Balloon Dilatation of the Cardiac Valves

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Key Points

- Percutaneous balloon pulmonary valvuloplasty (PPV) has become the treatment of choice for patients with isolated pulmonic valvular stenosis.
- Percutaneous mitral balloon commissurotomy (PMV) has been successfully used as an alternative to open or closed surgical mitral commissurotomy in the treatment of patients with symptomatic rheumatic mitral stenosis.
- Increase of mitral valve area with PMV is inversely related to the presence of atrial fibrillation.
- The presence and severity of MR before PMV is an independent predictor of unfavorable outcome of PMV.
- Following PMV, the majority of patients have marked clinical improvement and become New York Heart Association (NYHA) class I or II in intermediate- and long-term follow-up.
- Patients with heavily calcified mitral valves under fluoroscopy have a poorer immediate outcome with PMV.
- The degree of pulmonary artery hypertension before PMV is inversely related to immediate and long-term outcome of PMV.
- The degree of tricuspid regurgitation before PMV is inversely related to the immediate and long-term outcome of PMV.
- Aortic valve replacement is the treatment of choice for symptomatic patients with severe valvular aortic stenosis, but in nonsurgical candidates, because of associated major medical comorbid conditions, percutaneous aortic balloon valvuloplasty (PAV) may be considered a short-term palliative intervention. However, clinical restenosis occurs, frequently, 6 to 12 months after PAV.

Before 1982, cardiac surgery was the conventional form of treatment for symptomatic stenotic valvular heart lesions. Today, percutaneous balloon dilatation of stenotic cardiac valves is being used in many centers for the treatment of patients with pulmonic, mitral, aortic and tricuspid stenosis.

Percutaneous Pulmonic Valvuloplasty

Since its introduction by Kan et al. in 1982, percutaneous balloon pulmonary valvuloplasty (PPV) has become the treatment of choice for patients with isolated pulmonic valvular stenosis.1–3 In both children and adults with valvular pulmonic stenosis balloon valvuloplasty produces excellent immediate and long-term results. Patients with isolated pulmonic stenosis and a transvalvular gradient greater than 40 mm Hg are candidates for this technique (Table 23.1).3–9

The technique of PPV is relatively simple. It is performed with the patient under sedation and local anesthesia. Before performing PPV, accurate measurement of the pulmonary annulus by two-dimensional (2D) echocardiography and angiography is fundamental in the appropriate selection of balloon size. Complete right and left catheterization and right ventricular cineangiography in both the anteroposterior and lateral projections are performed before PPV to document the severity of the stenosis and the presence of associated lesions.

The stenotic pulmonic valve is crossed with an end-hole balloon wedge catheter, and the catheter is placed in the left pulmonary artery. A 0.035- or 0.038-inch exchange guidewire is advanced in the distal left pulmonary artery, and the catheter and venous introducer are removed. When using the double-balloon technique, a second guidewire could be placed parallel to the first guidewire with the help of a double-lumen catheter. In smaller children, double-balloon PPV can be performed by introducing a dilating balloon through each of the femoral veins. The balloon or balloons dilating the catheters are then advanced and placed straddling the pulmonic valve. A balloon combination that provides a diameter 20% to 30% greater than the pulmonary annulus is used to provide adequate relief of the stenosis. The valvuloplasty balloons are then inflated by hand until the waist produced by the stenotic pulmonic valve disappears. Two to four brief inflations are performed to minimize the period of hypotension. The inflation/deflation process takes between 15 and 20 seconds. Double-balloon PPV is tolerated better than...
TABLE 23.2. Immediate results of percutaneous pulmonic valvuloplasty in patients with isolated pulmonic stenosis

<table>
<thead>
<tr>
<th>Current indication</th>
<th>Pulmonary pressure (mmHg)</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients with exertional dyspnea, angina, syncope, or pre-syncpe</td>
<td>Pre-PPV</td>
<td>Post-PPV</td>
</tr>
<tr>
<td>Asymptomatic patients with normal cardiac output</td>
<td>68 ± 27</td>
<td>23 ± 5</td>
</tr>
<tr>
<td>Transvalvar gradient &gt;50mmHg</td>
<td>91 ± 41</td>
<td>26 ± 19</td>
</tr>
<tr>
<td>Transvalvar gradient 40 to 49mmHg</td>
<td>71 ± 33</td>
<td>28 ± 21</td>
</tr>
<tr>
<td>Transvalvar gradient 30 to 39mmHg</td>
<td>70 ± 24</td>
<td>30 ± 17</td>
</tr>
<tr>
<td>Transvalvar gradient &lt;30mmHg</td>
<td>97 ± 30</td>
<td>22 ± 20</td>
</tr>
</tbody>
</table>

single-balloon PPV, resulting in less hypotension and bradycardia during balloon inflations. Following completion of the dilatations, the deflated catheters are removed and repeat hemodynamics and right ventricular cineangiography are repeated. At the end of the procedure, the catheters are removed and hemostasis is achieved by local pressure. In most adults, two balloons are required. Patients are observed after the procedure in a general medical ward and discharged the following day.

Percutaneous balloon pulmonary valvuloplasty produces a significant decrease in pulmonic gradient. In general, the pulmonic gradient decreases by 50% to 80%. The results of PPV from different centers are shown in Table 23.2. Patients with severe pulmonary dysplasia and with hypoplasia of the pulmonic annulus are unlikely to have improvement after PPV. In some patients, a significant gradient could develop across the infundibulum following relief of the valvular pulmonic stenosis and may be reduced by the use of beta-blockers or calcium channel blockers. This infundibular gradient has no clinical importance and disappears or markedly decreases at follow-up cardiac catheterization or Doppler echocardiography.

Complications of PPV are rare. They are more frequent in neonates. Perforation of the right ventricular outflow tract has been reported to occur in neonates when attempts have been made to cross the pulmonary valve. Similarly, vessel trauma is more frequent in neonates and infants and can be diminished by using the double-balloon technique. Mild pulmonary insufficiency occurs frequently, but it does not have significant clinical or hemodynamic consequences.

Follow-up studies have shown that restenosis is uncommon. Follow-up cardiac catheterization and Doppler echocardiography studies have demonstrated that significant restenosis appears to be uncommon. Recurrent stenosis is much less likely if the final gradient after PPV is less than 30mmHg. The residual gradient measured 6 months after PPV has been significantly smaller than the one measured immediately after the procedure. This finding is probably related to improvement in the infundibulum stenosis, which frequently occurs immediately after PPV.

### Percutaneous Mitral Balloon Valvotomy for Patients with Rheumatic Mitral Stenosis

Since its introduction in 1984 by Inoue et al., percutaneous mitral balloon commissurotomy (PMV) has been used successfully as an alternative to open or closed surgical mitral commissurotomy in the treatment of patients with symptomatic rheumatic mitral stenosis. It produces good immediate hemodynamic outcome, has a low complication rate, and results in clinical improvement in the majority of patients with mitral stenosis. It is safe and effective, and provides sustained clinical and hemodynamic improvement in patients with rheumatic mitral stenosis. The immediate and long-term results appear to be similar to those of surgical mitral commissurotomy.

Today, PMV is the preferred form of therapy for relief of mitral stenosis for a selected group of patients with symptomatic mitral stenosis.

#### Patient Selection

Selection of patients for PMV should be based on symptoms, physical examination, and 2D and Doppler echocardiographic findings. Percutaneous mitral balloon commissurotomy is usually performed electively. However, emergency PMV can be performed as a lifesaving procedure in patients with mitral stenosis and severe pulmonary edema refractory to medical therapy or to cardiogenic shock. Patients considered for PMV should be symptomatic [New York Heart Association (NYHA) class II or greater], should have no recent thromboembolic events, have less than two grades of mitral regurgitation by contrast ventriculography (using the Sellers classification), and have no evidence of left atrial thrombus on 2D and transesophageal echocardiography. Transthoracic and transesophageal echocardiography should be performed routinely before PMV. Patients in atrial fibrillation and patients with previous embolic episodes should be anticoagulated with warfarin with a therapeutic prothrombin time for at least 3 months before PMV. Patients with left atrium thrombus on 2D-echocardiography should be excluded. However, PMV could be performed in these patients if the left atrium thrombus has resolved after warfarin therapy.

#### Technique

The PMV is performed with the patient in the fasting state and under mild sedation. Antibiotics (dicloxacillin 500mg p.o. q6h for four doses starting before the procedure, or
Patients with mild mitral stenosis III Grade C surgery

Asymptomatic patients, moderate or severe mitral stenosis (area < 1.5 cm²) and valve morphology favorable for percutaneous balloon valvuloplasty in the absence of left atrial thrombus or moderate to severe mitral regurgitation.

Patients with NYHA functional class III to IV, moderate or severe mitral stenosis IIa Grade B moderate to severe mitral regurgitation at rest or 60 mm Hg with exercise) in the absence of left atrial thrombus or have pulmonary hypertension (pulmonary artery systolic pressure > 50 mm Hg) in the absence of left atrial thrombus or moderate to severe mitral regurgitation.

PMV has also been described. Recently, a technique of PMV using a newly designed metallic valvulotome was introduced. The device consists of a detachable metallic cylinder with two articulated bars screwed onto the distal end of a disposable catheter whose proximal end is connected to an activating pliers. Squeezing the pliers opens the bars up to a maximum of 40 mm (Fig. 23.3). The results with this device are at least comparable to those of the other balloon techniques of PMV and multiple uses after sterilization should markedly decrease procedural costs.

