JACC Vol. 19, No. 1
January 1992:186–91

DIAGNOSTIC STUDIES

Unusual Sequelae After Percutaneous Mitral Valvuloplasty: A Doppler Echocardiographic Study

JOHN P. O'SHEA, MBBS, FRACP, VIVIAN M. ABASCAL, MD, GERARD T. WILKINS, MB, ChB, FRACP, JANE E. MARSHALL, BS, SERGIO BRANDI, MD,* HARRY ACQUATELLA, MD,* PETER C. BLOCK, MD, FACC, IGOR F. PALACIOS, MD, FACC, ARTHUR E. WEYMAN, MD, FACC

Boston, Massachusetts and Caracas, Venezuela

Percutaneous mitral valvuloplasty is a promising new technique for the treatment of mitral stenosis, with a relatively low complication rate reported to date. To assess the sequelae of this procedure, Doppler echocardiographic studies were prospectively performed before and after percutaneous mitral valvuloplasty in a series of 172 patients (mean age 53 ± 17 years). After balloon dilation, mitral valve area increased from 0.9 ± 0.3 to 2 ± 0.8 cm^2 ($p < 0.0001$), mean gradient decreased from 16 ± 6 to 6 ± 3 mm Hg ($p < 0.0001$) and mean left atrial pressure decreased from 24 ± 7 to 14 ± 6 mm Hg ($p < 0.0001$).

Although most patients were symptomatically improved, six (4%) were identified who had unusual sequelae evident on Doppler echocardiographic examination immediately after percutaneous mitral valvuloplasty. These included rupture of a posterior mitral valve leaflet, producing a flail distal leaflet portion with severe mitral regurgitation detected on Doppler color flow mapping (n = 1); asymptomatic rupture of the chordae tendineae attached to the anterior mitral valve leaflet with systolic anterior motion of the ruptured chordae into the left ventricular outflow tract (n = 1); a double-orifice mitral valve (n = 1); and evidence of a tear in the anterior mitral valve leaflet (n = 3), producing on both pulsed Doppler ultrasound and color flow mapping a second discrete jet of mitral regurgitation in addition to regurgitation through the main mitral valve orifice. All six patients made a satisfactory recovery and none has required mitral valve replacement.

In a small percent of cases, percutaneous mitral valvuloplasty may produce unusual disruption of the mitral valve and supporting apparatus that may be readily detected by Doppler echocardiographic studies.

(J Am Coll Cardiol 1992;19:186–91)

Percutaneous mitral valvuloplasty is a promising new nonsurgical approach to the management of patients with rheumatic mitral stenosis, with several early reports (1–6) of significant improvement after this procedure. A number of predictable complications of this technique have been described (2,3), including thromboembolic episodes (2,6,7), increased mitral regurgitation (2,3,5–8), complete heart block (2,6,7) and left to right shunting through an atrial septal defect (2,3,6,7,9).

From the Cardiac Unit, Department of Medicine, Massachusetts General Hospital and Harvard Medical School, Boston, Massachusetts and *Department of Medicine, Hospital Universitario de Caracas y Universidad Central de Venezuela, Caracas, Venezuela. Dr. O'Shea is an Overseas Clinical Fellow of the National Heart Foundation of Australia, Canberra, Australian Capital Territory, Australia and a recipient of the Athelstan and Amy Saw Postgraduate Medical Scholarship of the University of Western Australia, Perth, Australia. Dr. Wilkins was supported in part by the Odlin Fellowship of the Royal Australasian College of Physicians, Wellington, New Zealand. This study was presented in part at the 61st Scientific Session of the American Heart Association, Washington, D.C., November 1988.

Manuscript received June 19, 1990; revised manuscript received February 14, 1991, accepted July 16, 1991.

Address for reprints: Arthur E. Weyman, MD, Cardiac Noninvasive Laboratory, Phillips House, 8th Floor, Massachusetts General Hospital, Fruit Street, Boston, Massachusetts 02114.

