral valve*

***Degenerated valve*

diameter of the annulus, which some have termed the implantation area. The configuration of the valve orifice, as shown in the patient by orifice-view angiography, was comparable to the configuration of the porcine valve orifice photographed in an in vitro hydraulic cardiac simulator (Fig. 6). In the porcine aortic valve, the right coronary cusp does not open to the full extent of the annulus because of the muscular subvalvular shelf. During peak ejection, the margins of the orifice seemed somewhat irregular, and its configuration depended on the stroke volume, as did the size of the orifice.

An example of an orifice-view aortogram of a bioprosthetic valve in the mitral position is shown in Fig. 7. Among the six patients with bioprosthetic valves in the mitral position, the orifice area ranged from 1.2 to 2.8 cm^2 (Table I). One patient had severe prosthetic regurgitation, but none had stenosis. As with the valve in the aortic position, orifice sizes were considerably smaller than normal. The orifice area was only 24% of the area

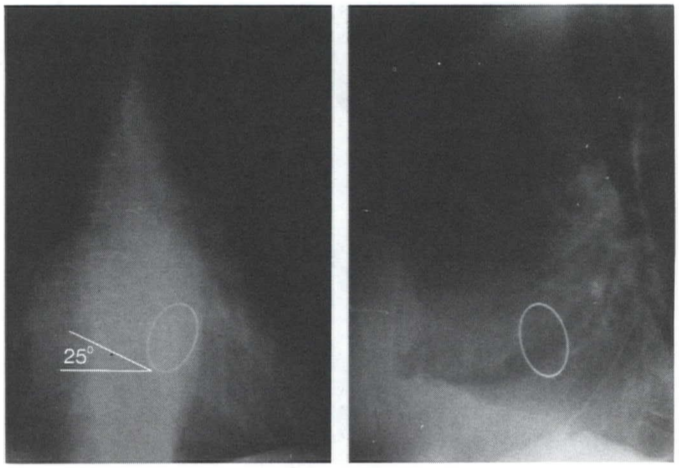

Fig. 3

Patient with porcine bioprosthetic valve in the mitral position. Left: Posterior-anterior projection. A 25° superior elevation from a true lateral usually will be perpendicular to the orifice. In this particular patient, if the x-ray beam were elevated slightly less than 25°, the beam would be perfectly perpendicular to the orifice. Right: Lateral projection. There is a significant anterior tilt of the valve. To accommodate for this anterior tilt, the U arm of the x-ray set should be rotated clockwise from the vertical. The amount of rotation in most patients is 30°.

inscribed by the tissue annulus diameter of these valves (the implantation area).

The areas of the orifices shown on orifice-view aortograms corresponded closely to the average orifice areas calculated on the basis of pooled data of hemodynamic measurements made by several other investigators in patients with normally functioning, unmodified Hancock porcine bioprosthetic valves (6-10). For example, the average orifice area of the 29 mm aortic valve shown at cardiac catheterization was 1.6 cm^2, while the average area shown on the orifice-view aortograms of this valve was 2.0 cm^2. In vitro motion pictures of the orifice of this size valve obtained in our laboratory showed a maximal opening of 1.7 cm^2. The observed orifice areas shown on orifice-view roentgenograms of porcine valves in the mitral position also were comparable to the orifice areas calculated by the Gorlin equation in patients catheterized by others after valve insertion (11).

The extent to which normal aortic valves (12) and normal mitral valves open (13) depends upon the flow across the valve. This is also true of stent-mounted valves (12,14). In vitro motion pictures in our laboratory demonstrated that with decreasing stroke volumes of 77, 42, and 10 ml, the opening area decreased to 1.7, 1.4, and 0.8 cm^2, respectively. If the stroke volume or rate of flow across the valve is abnormally low, therefore, a small orifice

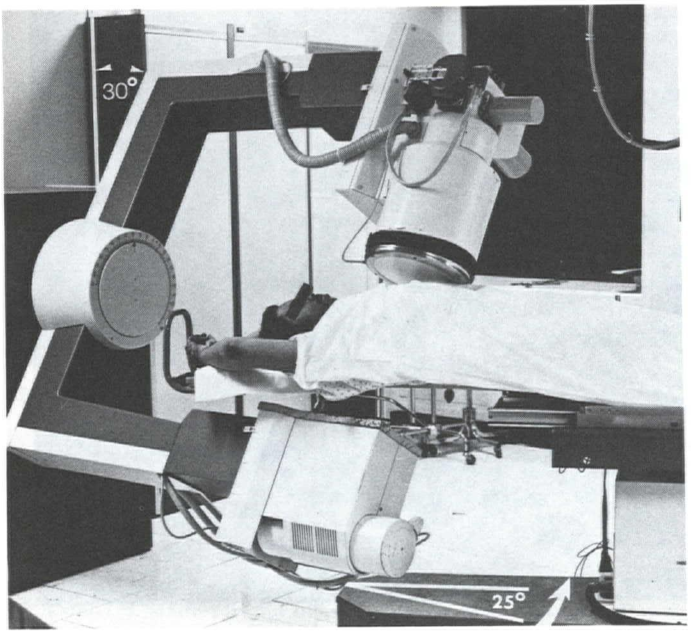

Fig. 4

Position for visualization of the orifice of the mitral valve. The table is rotated 25° counter-clockwise (see arrow). The U arm is rotated 30° clockwise from the vertical position.