TABLE 23.3. Recommendations for percutaneous mitral valvuloplasty

<table>
<thead>
<tr>
<th>Current indication</th>
<th>Class</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptomatic patients [NYHA functional class II, III, or IV], moderate or severe mitral stenosis (area &lt; 1.5 cm²), and valve morphology favorable for percutaneous balloon valvuloplasty in the absence of left atrial thrombus or moderate to severe mitral regurgitation</td>
<td>I</td>
<td>Grade A</td>
</tr>
<tr>
<td>Asymptomatic patients with moderate or severe mitral stenosis (area &lt; 1.5 cm²) and valve morphology favorable for percutaneous balloon valvuloplasty who have pulmonary hypertension (pulmonary artery systolic pressure &gt; 50 mm Hg) at rest or 60 mm Hg with exercise) in the absence of left atrial thrombus or moderate to severe mitral regurgitation</td>
<td>IIA</td>
<td>Grade C</td>
</tr>
<tr>
<td>Patients with NYHA functional class III to IV, moderate or severe mitral stenosis (area &lt; 1.5 cm²), and a nonpliable calcified valve who are at high risk for surgery in the absence of left atrial thrombus or moderate to severe mitral regurgitation.</td>
<td>IIA</td>
<td>Grade B</td>
</tr>
<tr>
<td>Asymptomatic patients, moderate or severe mitral stenosis (area &lt; 1.5 cm²), and valve morphology favorable for percutaneous balloon valvuloplasty who have new onset of atrial fibrillation in the absence of left atrial thrombus or moderate to severe mitral regurgitation</td>
<td>IIb</td>
<td>Grade B</td>
</tr>
<tr>
<td>Patients in NYHA functional class III to IV, moderate or severe mitral stenosis (area &lt; 1.5 cm²), and a nonpliable calcified valve who are low-risk candidates for surgery</td>
<td>IIb</td>
<td>Grade C</td>
</tr>
<tr>
<td>Patients with mild mitral stenosis</td>
<td>III</td>
<td>Grade C</td>
</tr>
</tbody>
</table>

ceftazolin 1 g i.v. at the time of the procedure) are used. Patients allergic to penicillin should receive vancomycin 1 g i.v. at the time of the procedure. All patients carefully chosen as candidates for mitral balloon valvuloplasty should undergo diagnostic right and left and transeptal left heart catheterization. Following transeptal left heart catheterization, systemic anticoagulation is achieved by the intravenous administration of 100 units/kg of heparin. In patients older than 40 years, coronary arteriography is recommended and should also be performed.

Hemodynamic measurements, cardiac output, and cine left ventriculography are performed before and after PMV. Cardiac output is measured by thermodilution and Fick method techniques. Mitral valve calcification and angiographic severity of mitral regurgitation (the Sellers classification) are graded qualitatively from 0 to 4 as described elsewhere. An oxygen diagnostic run is performed before and after PMV to determine the presence of left to right shunt across the atrial septum after PMV.

There is not a unique technique of percutaneous mitral balloon valvuloplasty. Most of the techniques of PMV require transeptal left heart catheterization and use of the antegrade approach. Antegrade PMV can be accomplished using a single- [Fig. 23.1] or a double-balloon technique [Fig. 23.2]. In this latter approach the two balloons could be placed through a single femoral vein and single transseptal punctures, or through two femoral veins and two separate atrial septal punctures. In the retrograde technique of PMV, the balloons dilating the catheters are advanced percutaneously through the right and left femoral arteries over guidewires that have been snared from the descending aorta. These guidewires have been advanced transeptally from the right femoral vein into the left atrium, the left ventricle, and the ascending aorta. A retrograde nontranseptal technique of PMV has also been described. Recently, a technique of PMV using a newly designed metallic valvulotome was introduced. The device consists of a detachable metallic cylinder with two articulated bars screwed onto the distal end of a disposable catheter whose proximal end is connected to an activating pliers. Squeezing the pliers opens the bars up to a maximum of 40 mm (Fig. 23.3). The results with this device are at least comparable to those of the other balloon techniques of PMV and multiple uses after sterilization should markedly decrease procedural costs.

The Antegrade Double-Balloon Technique

In performing PMV using the antegrade double-balloon technique [Fig. 23.2], two 0.038-inch, 260 cm long Teflon-coated exchange wires are placed across the mitral valve into the left ventricle, through the aortic valve into the ascending and then the descending aorta. Care should be taken to maintain large and smooth loops of the guidewires in the left ventricular cavity to allow appropriate placement of the dilating balloons. If a second guidewire cannot be placed into the ascending and descending aorta, a 0.038-inch Amplatz-type transfer guidewire (AGA Medical Corp., Golden Valley, MN) with a preformed curlew at its tip can be placed at the left ventricular apex. In patients with aortic valve prostheses, both guidewires with performed curlew tips should be placed at the left ventricular apex. When one or both guidewires are placed in the left ventricular apex, the balloons should be inflated sequentially. Care should be taken to avoid forward movement of the balloons and guidewires to prevent left ventricular perforation. Two balloon-dilating catheters, chosen according to the patient’s body surface area, are then advanced over each of the guidewires and positioned across the mitral valve parallel to the longitudinal axis of the left ventricle. The balloon valvotomy catheters are then inflated by hand until the indentation produced by the stenotic mitral valve is no longer seen. Generally one but occasionally two
or three inflations are performed. After complete deflation the balloons are removed sequentially.

THE INOUE TECHNIQUE

The PMV can also be performed using the Inoue technique [Fig. 23.2]. The Inoue balloon is a 12-French (F) shaft, coaxial, double-lumen catheter. The balloon is made of a double layer of rubber tubing with a layer of synthetic micromesh in between. Following transseptal catheterization, a stainless steel guidewire is advanced through the transseptal catheter and placed with its tip coiled into the left atrium and the transseptal catheter removed. A 14F dilator is advanced over the guidewire and used to dilate the femoral vein and the atrial septum. A balloon catheter chosen according to the patient’s height is advanced over the guidewire into the left atrium. The distal part of the balloon is inflated and advanced into the left ventricle with the help of the spring wire stylet that has been inserted through the inner lumen of the catheter. Once the catheter is in the left ventricle, the partially inflated balloon is moved back and forth inside the left ventricle to ensure that it is free of the chordae tendineae. The catheter is then gently pulled against the mitral plane until resistance is felt. The balloon is then rapidly inflated to its full capacity and then deflated quickly. During inflation of the balloon, an indentation should be seen in its midportion. The catheter is withdrawn into the left atrium and the mitral gradient and cardiac output measured. If further dilatations
are required, the stylet is introduced again and the sequence of steps described above repeated at a larger balloon volume. After each dilatation, its effect should be assessed by pressure measurement, auscultation, and 2D-echocardiography. If mitral regurgitation occurs, further dilation of the valve should not be performed.

Mechanism
The mechanism of successful PMV is splitting of the fused commissures toward the mitral annulus, resulting in commissural widening. This mechanism has been demonstrated by pathologic, surgical, and echocardiographic studies. In addition, in patients with calcific mitral stenosis, the balloons could increase mitral valve flexibility by the fracture of the calcified deposits in the mitral valve leaflets. Although rare, undesirable complications, such as leaflet tears, left ventricular perforation, tear of the atrial septum and rupture of chordae, mitral annulus, and papillary muscle could also occur.

Immediate Outcome
Figure 23.4 shows the hemodynamic changes produced by PMV in one patient. The PMV resulted in a significant decrease in mitral gradient, mean left atrium pressure, and...
mean pulmonary artery pressure; and an increase in cardiac output and mitral valve area (MVA). Table 23.4 shows the changes in MVA reported by several investigators using different techniques of PMV. In most series, PMV is reported to increase MVA from less than 1.0 cm² to approximately 2.0 cm².\(^\text{18–20,23,25–28,34}\)

At the Massachusetts General Hospital, 879 consecutive patients with mitral stenosis have undergone 939 PMVs between July 1986 and July 2000.\(^\text{28}\) As shown in Figure 23.5, in this group of patients, PMV resulted in a significant decrease in mitral gradient from 14 ± 6 to 6 ± 3 mm Hg. The mean cardiac output significantly increased from 3.9 ± 1.1 to 4.5 ± 1.3 L/min, and the calculated MVA from 0.9 ± 0.3 to 1.9 ± 0.7 cm². In addition, mean pulmonary artery pressure significantly decreased from 36 ± 13 to 29 ± 11 mm Hg and the mean left atrial pressure decreased from 25 ± 7 to 17 ± 7 mm Hg, and consequently, the calculated pulmonary vascular resistances decreased significantly following PMV.

A successful hemodynamic outcome [defined as a post-PMV mitral valve area ≥1.5 cm² and post-PMV mitral regurgitation (MR) <3 Sellers’ grades] was obtained in 72% of the patients. Although a suboptimal result occurred in 28% of the patients, a post-PMV MVA ≤1.0 cm² (critical mitral valve area) was present in only 8.7% of these patients.

### Predictors of Increase in Mitral Valve Area and Procedural Success

Univariate analysis demonstrated that the increase in MVA with PMV is directly related to the balloon size employed as it reflects in the effective balloon dilating area (EBDA) and is inversely related to the echocardiographic score, the presence of atrial fibrillation, the presence of fluoroscopic calcium, the presence of previous surgical commissurotomy, older age, NYHA pre-PMV class, and the presence of MR before PMV. Multiple stepwise regression analysis identified balloon size