0735-1097/92/$5.50

Two-dimensional and Doppler echocardiography have been found to be of great importance in selecting patients for percutaneous mitral valvuloplasty (6,10–12); these techniques aid in the identification of exclusion factors such as left atrial thrombus (2), the assessment of the postprocedural result (5,10–12) and the long-term follow-up assessment of the outcome of this technique (7,13).

To date, there have been no reports of unusual complications in patients after dilation of a stenotic mitral valve, such as rupture of chordae tendineae or tearing of mitral leaflets. This report describes the Doppler echocardiographic findings in a series of unusual complications of percutaneous mitral valvuloplasty in a consecutive group of patients undergoing the procedure.

Methods

Study patients. Between November 1985 and May 1988, 172 patients (141 female, 31 male) with severe mitral stenosis underwent percutaneous mitral valvuloplasty by the anterograde transseptal approach in all cases (2). The mean age of the study patients was 53 years (range 13 to 87); 101 patients (59%) had sinus rhythm before valvuloplasty and 71 (41%)

had atrial fibrillation. Twenty-two percent of patients had symptoms of New York Heart Association functional class IV, 62% had class III symptoms, 13% had class II symptoms and 3% were in class I. Twenty patients (12%) had a previous surgical commissurotomy. In the first 28 patients in this series the procedure was performed with the single-balloon technique; thereafter, the double-balloon dilating technique was used.

Mitral valvuloplasty. All patients underwent percutaneous mitral valvuloplasty by the use of either single- or double-balloon–dilating techniques, using effective balloon-dilating areas determined by geometric analysis and normalized for body surface area, as previously described (6). Before and after valvuloplasty, right and left heart pressures and cardiac output were measured. Cardiac output was determined by thermodilution in most patients, but when tricuspid regurgitation was present or an atrial septal defect detected by a step-up in oxygen saturation (>8% step-up from mixed venous sample to pulmonary artery sample), the Fick method was used. Mitral valve area was calculated by the Gorlin formula (14).

Doppler echocardiographic examination. Two-dimensional and Doppler echocardiographic examinations were performed before and <24 h after percutaneous mitral valvuloplasty. All studies were performed by one of three experienced operators. In most patients, two-dimensional images, pulsed Doppler and color flow mapping studies were performed with a Hewlett-Packard 77020A ultrasound imager equipped with a 2.5-MHz phased array transducer. An Advanced Technology Laboratories MK 600 ultrasound imager equipped with a 3-MHz mechanical transducer was used for some studies earlier in the series; in these instances, color flow mapping was added with the Hewlett-Packard machine whenever possible. Continuous wave Doppler data were obtained either with a 1.9-MHz nonimaging transducer connected to a Hewlett-Packard imager, a duplex 1.9/2.5-MHz imaging transducer or an Irex Excimplar imager equipped with a 3/2-MHz imaging transducer.

In each study, standard echocardiographic images were obtained in the parasternal long- and short-axis views and the apical four-chamber, two-chamber and long-axis views. In all views, meticulous care was taken to scan the mitral valve and subvalvular apparatus repeatedly for evidence of any pathologic disruption. With the use of pulsed Doppler ultrasound and color flow mapping, the patterns of mitral regurgitation were evaluated in all views and the presence of mitral regurgitation was defined as a high velocity systolic jet, extending from the mitral valve back into the left atrium. The Doppler sample volume was moved carefully and progressively throughout the entire left atrium to identify the maximal spatial extent of the regurgitant jet (15). All two-dimensional images and pulsed Doppler and color flow mapping studies were recorded on 0.5-in. (1.27-cm) videotape, allowing for subsequent frame by frame analysis. Continuous wave Doppler data were recorded on paper at a speed of 100 mm/s.