that results from an incomplete opening will be shown on the orifice-view roentgenogram. When interpreting the significance of a small visualized orifice, therefore, one should know the stroke volume. In this study, the stroke volume in the 11 patients in whom it was measured was $\geq$ 49 ml.

Other investigators have shown the usefulness of orifice-view angiography in a patient with a stenotic degenerated bioprosthetic valve in the mitral position (15). A 0.46 cm^2 orifice was shown by the orifice-view roentgenogram and confirmed by measurement of the excised surgical specimen.

The advantages of orifice-view roentgenography are that the valve orifice can be seen with sufficient clarity to permit the orifice area to be measured by planimetry. The technique is suitable for normal as well as abnormal valves. Because it is not necessary to cross the valve, orifice-view roentgenograms are particularly useful in patients in whom the valve cannot be crossed or in whom sufficiently accurate hemodynamic measurements cannot be made. In patients with heavily calcified natural aortic valves, it was possible to estimate the area of the orifice by the area circumscribed by calcium (16,17), thereby providing a totally noninvasive method. The normal aortic valve may be somewhat triangular or circular (1), depending in part upon the stroke volume and rate of ejection (12). Porcine valves inserted in the mitral

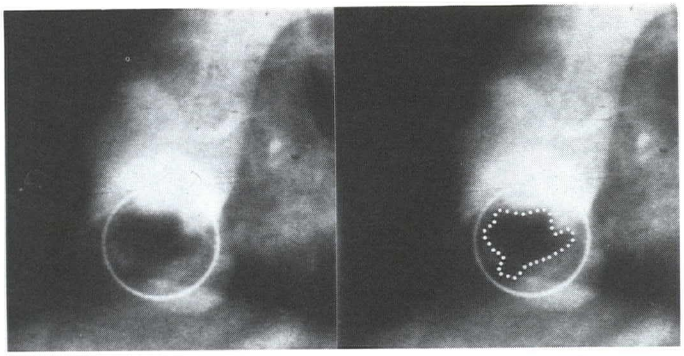

Fig. 5

Left: Orifice-view aortogram of the first patient. Right: Functional orifice area outlined by dots. Frames of the cine aortogram show maximal opening of the orifice. Reprinted with permission from Proc, International Symposium on Cardiac Bioprostheses (11).

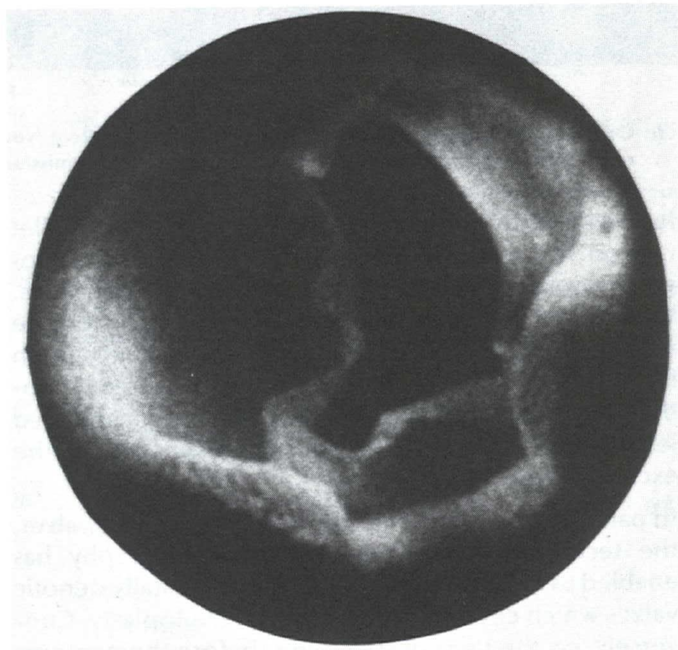

Fig. 6

Frame from in vitro motion picture showing maximal opening of a 29 mm Hancock aortic bioprosthetic valve (model 242). Stroke volume was 77 ml.

position show the same roentgenographic configuration as that of the aortic valve. Our previous studies of stenotic natural valves indicated that the size and configuration of the deformity can be visualized (2,18,19).