#### TABLE 23.4. Immediate changes in mitral valve area after percutaneous mitral valvuloplasty

<table>
<thead>
<tr>
<th>Author</th>
<th>Institution</th>
<th>No. of patients</th>
<th>Age</th>
<th>Pre-PMV</th>
<th>Post-PMV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palacios et al.</td>
<td>Massachusetts General Hospital</td>
<td>879</td>
<td>55 ± 15</td>
<td>0.9 ± 0.3</td>
<td>1.9 ± 0.7</td>
</tr>
<tr>
<td>Vahanian et al.</td>
<td>Tenon</td>
<td>1514</td>
<td>45 ± 15</td>
<td>1.0 ± 0.2</td>
<td>1.9 ± 0.3</td>
</tr>
<tr>
<td>Hernández et al.</td>
<td>Clinico Madrid</td>
<td>561</td>
<td>53 ± 13</td>
<td>1.0 ± 0.2</td>
<td>1.8 ± 0.4</td>
</tr>
<tr>
<td>Stefanadis et al.</td>
<td>Athens University</td>
<td>438</td>
<td>44 ± 11</td>
<td>1.0 ± 0.3</td>
<td>2.1 ± 0.5</td>
</tr>
<tr>
<td>Chen et al.</td>
<td>Guangzhou</td>
<td>4832</td>
<td>37 ± 12</td>
<td>1.1 ± 0.3</td>
<td>2.1 ± 0.2</td>
</tr>
<tr>
<td>NHLBI</td>
<td>Multicenter</td>
<td>738</td>
<td>54 ± 12</td>
<td>1.0 ± 0.4</td>
<td>2.0 ± 0.2</td>
</tr>
<tr>
<td>Inoue et al.</td>
<td>Takeda</td>
<td>527</td>
<td>50 ± 10</td>
<td>1.1 ± 0.1</td>
<td>2.0 ± 0.1</td>
</tr>
<tr>
<td>Inoue Registry</td>
<td>Multicenter</td>
<td>1251</td>
<td>53 ± 15</td>
<td>1.0 ± 0.3</td>
<td>1.8 ± 0.6</td>
</tr>
<tr>
<td>Ben Farhat et al.</td>
<td>Fattouma</td>
<td>463</td>
<td>33 ± 12</td>
<td>1.0 ± 0.2</td>
<td>2.2 ± 0.4</td>
</tr>
<tr>
<td>Arora et al.</td>
<td>G.B. Pan</td>
<td>600</td>
<td>27 ± 8</td>
<td>0.8 ± 0.2</td>
<td>2.2 ± 0.4</td>
</tr>
<tr>
<td>Cribier et al.</td>
<td>Ruen</td>
<td>153</td>
<td>36 ± 15</td>
<td>1.0 ± 0.2</td>
<td>2.2 ± 0.4</td>
</tr>
</tbody>
</table>

#### FIGURE 23.5. Mean changes in mitral valve area after PMV [A] and post-PMV development of severe [≥3+] mitral regurgitation [B].
(p < .02), the echocardiographic score (p < .0001), and the presence of atrial fibrillation (p < .009) and MR before PMV (p < .03) as independent predictors of the increase in MVA with PMV.

Univariate predictors of procedural success included age, pre-PMV MVA, mean pre-PMV pulmonary artery pressure, male sex, echocardiographic score, pre-PMV MR ≥ 2 +, history of previous surgical commissurotomy (OR 1.85, CI 1.20 to 2.86; p < .004), male sex (OR 1.92, CI 1.19 to 3.13; p < .008), and echocardiographic score ≤ 8 (OR 1.69, CI 1.18 to 2.44; p < .004).

Echocardiographic Score

The echocardiographic examination of the mitral valve can accurately characterize the severity and extent of the pathologic process in patients with mitral stenosis. The most utilized score to identify the anatomic abnormalities of the stenotic mitral valve is that described by Wilkins et al.43 (Table 23.5). This echocardiographic score is an important predictor of the immediate and long-term outcome of PMV. In this morphologic score, leaflet rigidity, leaflet thickening, valvular calcification, and subvalvular disease are scored from 0 to 4. A higher score represents a heavily calcified, thickened, and immobile valve with extensive thickening and calcification of the subvalvular apparatus. The increase in MVA with PMV is inversely related to the echocardiographic score. The best outcome with PMV occurs in those patients with echocardiographic scores ≤ 8. The increase in MVA is significantly greater in patients with echocardiographic scores ≤ 8 than in those with echocardiographic scores > 8. Among the four components of the echocardiographic score, valve leaflets thickening and subvalvular disease correlate best with the increase in MVA produced by PMV.44 Therefore, suboptimal results with PMV are more likely to occur in patients with valves that are more rigid and more thickened, and those with more subvalvular fibrosis and calcification.

Balloon Size and Effective Balloon Dilating Area

The increase in mitral valve area with PMV is directly related to balloon size. This effect was first demonstrated in a subgroup of patients who underwent repeat PMV.45 They initially underwent PMV with a single balloon, resulting in a mean mitral valve area of 1.2 ± 0.2 cm². They underwent repeat PMV using the double-balloon technique, which increased the EBDA normalized by body surface area (EBDA/BSA) from 3.41 ± 0.2 to 4.51 ± 0.2 cm²/m². The mean mitral valve area in this group after repeat PMV was 1.8 cm² ± 0.7 cm². The increase in MVA in patients who underwent PMV at the Massachusetts General Hospital using the double-balloon technique (EBDA of 6.4 ± 0.03 cm²/m²) was significantly greater than the increase in MVA achieved in patients who underwent PMV using the single-balloon technique (EBDA of 4.3 ± 0.02 cm²/m²). The mean MVAs were 1.9 ± 0.7 and 1.4 ± 0.1 cm² for patients who underwent PMV with the double-balloon and the single-balloon techniques, respectively. However, care should be taken in the selection of dilating balloon catheters so as to obtain an adequate final MVA and no change or a minimal increase in MR.

Mitrail Valve Calcification

The immediate outcome of patients undergoing PMV is inversely related to the severity of valvular calcification seen by fluoroscopy. Patients without fluoroscopic calcium have a greater increase in MVA after PMV than patients with calcified valves. Patients with either no or 1+ fluoroscopic calcium have a greater increase in MVA after PMV (1.1 ± 0.6 and 0.9 ± 0.5 cm², respectively) than those patients with 2, 3, or 4+ of calcium (0.8 ± 0.6, 0.8 ± 0.5, and 0.6 ± 0.4 cm², respectively).

Table 23.5. The echocardiographic score: echocardiographic grading of the severity and extent of the anatomic abnormalities in patients with mitral stenosis

<table>
<thead>
<tr>
<th>Grade</th>
<th>Leaflet mobility</th>
<th>Valvular thickening</th>
<th>Valvular calcification</th>
<th>Subvalvular thickening</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>1</td>
<td>Highly mobile</td>
<td>Leaflet near normal</td>
<td>A single area of</td>
<td>Minimal thickening</td>
</tr>
<tr>
<td></td>
<td>with restriction of only the leaflet tips</td>
<td>4–5 mm</td>
<td>increased echo brightness</td>
<td>chordal structures just below the valve</td>
</tr>
<tr>
<td>2</td>
<td>Middle portion and base of leaflets reduced mobility</td>
<td>Mid-leaflet thickening, marked at the margins</td>
<td>Scattered areas of brightness confined to thickening of leaflet margins</td>
<td>Thickening of chordae extending up to one third of chordal length</td>
</tr>
<tr>
<td>3</td>
<td>Valve leaflets move forward in diastole mainly at the base</td>
<td>Thickening extending through the entire leaflets</td>
<td>Brightness extending into the midportion of leaflets (5–8 mm)</td>
<td>Thickening extending to the distal third of the chordae</td>
</tr>
<tr>
<td>4</td>
<td>No or minimal forward movement of the leaflets in diastole</td>
<td>Marked thickening of all leaflet tissue</td>
<td>Extensive brightness throughout most of the leaflet tissue</td>
<td>Extensive thickening and shortening of all chordae extending down to the papillary muscles</td>
</tr>
</tbody>
</table>

* The total score is the sum of each of these echocardiographic features (maximum 16).
Although the increase in MVA with PMV is inversely related to the presence of previous surgical mitral commissurotomy, PMV can produce a good outcome in this group of patients. The post-PMV mean MVA in 154 patients with previous surgical commissurotomy was $1.8 \pm 0.7 \text{cm}^2$ compared with a valve area of $1.9 \pm 0.6 \text{cm}^2$ in patients without previous surgical commissurotomy ($p < .05$). In this group of patients, an echocardiographic score $\leq 8$ was an important predictor of a successful hemodynamic immediate outcome.

**Age**

The immediate outcome of PMV is directly related to the age of the patient. The percentage of patients obtaining a good result with this technique decreases as age increases. A successful hemodynamic outcome from PMV was obtained in only <50% of patients <65 years old. $46$ This inverse relationship between age and the immediate outcome from PMV is only ≥65 years old. $46$ This inverse relationship between age and the immediate outcome from PMV is due to the higher frequency of atrial fibrillation, calcified valves, and higher echocardiographic scores in elderly patients.

**Atrial Fibrillation**

The increase in MVA with PMV is inversely related to the presence of atrial fibrillation. The post-PMV MVA of patients in normal sinus rhythm was $2.0 \pm 0.7 \text{cm}^2$ compared with a valve area of $1.7 \pm 0.6 \text{cm}^2$ of those patients in atrial fibrillation. The inferior immediate outcome of PMV in patients with mitral stenosis who are in atrial fibrillation is more likely related to the presence of clinical and morphologic characteristics associated with inferior results after PMV. Patients in atrial fibrillation are older and present more frequently with echocardiographic scores >8, NYHA functional class IV, calcified mitral valves under fluoroscopy, and a previous history of surgical mitral commissurotomy.

**Mitral Regurgitation Before PMV**

The presence and severity of mitral regurgitation before PMV is an independent predictor of unfavorable outcome of PMV. The increase in MVA after PMV is inversely related to the severity of MR determined by angiography before the procedure. This inverse relationship between presence of MR and immediate outcome of PMV is in part due to the higher frequency of atrial fibrillation, higher echocardiographic scores, calcified mitral valves under fluoroscopy, and older age in patients with MR before PMV.

**Complications**

Table 23.6 shows the complications reported by several investigators after PMV. $18-20,23,25-28,34$ Mortality and morbidity with PMV are low and similar to surgical commissurotomy. Overall, there is <1% mortality. Severe MR (four grades by angiography) has been reported in 1% to 5.2% of the patients. Some of these patients required in-hospital mitral valve replacement. Thromboembolic episodes and stroke have been reported in 0% to 3.1% and pericardial tamponade in 0.2% to 4.6% of cases in these series. Pericardial tamponade can occur from transseptal catheterization and more rarely from ventricular perforation. The PMV is associated with a 3% to 16% incidence of left to right shunt immediately after the procedure. However, the pulmonary to systemic flow ratio is ≥2:1 in only a minimum number of patients.

We have demonstrated that severe MR (four grades by angiography) occurs in about 3% of patients undergoing PMV. $45$ An undesirable increase in MR (two or more grades by angiography) occurred in 10.1% of patients. This undesirable increase in MR is well tolerated in most patients. Furthermore, more than half of them have less MR at follow-up cardiac catheterization. We have demonstrated that the ratio of the effective balloon dilating area to body surface area (EBDA/BSA) is the only predictor of increased MR after PMV. $57-49$ The EBDA is calculated using standard geometric formulas. The incidence of MR is lower if balloon sizes are chosen so that EBDA/BSA is ≤4.0cm$^2$/m$^2$. The single-balloon technique results in a lower incidence of MR but provides less relief of mitral stenosis than the double-balloon technique. Thus, there is an optimal effective balloon dilating area between 3.1 and 4.0cm$^2$/m$^2$, which achieves a maximal MVA with a minimal increase in MR. An echocardiographic score for the mitral valve that can predict the development of severe MR following PMV has also been described. $45$ This

<table>
<thead>
<tr>
<th>Author</th>
<th>No. of patients</th>
<th>Mortality</th>
<th>Tamponade</th>
<th>Severe mitral regurgitation</th>
<th>Embolism</th>
</tr>
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<tbody>
<tr>
<td>Palacios et al.</td>
<td>879</td>
<td>0.6%</td>
<td>1.0%</td>
<td>3.4%</td>
<td>1.8%</td>
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<tr>
<td>Vahanian et al.</td>
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<tr>
<td>Hernández et al.</td>
<td>561</td>
<td>0.4%</td>
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<td>Stefanadis et al.</td>
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<td>Chen et al.</td>
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<td>NHLBI</td>
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<td>Inoue et al.</td>
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<td>Inoue registry</td>
<td>1251</td>
<td>0.6%</td>
<td>1.4%</td>
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<tr>
<td>Ben Farhat et al.</td>
<td>463</td>
<td>0.4%</td>
<td>0.7%</td>
<td>4.6%</td>
<td>2.0%</td>
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<td>Arora et al.</td>
<td>600</td>
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<td>1.3%</td>
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<td>Cribier et al.</td>
<td>153</td>
<td>0.0%</td>
<td>0.7%</td>
<td>1.4%</td>
<td>0.7%</td>
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score takes into account the distribution (even or uneven) of leaflet thickening and calcification, the degree and symmetry of commissural disease, and the severity of subvalvular disease.

Left to right shunt through the created atrial communication occurred in 3% to 16% of the patients undergoing PMV. The size of the defect is small as reflected in the pulmonary to systemic flow ratio of <2:1 in the majority of patients. Older age, fluoroscopic evidence of mitral valve calcification, higher echocardiographic score, pre-PMV lower cardiac output, and higher pre-PMV NYHA functional class are the factors that predispose patients to develop left to right shunt post-PMV. Clinical, echocardiographic, surgical, and hemodynamic follow-up of patients with post-PMV left to right shunt demonstrated that the defect closed in approximately 60%. Persistent left to right shunt at follow-up is small (QP/QS <2:1) and clinically well tolerated. In the series from the Massachusetts General Hospital, there is one patient in whom the atrial shunt remained hemodynamically significant at follow-up. This patient underwent percutaneous transcatheter closure of her atrial defect with a clamshell device. Desideri et al. reported atrial shunting determined by color flow transthoracic echocardiography in 61% of 57 patients immediately after PMV. The shunt persisted in 30% of patients at 19 ± 6 [range 9–33] months follow-up. The authors identified the magnitude of the post-PMV atrial shunt (QP/QS ≤1.5:1), use of a Bifoil balloon (two balloons on one shaft) and smaller post-PMV MVA as independent predictors of the persistence of atrial shunt at long-term follow-up.

Clinical Follow-Up

Long-term follow-up studies after PMV are encouraging. Following PMV, the majority of patients have marked clinical improvement and are assessed as NYHA class I or II. The symptomatic, echocardiographic, and hemodynamic improvement produced by PMV persists in intermediate- and long-term follow-up. The best long-term results are seen in patients with echocardiographic scores ≤8. When PMV produces a good immediate outcome in this group of patients, restenosis is unlikely to occur at follow-up. Although PMV can result in a good outcome in patients with echocardiographic scores >8, hemodynamic and echocardiographic restenosis is frequently demonstrated at follow-up despite ongoing clinical improvement. Table 23.7 shows long-term follow-up results of patients undergoing PMV at different institutions. We reported an estimated 12-year survival rate of 74% in a cohort of 879 patients undergoing PMV at the Massachusetts General Hospital [Fig. 23.6]. Death at follow-up was directly related to age, post-PMV pulmonary artery pressure, and pre-PMV NYHA functional class IV. In the same group of patients, the 12-year event-free survival (alive and free of mitral valve replacement or repair and redo PMV) was 33% [Fig. 23.7]. Cox regression analysis identified age [risk ratio (RR) 1.02, CI 1.01–1.03, p < .0001], pre-PMV NYHA functional class IV [RR 1.35, CI 1.00–1.81, p = .05], prior commissurotomy [RR 1.50, CI 1.16–1.92, p = .002], the echocardiographic score [RR 1.31, CI 1.02–1.67, p = .003], pre-PMV mitral regurgitation ≥2+ [RR 1.56, CI 1.09–2.22, p = .02], post-PMV mitral regurgitation ≥3+ [RR 3.54, CI 2.61–4.72, p < .0001], and post-PMV mean pulmonary artery pressure [RR 1.02, CI 1.01–1.03, p < .0001] as independent predictors of combined events at long-term follow-up.

Actuarial survival and event-free survival rates throughout the follow-up period were significantly better in patients with echocardiographic scores ≤8. Survival rates were 82% for patients with echocardiographic score ≤8 and 57% for patients with score >8 at a follow-up time of 12 years [p < .0001]. Event-free survival (38% versus 22%; p < .0001) at 12 years’ follow-up were also significantly higher for patients

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**TABLE 23.7. Clinical long-term follow-up after percutaneous mitral valvuloplasty**

<table>
<thead>
<tr>
<th>Author</th>
<th>No. of patients</th>
<th>Age</th>
<th>Follow-up (years)</th>
<th>Survival</th>
<th>Event-free survival</th>
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<td>Iung et al.</td>
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<td>Hernández et al.</td>
<td>561</td>
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<td>69%</td>
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<td>Oränge et al.</td>
<td>132</td>
<td>44</td>
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<tr>
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<td>30</td>
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<td>7</td>
<td>100%</td>
<td>90%</td>
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<tr>
<td>Stefanidis et al.</td>
<td>441</td>
<td>44</td>
<td>9</td>
<td>98%</td>
<td>75%</td>
</tr>
</tbody>
</table>

*Only cardiovascular death considered.
#Survival without intervention and in NYHA class I to II.
with echocardiographic score ≤8. Similar follow-up studies have been reported in other series with the double-balloon technique and with the Inoue technique of PMV. Over 90% of young patients with pliable valves, in sinus rhythm and with no evidence of calcium under fluoroscopy remain free of cardiovascular events at approximately 5 years follow-up.

Functional deterioration at follow-up is late and related primarily to mitral restenosis. The incidence of restenosis, as assessed by sequential echocardiography, is approximately 40% after 7 years. Repeat PMV can be proposed if recurrent stenosis leads to symptoms. At the moment, we have only a small number of series available on redo PMV. They show encouraging results in selected patients with favorable characteristics when restenosis occurs several years after an initially successful procedure, and if the predominant mechanism of restenosis is commissural refusion.

**Follow-Up in the Elderly**

Tuzcu et al. reported the outcome of PMV in 99 elderly patients (≥65 years of age). A successful outcome (valve area ≥1.5 cm² without ≥2+ increase in MR and without left to right shunt of ≥1.5:1) was achieved in 46 patients. The best multivariate predictor of success was the combination of echocardiographic score, NYHA functional class, and inverse of MVA. Patients who had an unsuccessful outcome from PMV were in a higher NYHA functional class, had higher echocardiographic scores, and smaller MVAs pre-PMV compared to those patients who had a successful outcome. Actuarial survival and combined event-free survival at 3 years were significantly better in the successful group. Mean follow-up was 16 ± 1 months. Actuarial survival (79% ± 7% vs. 62% ± 10%; p = .04), survival without mitral valve replacement (71% ± 8% vs. 41% ± 8%; p = .002), and event-free survival (54% ± 12% vs. 38% ± 8%; p = .01) at 3 years were significantly better in the successful group of 46 patients than the unsuccessful group of 53 patients. Low echocardiographic score was the independent predictor of survival and lack of mitral valve calcification was the strongest predictor of event-free survival.

Recently, data reported in 96 patients ≥75 years of age have shown that these patients present a lower pre-PMV MVA (0.8 ± 0.3 vs. 0.9 ± 0.3; p = .009), a lower post-PMV MVA (1.6 ± 0.6 vs. 1.9 ± 0.7; p < .0001), and a lower procedural success (51.0% vs. 71.4%; p < .0001) compared with patients younger than 75 years of age. Patients ≥75 years exhibited a higher in-hospital mortality than patients younger than 75 years (3.1% vs. 0.3%) with no significant differences in the other procedure-related complications [cardiac tamponade, severe MR, significant left to right shunt, and embolism]. Although, in-hospital mortality was higher, in the majority of these patients PMV was considered as a palliative treatment. However, technical complications were similar to those more favorable patients aged <75. Survival and event-free survival rates were 60% and 49% for patients ≥75 years at a follow-up time of 3 years. The echo score is an imperfect predictor of hemodynamic improvement in elderly patients.

Unfortunately, no randomized study is available for elderly patients, and a comparison of the results of PMV with those of the surgical series is difficult because of the differences in the patients and surgical techniques involved.