A particularly useful aspect of orifice-view angiography for the evaluation of bioprosthetic valves is its capability of showing only partial opening of the leaflets. Even though patients with bioprosthetic valves rarely present with clinically severe stenosis, most have stiffening of the

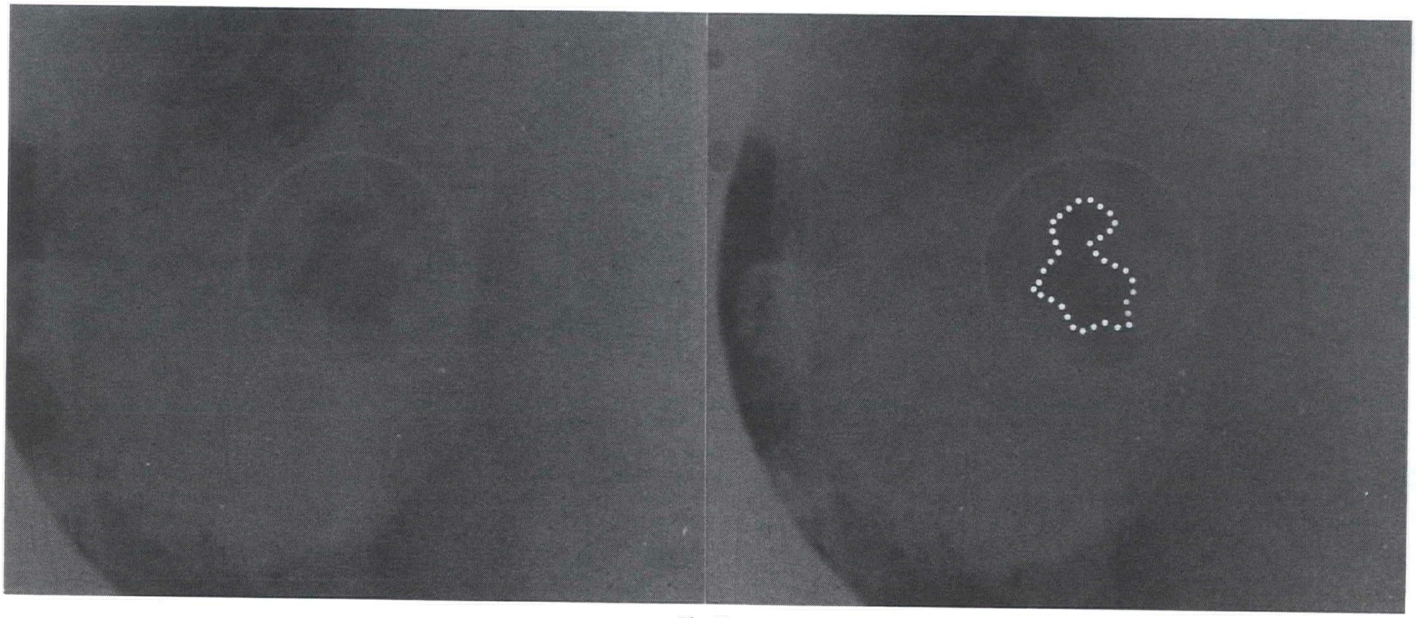

Fig. 7

Left: Orifice-view roentgenogram of the mitral valve of patient No. 11. Right: Functional orifice area outlined by dots. Frame selected for reproduction shows maximal opening. Reprinted with permission from Proc, International Symposium on Cardiac Bioprostheses (11).

leaflets and deposits of calcium which impair leaflet motion. It is possible, therefore, that orifice-view angiography can be used to detect early degenerative changes. We suspect that such valvular stiffening occurs before regurgitation becomes clinically apparent. Leaflet motion is rarely impaired enough to allow the measured hemodynamics to define degeneration, even though impaired leaflet motion may be obvious by inspection of the excised valves.

In patients with natural valves, particularly aortic valves, the technique of orifice-view roentgenography has enabled us to identify children with congenitally stenotic valves which could be improved by valvuloplasty. Conversely, on the basis of such films, before thoracotomy we have identified children who require valve replacement rather than valvuloplasty. Orifice-view roentgenography has occasionally identified patients who require particularly large or particularly small bioprosthetic valves to fit the annulus. For example, a patient with the Ehlers-Danlos syndrome (20) had a strikingly enlarged aortic valve with a dilated annulus that was shown by orifice-view aortography.

Summary

Orifice-view roentgenograms demonstrate the functional orifice of bioprosthetic valves in the aortic and mitral positions with sufficient detail to permit the orifice areas to be measured. The areas of the orifices of normally functioning valves correspond well to hemodynamic measurements obtained by cardiac catheterization. The areas shown on orifice-view roentgenograms also correspond well to measurements of the orifice obtained by motion pictures in vitro.

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