**Follow-Up of Patients with Calcified Mitral Valves**

The presence of fluoroscopically visible calcification on the mitral valve influences the success of PMV. Patients with heavily [≥3 grades] calcified valves under fluoroscopy have a poorer immediate outcome as reflected in a smaller post-PMV MVA and greater post-PMV mitral valve gradient. Immediate outcome is progressively worse as the calcification becomes more severe. The long-term results of percutaneous mitral balloon valvuloplasty are significantly different in calcified and uncalkified groups and in subgroups of the calcified group. The estimated 2-year survival is significantly lower for patients with calcified mitral valves than for those with uncalkified valves (80% vs. 99%). The survival curve becomes worse as the severity of valvular calcification becomes more severe. Freedom from mitral valve replacement at 2 years was significantly lower for patients with calcified mitral valves than for those with uncalkified valves (67% vs. 93%). Similarly, the estimated event-free survival at 2 years in the calcified group became significantly poorer as the severity of calcification increased. The estimated event-free survival at 2 years was significantly lower for the calcified than for the uncalkified group (63% vs. 88%). The actuarial survival curves with freedom from combined events at 2 years in the calcified group became significantly poorer as the severity of calcification increased. These findings are in agreement with several follow-up studies of surgical commissurotomy that demonstrate that patients with calcified mitral valves had a poorer survival compared to those patients with uncalkified valves.

**Follow-Up of Patients with Previous Surgical Commissurotomy**

The PMV also has been shown to be a safe procedure in patients with previous surgical mitral commissurotomy.
Although a good immediate outcome is frequently achieved in these patients, follow-up results are not as favorable as those obtained in patients without previous surgical commissurotomy. Although there is no difference in mortality between patients with or without a history of previous surgical commissurotomy at 4-year follow-up, the number of patients who required mitral valve replacement (26% vs. 8%) or were in NYHA class III or IV (35% vs. 13%) was significantly higher among those patients with previous commissurotomy. However, when the patients are carefully selected according to the echocardiographic score (≤8), the immediate outcome and the 4-year follow-up results are excellent and similar to those seen in patients without previous surgical commissurotomy.

**Follow-Up of Patients with Atrial Fibrillation**

We have reported that the presence of atrial fibrillation is associated with inferior immediate and long-term outcome after PMV as reflected in a smaller post-PMV MVA and a lower event-free survival (freedom of death, redo-PMV, and mitral valve surgery) at a median follow-up time of 61 months [32% vs. 61%, p < .0001]. Analysis of preprocedural and procedural characteristics revealed that this association is most likely explained by the presence of multiple factors in the atrial fibrillation group that adversely affect the immediate and long-term outcome of PMV. Patients in atrial fibrillation are older and presented more frequently with NYHA class IV, echocardiographic score ≥8, calcified valves under fluoroscopy, and a history of previous surgical commissurotomy. In the group of patients in atrial fibrillation, we identified severe post-PMV mitral regurgitation (≥3+) [p = .0001], echocardiographic score ≥8 [p = .004] and pre-PMV NYHA class IV [p = .046] as independent predictors of combined events at follow-up. The presence of atrial fibrillation per se should not be the only determinant in the decision process regarding treatment options in a patient with rheumatic mitral stenosis. The presence of an echocardiographic score ≤8 primarily identifies a subgroup of patients with atrial fibrillation in whom percutaneous balloon valvotomy is very likely to be successful and provide good long-term results. Therefore, in this group of patients, PMV should be the procedure of choice.

**Follow-Up of Patients with Pulmonary Artery Hypertension**

The degree of pulmonary artery hypertension before PMV is inversely related to the immediate and long-term outcome of PMV. Chen et al. divided 564 patients undergoing PMV at the Massachusetts General Hospital into three groups on the basis of the pulmonary vascular resistance (PVR) obtained at cardiac catheterization immediately prior to PMV: group I with a PVR ≤250 dynes-sec/cm² (normal/mildly elevated resistance) comprised 332 patients (59%), group II with a PVR between 251 and 400 dynes-sec/cm² (moderately elevated resistance) comprised 110 patients (19.5%), and group III with a PVR ≥400 dynes-sec/cm² comprised of 122 patients (21.5%). Patients in groups I and II were younger, had less severe heart failure symptoms measured by NYHA class, and had a lower incidence of echocardiographic scores ≥8, atrial fibrillation, and calcium noted on fluoroscopy than patients in group III. Before and after PMV, patients with higher PVR had a smaller MVA, lower cardiac output, and higher mean pulmonary artery pressure. For groups I, II, and III, the immediate success rates for PMV were 68%, 56%, and 45%, respectively. Therefore, patients in the group with severely elevated pulmonary artery resistance before the procedure had lower immediate success rates of PMV. At long-term follow-up patients with severely elevated pulmonary vascular resistance had a significant lower survival and event-free survival [survival with freedom from mitral valve surgery or NYHA class III or IV heart failure].

**Follow-Up of Patients with Tricuspid Regurgitation**

The degree of tricuspid regurgitation before PMV is inversely related to the immediate and long-term outcome of PMV. Sagie et al. divided patients undergoing PMV at the Massachusetts General Hospital into three groups on the basis of the degree of tricuspid regurgitation determined by 2D and color flow Doppler echocardiography before PMV. Patients with severe tricuspid regurgitation before PMV were older, had more severe heart failure symptoms measured by NYHA class, and had a higher incidence of echocardiographic scores ≥8, atrial fibrillation, and calcified mitral valves on fluoroscopy than patients with mild or moderate tricuspid regurgitation. Patients with severe tricuspid regurgitation had smaller MVAs before and after PMV than the patients with mild or moderate tricuspid regurgitation. At long-term follow-up, patients with severe tricuspid regurgitation had significantly lower survival and event-free survival [survival with freedom from mitral valve surgery or NYHA class III or IV heart failure]. The degree of tricuspid regurgitation can be diminished when the transmural pressure gradient is sufficiently relieved with PMV.

**Follow-Up of the Best Patients for PMV**

In patients identified as optimal candidates for PMV, this technique results in excellent immediate and long-term outcome. Optimal candidates for PMV are those patients meeting the following characteristics: (1) age ≤45 years old, (2) normal sinus rhythm, (3) echocardiographic score ≤8, (4) no history of previous surgical commissurotomy, and (5) pre-PMV mitral regurgitation ≤1- Sellers’ grade. From 879 consecutive patients undergoing PMV, we identified 136 patients with optimal preprocedure characteristics. In these patients, PMV results in an 81% success rate and a 3.4% incidence of hospital combined events (death and/or MVR). In these patients, PMV results in a 95% survival and 61% event-free survival at 12-year follow-up.

**The Double Balloon vs. the Inoue Techniques**

Today, the Inoue approach of PMV is the technique more widely used. There was controversy as to whether the double-balloon or the Inoue technique provided superior immediate and long-term results. We compared the immediate procedural and the long-term clinical outcomes after PMV using the double-balloon technique [n = 659] and Inoue technique [n = 233]. There were no statistically significant differences in baseline clinical and morphologic characteristics between
the double balloon and Inoue patients. Although the post-
PMV MVA was larger with the double-balloon technique [1.94 ± 0.72 cm² vs. 1.81 ± 0.58 cm²; p = 0.01], success rate [71.3% vs. 69.1%; p = NS], incidence of ≥3+ MR [9% vs. 9%], in-hospital complications, and long-term and event-free sur-
vival were similar with both techniques. In conclusion, both
the Inoue and the double-balloon techniques are equally
effective techniques of PMV. The procedure of choice should
be performed based on the interventionist’s experience in the
technique.

Echocardiographic and Hemodynamic Follow-Up

Follow-up studies have shown that the incidence of hemo-
dynamic and echocardiographic restenosis is low after
PMV. A study of a group of patients undergoing simulta-
eous clinical evaluation, 2D-Doppler echocardiography,
and transeptal catheterization 2 years after PMV reported a
90% of patients in NYHA classes I and II and 10% of patients
in NYHA class ≥III. In this study hemodynamic determi-
nation of MVA using the Gorlin equation showed a signifi-
cant decrease in MVA from 2.0 cm² immediately after PMV
to 1.6 cm² at follow-up. However, there was no significant
difference between the echocardiographic MVAs immedi-
ately after PMV and at follow-up (1.8 cm² and 1.6 cm², respec-
tively, p = NS). Although there was a significant difference
in the MVA after PMV determined by the Gorlin equation and
by 2D echocardiography [2.0 cm² vs. 1.8 cm²], there was
no significant difference between the MVA determined by
the Gorlin equation and the echocardiographic calculated
MVA [1.6 cm² for both] at follow-up. The discrepancy between
the 2D-echocardiographic and Gorlin equation determined
post-PMV MVAs is due to the contribution of left to right
shunting (undetected by oximetry) across the created inter-
atrial communication, which results in both an erroneously
high cardiac output and an overestimation of the MVA by
the Gorlin equation. Desideri et al. showed no significant
differences in MVA [measured by Doppler echocardiography]
at 19 ± 6 (range 9–33) months’ follow-up between the post-
PMV and follow-up MVAs. Mitral valve areas were 2.2 ±
0.5 cm² and 1.9 ± 0.5 cm², respectively. Echocardiographic
restenosis [MVA ≤ 1.5 cm² with >50% reduction of the gain]
was estimated in 39% at 7 years’ follow-up with the Inoue
technique. A mitral area loss ≥0.3 cm² was seen in 12%,
22%, and 27% of patients at 3, 5, and 7 years, respectively.
Predictors of restenosis included a post-MVA <1.8 cm² and an
echo score >8.

PMV vs. Surgical Mitral Commissurotomy

Results of surgical closed mitral commissurotomy have
demonstrated favorable long-term hemodynamic and symp-
tomatic improvement from this technique. A restenosis rate
of 4.2 to 11.4 per 1,000 patients per year was reported by John
et al. in 3724 patients who underwent surgical closed mitral
commissurotomy. Survival after PMV is similar to that
reported after surgical mitral commissurotomy. Although
freedom from mitral valve replacement and freedom from all
events after PMV are lower than reported after surgical com-
missurotomy, freedom from both mitral valve replacement
and all events in patients with echocardiographic scores
≥8 are similar to that reported after surgical mitral commissurotomy.

Restenosis after both closed and open surgical mitral commissurotomy has been well documented. Although surgical closed mitral commissurotomy is uncommonly per-
formed in the United States, it is still used frequently in
other countries. Long-term follow-up of 267 patients who
underwent surgical transventricular mitral commissurot-
omy at the Mayo Clinic showed a 79%, 67%, and 55% sur-
vival at 10, 15, and 20 years, respectively. Survival with
freedom from mitral valve replacement was 57%, 36%, and
24%, respectively. At the patient ages in this study, atrial
fibrillation and male gender were independent predictors of
death, whereas mitral valve calcification, cardiomegaly, and
MR were independent predictors of repeat mitral valve sur-
urgery.

Because of similar patient selection and mechanism of
mitral valve dilatation, similar long-term results should be
expected after PMV. Indeed, prospective, randomized trials
comparing PMV and surgical closed or open mitral commis-
surotomy have shown no differences in immediate and 3-
year follow-up results between both groups of patients.
Furthermore, restenosis at 3-year follow-up occurred in 10%
and 13% of the patients treated with mitral balloon valvu-
loplasty and surgical commissurotomy, respectively.
Interpretation of long-term clinical follow-up of patients
undergoing percutaneous mitral balloon valvuloplasty as
well as their comparison with surgical commissurotomy
series are confounded by heterogeneity in patient popula-
tions. Most surgical series have involved a younger popula-
tion with optimal mitral valve morphology, with a pliable
valve and no calcification and no evidence of subvalvular
disease. Comparisons were also made at the beginning of
PMV. Therefore, surgeons were more experienced than inter-
ventional cardiologists. Differences in age and valve morphol-
ogy may also account for the lower survival and event-free
survival in PMV series from the United States and Europe.
Several studies have compared the immediate and early
follow-up results of PMV versus closed surgical commissuro-
tomy in optimal patients for these techniques. The results
of these studies have been controversial, showing either supe-
rior outcome from PMV or no significant differences between
both techniques. Patel et al. randomized 45 patients
with mitral stenosis and optimal mitral valve morphology to
closed surgical commissurotomy and to PMV. They demon-
strated a larger increase in MVA with PMV [2.1 ± 0.7 vs. 1.3 ±
0.3 cm²]. Shrivastava et al. compared the results of single-
balloon PMV, double-balloon PMV, and closed surgical com-
missurotomy in three groups of 20 patients each. The MVA
postintervention was larger for the double-balloon technique
of PMV. Postintervention valve areas were 1.9 ± 0.8, 1.5 ± 0.4,
and 1.5 ± 0.5 cm² for the double balloon, the single balloon,
and the closed surgical commissurotomy techniques, respec-
tively. On the other hand, Arora et al. randomized 200
patients with a mean age of 19 ± 7 years and mitral stenosis
with optimal mitral valve morphology to PMV and to closed
mitral commissurotomy. Both procedures resulted in similar
postintervention MVAs [2.39 ± 0.9 vs. 2.2 ± 0.9 cm² for the
PMV and the mitral commissurotomy groups, respectively]
and no significant differences in event-free survival at a
mean follow-up period of 22 ± 6 months. Restenosis docu-
ment of anesthesia and surgery for the mother and the fetus are often unsatisfactory. Since open commissurotomy is associated with a thoracotomy, need for cardiopulmonary bypass, myocardial infarction, diabetes mellitus, renal failure, and, most of all, emergent operation, are independent predictors for operative death in elderly patients undergoing aortic valve replacement. Furthermore, 54% of octogenarians require concomitant surgical procedures, including coronary artery bypass surgery or mitral valve replacement.90,91 Elective perioperative mortality for octogenarians undergoing aortic valve replacement and coronary artery bypass graft is 24%,92 Emergent perioperative mortality increases to 37% in patients with severe congestive heart failure requiring pressors, and can be as high as 50% in patients with cardiogenic shock.93,94 Finally, complicated postoperative course, including encephalopathy with discharge to a rehabilitation facility is present in 38% of the patients.95

Since the initial report by Cribier et al.94 in 1986, percutaneous aortic balloon valvuloplasty (PAV) has been
considered a palliative form of treatment for elderly patients with calcific aortic stenosis. It is associated with significant immediate clinical and hemodynamic improvement. However, the risk of major complications and the high restenosis rate during the first year are major limitations of this technique.95–99 In fact, since PAV does not change the natural history of severe aortic stenosis,100–103 its use in some institutions has been abandoned.104 Therefore, elderly patients with profound hemodynamic instability due to severe aortic stenosis present a challenging dilemma in critical care medicine. If surgery is not an option, PAV can be effectively used as a lifesaving procedure for immediate relief of the transaortic valve gradient with subsequent hemodynamic stabilization and further consideration for an elective bridge to aortic valve replacement [Table 23.8].

In contrast, balloon valvuloplasty is an efficacious treatment option for adolescents and young adults in their early 20s with aortic stenosis. Balloon valvuloplasty has resulted in good long-term palliation with little morbidity and little or no short- or long-term mortality in these patients. Thus, the indications for intervention are considerably more liberal than those in older adults [Table 23.9].

Technique

The technique of percutaneous balloon aortic valvuloplasty is not complex and can be performed using either the retrograde or the antegrade techniques.95

### Retrograde Technique

After crossing the aortic valve and determining resting hemodynamics, a 0.038-inch Amplatz-type heavy exchange wire is advanced through the retrograde catheter and placed into the left ventricular cavity. The retrograde catheter is then removed leaving the guidewire across the stenotic aortic valve coiled in the left ventricular apex. A dilating balloon catheter chosen according to the size of the aortic annulus is then advanced over the guidewire, placed across the aortic valve, and inflated by hand [Fig. 23.8].

### Antegrade Technique

The left atrium is entered using transseptal catheterization with a modified Brockenbrough needle and a Mullins sheath. A balloon-wedge catheter is advanced through the Mullins sheath and passed into the left ventricle and then antegrade through the stenotic aortic valve. A soft 0.038-inch exchange wire is advanced through the catheter into the ascending and descending aorta, and the catheter and Mullins sheath are removed. A chosen dilating balloon catheter is then advanced antegrade across the mitral valve, placed across the aortic valve, and inflated. A variation of the transseptal antegrade technique using the Inoue balloon has also been reported. With this technique, a 26-mm Inoue balloon catheter (at maximum balloon volume of 22 to 25 cc) is advanced antegrade over a 0.025-inch exchange-length guidewire that has been advanced transseptally from the right atrium into the

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<thead>
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<th>Class</th>
<th>Level of evidence</th>
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<tr>
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<td>IIA</td>
<td>Grade B</td>
</tr>
<tr>
<td>Palliation in patients with serious comorbid conditions</td>
<td>IIB</td>
<td>Grade B</td>
</tr>
<tr>
<td>Patients who require urgent noncardiac surgery</td>
<td>IIB</td>
<td>Grade B</td>
</tr>
<tr>
<td>An alternative to aortic valve replacement</td>
<td>III</td>
<td>Grade B</td>
</tr>
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<tr>
<th>Current indication</th>
<th>Class</th>
<th>Level of evidence</th>
</tr>
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<tbody>
<tr>
<td>Symptoms of angina, syncope and dyspnea on exertion, with catheterization peak gradient &gt;50 mm Hg</td>
<td>I</td>
<td>Grade B</td>
</tr>
<tr>
<td>Catheterization peak gradient &gt;60 mm Hg</td>
<td>I</td>
<td>Grade B</td>
</tr>
<tr>
<td>New-onset ischemic or repolarization changes on ECG at rest or with exercise (ST depression, T-wave inversion over left precordium) with a gradient &gt;50 mm Hg</td>
<td>I</td>
<td>Grade B</td>
</tr>
<tr>
<td>Catheterization peak gradient &gt;50 mm Hg if patient wants to play competitive sports or desires to become pregnant</td>
<td>IIa</td>
<td>Grade C</td>
</tr>
<tr>
<td>Catheterization gradient &lt;50 mm Hg without symptoms or ECG changes</td>
<td>III</td>
<td>Grade C</td>
</tr>
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Balloon dilatation of the cardiac valves

FIGURE 23.8. Cineangiographic frames of retrograde percutaneous aortic balloon valvuloplasty. (A) The guidewire in place across the aortic valve with a loop into the left ventricle. (B) The dilating balloon catheter is placed across the aortic valve. (C) The dilating balloon catheter is partially inflated across the stenotic aortic valve. Note the indentation in the balloon caused by the stenotic aortic valve. (D) Full inflation of the dilating balloon across the aortic valves.

Figure 23.9. Transseptal, antegrade aortic balloon valvuloplasty using the Inoue balloon catheter. Following transseptal left heart catheterization a balloon tip catheter is advanced from the right atrium into the left atrium and then across the mitral valve into the ascending and descending aorta from either of the femoral arteries (Fig. 23.9).

With both techniques, multiple balloon inflations are performed to relieve the stenosis. To monitor systemic blood pressure during and immediately after balloon inflations, a radial arterial line should be in place before the inflations. In two thirds of the patients, inflations are well tolerated and from the descending aorta with the use of a 5-French Microvena snare catheter and the balloon catheter removed. Thereafter, a 26-mm Inoue balloon catheter is advanced antegrade across the aortic valve and inflated at a volume between 20 to 24cc according to the aortic annulus until the indentation produced by the stenotic valve is resolved.
longer balloon inflations (>30 seconds) can be performed. In the other third of the patients only short balloon inflations (15 to 30 seconds) can be performed because of significant hypotension during balloon inflation. Short balloon inflations and a longer period between inflations are used in patients with severe depression of left ventricular ejection fraction as well as in patients with severe coronary artery disease or carotid disease. The size of the dilating balloon catheter [18 to 25 mm in diameter] is chosen according to the size of the aortic annulus (not greater than 100% of annulus) determined by 2D-echocardiography or angiography.

Hemodynamic measurement and cardiac output using the thermodilution method are determined before and after completion of the procedure. For patients with significant tricuspid regurgitation or left to right shunting, cardiac output is determined using the Fick method. The aortic valve area (cm²) is calculated using the Gorlin equation. Aortic valve resistance (dynes-sec/cm²) is calculated using the Fick method. The aortic valve area (cm²) is calculated using the Gorlin equation. Aortic valve resistance (dynes-sec/cm²) is calculated using the Fick method.

Mechanism

The final aortic valve area obtained with PAV is most likely related to the underlying valve pathology. Fresh post-mortem studies of patients with degenerative calcific aortic stenosis in whom commissural fusion, is minimal have shown that the increase in aortic valve area in these patients occurs as the result of fracture of calcium deposit in the aortic leaflets. In patients with commissural fusion such as rheumatic aortic stenosis and some patients with noncalcific bicuspid valve stenosis, PAV produces commissural splitting with or without cuspal crack. In addition, PAV produces stretching of the aortic wall at nonfused commissural sites. Stretching is probably transient and is responsible for the cases of early restenosis seen in some patients. Although opening of fused commissures is probably the most effective mechanism of PAV, commissure fusion seldom occurs in the elderly with calcific aortic stenosis.

Immediate Results

Between February 1986 and February 1993, 394 PAV procedures were performed at the Massachusetts General Hospital in 310 symptomatic patients with severe, calcific, aortic stenosis. The patients were considered nonsurgical or very high risk surgical candidates at the time of presentation because of associated major comorbid conditions. In addition, PAV was performed in patients with severe aortic stenosis discovered at the time of evaluation for major non-cardiac surgery, in 65 patients who presented with symptomatic aortic valve restenosis after a previous successful procedure (redo-PAV), and in 21 patients who presented in cardiogenic shock due to critical aortic stenosis. There were 180 women and 130 men with a mean age of 79 ± 1 (range: 35–96) years. Mean left ventricular ejection fraction was 48% ± 15% (range: 10–81%). Ninety percent of the patients were in NYHA functional classes III to IV. All patients had more than one major comorbid condition (average 1.3/patient) at the time of presentation, including chronic renal failure (21%), severe chronic obstructive pulmonary disease (21%), peripheral vascular disease (17%), previous stroke (15%), cancer (15%), and other major comorbidities (38%); liver failure, hip fracture, pulmonary hemorrhage, pulmonary embolism, Alzheimer’s disease, sepsis, diabetes with multiple organ complications, thyroid disease, bleeding disorders, incapacitating arthritis, multiple myeloma, and AIDS.

Percutaneous aortic balloon valvuloplasty results in a decrease in aortic gradient and a modest increase in aortic valve area in the great majority of patients with degenerative calcific aortic stenosis. The hemodynamic changes produced by PAV are shown in Table 23.10. Percutaneous aortic balloon valvuloplasty resulted in a significant decrease in mean systolic aortic gradient from 56 ± 1 to 25 ± 1 mm Hg (p = .0001) and a significant increase in both cardiac output from 3.7 ± 0.06 to 3.9 ± 0.06 L/min (p = .0001) and aortic valve area from 0.5 ± 0.01 to 0.9 ± 0.02 cm² (p = .0001). Failure of PAV (no change in aortic valve area) occurred in only 3% of the patients. An aortic valve area ≤0.7 cm² was obtained in about 38% of the patients. An aortic valve area >0.7 cm² was obtained in 59% of the patients, including 27% of patients in whom PAV results in an aortic valve area ≥1.0 cm². The increase in aortic valve area with PAV is inversely related to the NYHA functional class before PAV and to the severity of aortic stenosis as reflected in higher aortic gradient and smaller aortic valve area before PAV.

Complications

Procedural mortality (death in the catheterization laboratory) occurred in 12 patients (3%), in-hospital (30-day) mortality occurred in 34 patients (8.6%), and local vascular complications in 49 patients (12%), including the need for vascular surgery in 38 patients (9.6%), two of whom required leg amputation (0.5%). Cerebrovascular accident occurred in five patients (1.2%), severe aortic regurgitation in six patients (1.8%), acute renal failure in seven patients (1.7%), significant atrial septal defect in two patients (0.5%) who had antegrade

<table>
<thead>
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<th>Variable</th>
<th>Pre-PAV</th>
<th>Post-PAV</th>
<th>p value</th>
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<tr>
<td>Mean aortic gradient, mm Hg</td>
<td>56 ± 1</td>
<td>25 ± 1</td>
<td>.0001</td>
</tr>
<tr>
<td>Cardiac output, L/min</td>
<td>3.7 ± 0.1</td>
<td>3.9 ± 0.1</td>
<td>.0001</td>
</tr>
<tr>
<td>Aortic valve area, cm²</td>
<td>0.49 ± 0.01</td>
<td>0.87 ± 0.02</td>
<td>.0001</td>
</tr>
<tr>
<td>Systolic aortic pressure, mm Hg</td>
<td>129 ± 2</td>
<td>144 ± 2</td>
<td>.0001</td>
</tr>
<tr>
<td>Systolic pulmonary artery pressure, mm Hg</td>
<td>49 ± 1</td>
<td>45 ± 1</td>
<td>.003</td>
</tr>
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PAV, cholesterol emboli in three patients (0.8%), nonfatal ventricular fibrillation in seven patients (1.7%), myocardial infarction in six patients (1.5%), and left ventricular perforation in one patient (0.2%).

Long-Term Follow-Up

Although PAV results in immediate hemodynamic and symptomatic improvement in the great majority of patients, the long-term results of PAV show that clinical restenosis occurs frequently 6 to 12 months after PAV. Estimated actuarial survival at 1-, 3-, and 5-year follow-up of the Massachusetts General Hospital series were 55% ± 3%, 25% ± 3%, and 22% ± 3%, respectively (Fig. 23.10). The corresponding estimated actuarial event-free survival were 33% ± 2%, 13% ± 2%, and 2% ± 1%, respectively (Fig. 23.11). Clinical follow-up of the patients who have undergone percutaneous aortic valvuloplasty have demonstrated that cardiac mortality and clinical restenosis (defined as cardiac mortality and patients returning to the pre-PAV NYHA functional class) after balloon valvuloplasty is very high. Although mortality is greater in those patients in whom PAV resulted in an aortic valve area <0.7 cm² than in those with post-PAV valve areas >0.7 cm² (Fig. 23.10), the survival curve of the natural history of patients with severe aortic stenosis treated medically is unaffected by balloon valvuloplasty. The presence of left ventricular dysfunction and the presence of coronary artery disease adversely affect the prognosis of patients undergoing PAV. The decrease in aortic valve area at follow-up is inversely related to the post-PAV aortic valve area (Fig. 23.12). One-year clinical restenosis is greater in patients in whom post-PAV aortic valve area was ≤0.7 cm² than in those in whom post-PAV aortic valve area was >0.7 cm². A high restenosis rate (>50%) was also present in patients who have a second or third PAV with larger balloon sizes.

A high incidence of restenosis after PAV in elderly patients with calcific aortic stenosis is not unexpected. Previous attempts at surgical aortic valvuloplasty using a wide variety of instruments were accompanied by a high rate of restenosis. Healing of the fracture calcium nodules could be expected to occur early after PAV, resulting in the high incidence of restenosis. However, it is possible that if commissure splitting had occurred at the time of PAV, restenosis may not be as rapid. Although only speculative, this mechanism may account in part for those patients with a superior long-term result.

PAV as a Bridge to Aortic Valve Replacement

From our cohort of 310 patients who underwent PAV at the Massachusetts General Hospital, there were 40 patients (13%), 21 men and 19 women, mean age of 75 ± 2 years, who underwent aortic valve replacement 6 ± 1 months after PAV. When compared with the group that did not undergo aortic valve replacement after PAV (n = 270), the group of patients bridged to surgery were younger (p = .003), had a higher cardiac output (p < .003), higher aortic valve area (p = .006), and higher left ventricular end diastolic pressure (p < .034) before PAV. Left ventricular ejection fraction was similar in both groups. With PAV, the mean aortic gradient decreased from 57 ± 3 to 26 ± 2 mm Hg (p < .001), the cardiac output increased from 4.2 ± 1 to 4.5 ± 1 L/min (p = .11), and the aortic valve area increased from 0.6 ± 0.04 to 1.0 ± 0.07 cm² (p < .001). Patients who underwent aortic valve replacement had both higher cardiac output (p < .001) and larger aortic valve area (p = .03) after PAV than the group of patients that did not undergo surgery. In-hospital surgical mortality was 10%. There were seven deaths occurring at 18 ± 6 months after PAV. There was a significant improvement in symptoms after aortic valve replacement. At a mean follow-up of 35 ± 3 months, 87% of the patients bridged to aortic valve replacement after PAV were in NYHA class I-II and 13% were in class III-IV. As shown in Figure 23.12 estimated actuarial survival curves at 1, 3, and 5 years were significantly better for the group of patients bridged to aortic valve replacement after PAV.
PAV for Patients in Cardiogenic Shock

Percutaneous aortic balloon valvuloplasty can be performed successfully in patients with cardiogenic shock due to severe aortic stenosis.110 In these patients, PAV resulted in a significant decrease in aortic gradient and a significant increase in aortic valve area and systolic arterial pressure in 90% of these moribund patients. From our cohort of 310 patients who underwent PAV at the Massachusetts General Hospital, there were 21 patients, 10 men and 11 women, mean age of 74 ± 3 [range 35–90] years, mean left ventricular ejection fraction of 29% ± 3% [range 15–61%] who underwent PAV for cardiogenic shock. All patients met the following criteria of cardiogenic shock: (1) sustained arterial hypotension with systolic blood pressure <90mmHg despite maximal inotropic and pressor pharmacologic support, (2) cardiac index <2.2 L/min/m²; (3) mean pulmonary capillary wedge pressure or left ventricular end-diastolic pressure (LVEDP) >20mmHg, (4) urinary output <0.5 mL/kg/h, and (5) clinical evidence of decreased tissue perfusion.

Before PAV, patients with cardiogenic shock exhibit a lower left ventricular ejection fraction [p = .001], and lower cardiac index [p < .0003] than the group of patients without cardiogenic shock. Percutaneous aortic balloon valvuloplasty resulted in a significant reduction in mean aortic gradient from 49 ± 4 to 21 ± 3 mmHg [p = .0001], a borderline improvement in cardiac index from 1.8 ± 0.1 to 2.2 ± 0.1 L/min/m² [p = .06], and a significant improvement in aortic valve area from 0.5 ± 0.04 to 0.8 ± 0.06 cm² [p = .0001] in the group of patients presenting in cardiogenic shock. Sixteen of these patients were successfully weaned from the inotropic support in the first 24 hours after the valvuloplasty procedure. Complications in this cohort of patients included procedural mortality in two patients (9.5%), total in-hospital [30-day] mortality in nine patients (43%), local vascular complications in five patients (24%), local vascular surgery in three patients (14%), cerebrovascular accident in one patient (5%), severe aortic regurgitation in one patient (5%), and cholesterol embolization in one patient (5%). The major cause of in-hospital mortality was multiorgan failure despite successful PAV.

Actuarial survival was 38% ± 11% at 27 months’ follow-up. Cox regression analysis identified post-PAV cardiac index as the only predictor for longer survival [p = .02]. Although high, the procedure-related mortality after PAV in this group of patients with cardiogenic shock compares favorably with the extremely high mortality rate reported in previous surgical studies in patients with cardiogenic shock and severe aortic stenosis.91,92 Even though surgical correction with aortic valve replacement is the only therapy that alters the natural history of severe, symptomatic aortic stenosis in the elderly, there are important guidelines that have to be kept in mind when managing elderly patients with cardiogenic shock due to critical aortic stenosis: (1) sustained hypotension-associated severe congestive heart failure constitutes a medical emergency, and pharmacologic therapy and bedside hemodynamic monitoring should be started immediately; (2) there is no time for procrastination, and emergent interventional therapy (PAV or aortic valve replacement) should be done as soon as possible; (3) PAV should be considered as a bridge to aortic valve replacement, and aortic valve replacement with myocardial revascularization, if needed, should be performed early after percutaneous balloon valvuloplasty.

Palliation PAV

Percutaneous aortic balloon valvuloplasty is a palliative treatment for adult patients with aortic stenosis who are not candidates for aortic valve replacement.104,110 It provides immediate hemodynamic and clinical improvement with a low incidence of life-threatening complications. However, the major limitation of PAV is the high incidence of restenosis within 1 year after the procedure. Although PAV results in immediate hemodynamic and symptomatic improvement in the great majority of patients, the long-term results of PAV show that clinical restenosis occurs frequently 6 to 12 months after PAV.

PAV for Patients Undergoing Emergency Noncardiac Surgery

Some studies have shown that patients with severe aortic stenosis undergoing noncardiac surgery could benefit from PAV, resulting in a significant improvement in aortic valve gradient and aortic valve area with very low complications during noncardiac surgery.111-113 However, O’Keefe et al.114 in 48 patients with severe aortic stenosis who underwent noncardiac surgery without preoperative PAV, found no major perioperative complications if patients were managed with careful monitoring of systemic and pulmonary artery pressure during anesthesia. Therefore, PAV should be limited to those patients with critical aortic stenosis and low ejection fraction, heart failure, or cardiogenic shock, in whom transient hemodynamic improvement may decrease the risk of perioperative complications.

PAV in Pregnant Women

As aortic stenosis in pregnant patients is most commonly bicuspid with two commissures, PAV should provide effec-
PAV for Patients with Congenital Aortic Stenosis

Lababidi et al.\textsuperscript{115} introduced balloon aortic valvuloplasty for congenital valvular aortic stenosis in 1984. The aortic valve in patients with congenital aortic stenosis is most commonly bicuspid with two commissures, less frequently is unicommissural or noncommissural, and rarely is tricuspid with fusion of one or more of the three commissures. Balloon valvuloplasty in this patient population provides effective gradient relief with minimal restenosis at follow-up, though progressive aortic insufficiency has been reported.\textsuperscript{111,117-122} In this patient cohort, PAV is a good alternative to surgical valvuloplasty, and this later technique should be reserved for those patients with congenital aortic stenosis in whom PAV is unsuccessful or impossible (Table 23.9). Complications are rare and most of them transient. Arterial access problems due to the large balloon size are the most common complications. The incidence of a degree of aortic regurgitation post-PAV is comparable to that associated with surgical open valvuloplasty. Appropriate balloon sizing (a balloon diameter equal to or less than the aortic annulus measured by echocardiography or cineangiography) is essential to decrease the incidence of severe aortic regurgitation and or disruption of the aortic annulus after PAV.

Patient Selection

It is well known that the onset of symptoms in patients with severe aortic stenosis begins after a latent period of several years, during which increasing left ventricular obstruction and myocardial overload occurs.\textsuperscript{123} After the onset of symptoms, the prognosis of patients with aortic stenosis without aortic valve replacement is very poor. The 5-year survival is less than 50% when congestive heart failure, syncope, or angina develops in patients treated medically. Congestive heart failure carries the worse prognosis; the 50% survival of these patients is 2 years if surgery is not performed. Thus, once symptoms develop, medical therapy has a limited role in the treatment of patients with aortic stenosis. Aortic valve replacement is the treatment of choice for these patients. This technique has been clearly demonstrated to change the natural history of patients with severe aortic stenosis. Aortic valve replacement can be performed with low operative mortality and morbidity. Follow-up studies of these patients demonstrated significant improvement in symptoms and excellent long-term survival. Although aortic valve replacement in elderly patients, particularly those octogenarians with severe aortic stenosis, is associated with a greater morbidity and mortality, it can be performed safely with low mortality in a selected group of these patients. Furthermore, after surgery, the survival of these patients is not different from the survival of other octogenarians with no cardiac diseases.\textsuperscript{95}

Although the hemodynamic and clinical improvement produced by PAV in more patients with degenerative calcific aortic stenosis is short lived, it provides a window of opportunity, making this technique an attractive alternative for a select group of patients with symptomatic calcific aortic stenosis. Today, the PAV indications for patients with severe degenerative aortic stenosis include the following: 1. Patients who are not surgical candidates or are very high risk surgical candidates and are incapacitated by symptoms of aortic stenosis: Consultation with a cardiac surgeon is recommended to identify patients who are truly not candidates for cardiac surgery. Elderly patients with aortic stenosis should not be denied the opportunity for aortic valve replacement solely on the basis of age. 2. As a bridge to aortic valve replacement in patients with calcific aortic stenosis who require urgent major noncardiac surgical intervention for other organ dysfunction: These patients may have PAV done to transiently improve their hemodynamics, and therefore, the safety of their urgent major surgical procedure. After recovery from this surgery, the decision to replace the aortic valve should be made. 3. As a bridge to aortic valve replacement in patients with severe heart failure or cardiogenic shock due to aortic stenosis. 4. In patients with “the Gorlin conundrum” characterized by poor left ventricular function, low cardiac output, and small transaortic gradient whose calculated aortic valve areas by the Gorlin formula are small: In these patients, the low left ventricular ejection fraction could be secondary to a myopathic left ventricle with an aortic valve that is not stenotic, but with a low flow state that results in a falsely low calculated aortic valve area, or secondary to afterload mismatch due to severe stenotic aortic valve. In the former, surgery will not be of benefit and the surgical risk is very high, and in the latter, aortic valve replacement should be performed. A PAV can be used to solve this dilemma. Improvement of left ventricular ejection fraction after a successful PAV indicates that aortic stenosis was present and the patient should undergo aortic valve replacement. In contrast, the lack of improvement in the left ventricular ejection fraction after a successful PAV indicates that aortic stenosis was never present and the patient was suffering from a cardiomyopathy. Under these later conditions, aortic valve replacement should not be performed.

Percutaneous Tricuspid Balloon Valvuloplasty

Tricuspid stenosis is rare and is associated with mitral stenosis. Percutaneous tricuspid balloon valvuloplasty [PTV] has been performed in few isolated cases with good outcome.\textsuperscript{114-116} Because of the large tricuspid annulus, the double-balloon technique is preferable. Results from PTV have been similar to those reported for surgery. The PTV results in a dramatic clinical and hemodynamic improvement in patients with tricuspid stenosis. With PTV, there is a decrease in tricuspid gradient and an increase in cardiac output. Significant tricuspid regurgitation rarely occurs, and restenosis at follow-up is infrequent. Patients with associated moderate or severe tricuspid regurgitation are not candidates for PTV.
Future Research

After more than 15 years of extensive clinical evaluation, the technique of percutaneous valvuloplasty, which for practical purposes can be summed up as PMV, has a significant place in the treatment of mitral stenosis. Pragmatically, a larger use of PMV will depend on the solution of economic problems that limit the use of the technique in the countries in which rheumatic disease is still endemic but in which means are lacking. In the industrialized countries, the debate on the use of PMC in patients with unfavorable anatomy will require further studies, including a large number of patients and a long follow-up. Further proof of the efficacy of PMV in the prevention of embolism and atrial fibrillation is necessary to further extend the indications to asymptomatic patients. New tools, such as 3D-echocardiography, may help to refine patient selection and better assess the results. Intracardiac echocardiography could avoid the need for transesophageal echocardiography to exclude left atrial thrombosis and help in transseptal puncture, the pitfall being the price of the device. Finally, in the future, it could be possible to perform PMV in combination with other percutaneous procedures, such as coronary revascularization, ablation in patients with supraventricular arrhythmias, or occlusion of the left atrial appendage to prevent stroke. The question with PAV is to know whether it still has a place. It would, however, appear important to evaluate PAV better in rheumatic aortic stenosis, where it might ultimately be an attractive application of the technique.

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