An echocardiographic scoring system based on morphologic characteristics of the mitral valve (mobility, thickening, calcification and subvalvular thickening) (8,10,12) was applied to all subjects in this series before percutaneous mitral valvuloplasty was performed.

Statistical methods. Measurements before and after percutaneous mitral valvuloplasty were compared by using the Student's paired *t* test for parametric data and the Wilcoxon signed-rank test for nonparametric data. Differences with p values <0.05 were considered significant. All results are expressed as mean values ± SEM.

Results

In the overall group of 172 patients, balloon dilation of the mitral valve resulted in an increase in mitral valve area from 0.9 ± 0.3 to 2 ± 0.8 cm^2 (<0.0001), a decrease in mean transmitral gradient from 16 ± 6 to 6 ± 3 mm Hg ($p < 0.0001$) and a decrease in mean left atrial pressure from 24 ± 7 to 14 ± 6 mm Hg ($p < 0.0001$).

Six patients in this series had unusual sequelae evident on the Doppler echocardiographic study performed within 24 h of percutaneous mitral valvuloplasty. Details of these patients' hemodynamic data are listed in Table 1. The following sequelae were observed.

Case Reports

Case 1: partial rupture of distal portion of posterior mitral valve leaflet (Fig. 1). A 28-year old woman underwent percutaneous mitral valvuloplasty by the double-balloon technique. She was in sinus rhythm, had symptoms of functional class III, an echocardiographic score of 8 and no prior mitral valve surgery. After percutaneous mitral valvuloplasty, the mitral valve area (assessed by the Gorlin formula) increased from 0.7 to 2.5 cm^2 and the mean transmitral gradient decreased from 19 to 1 mm Hg. Although she had no mitral regurgitation before the procedure, severe mitral regurgitation developed immediately after the procedure and progressed to pulmonary edema.

Doppler and two-dimensional echocardiographic examination at this time demonstrated the presence of partial rupture of the distal portion of the posterior mitral valve leaflet, with a flail portion of the posterior leaflet evident on the atrial side of the coapted mitral valve leaflets at the onset of systole (Fig. 1). Doppler color flow mapping showed severe mitral regurgitation, but the patient was managed conservatively and made a satisfactory recovery over the ensuing 24 h. She remained well thereafter in functional class II and has required no further intervention.

Case 2: double-orifice mitral valve (Fig. 2). A 58-year old woman underwent percutaneous mitral valvuloplasty by the single-balloon technique. She had atrial fibrillation, was in functional class III and had an echocardiographic score of 9. She had no prior mitral valve surgery. As a result of the procedure, the mitral valve area increased from 1.4 to

Table 1. Summary of Six Cases of Postvalvuloplasty Complications

Pt No.	Age (yr)/ Gender	Rhythm	NYHA Functional Class Pre	NYHA Functional Class Post	Mean Gradient (mm Hg) Pre	Mean Gradient (mm Hg) Post	MVA (cm^2) Pre	MVA (cm^2) Post	MR Grade Pre	MR Grade Post	Echo Score (0 to 16)	Prior Commissurotomy	No. of Balloons Used	Sequela of Valvuloplasty
1	28/F	SR	III	II	19	1	0.7	2.5	0	4	8	No	2	Rupture of posterior leaflet
2	58/F	AF	III	II	15	6	1.4	2.2	0	1	9	No	1	Double-orifice mitral valve
3	41/F	AF	III	I	14	5	0.9	2	0	1	7	Yes	2	Ruptured chordae
4	48/F	SR	III	I	16	2	0.7	2.4	0	1	6	Yes	2	Two jets of MR
5	26/M	SR	III	I	30	8	0.6	2.5	0	1	9	Yes	2	Two jets of MR
6	41/F	SR	II	I	16	8	0.8	1.3	1	2	8	Yes	2	Two jets of MR

AF = atrial fibrillation; Echo = echocardiographic; F = female; M = male; MR = mitral regurgitation; MVA = mitral valve area; NYHA = New York Heart Association; Post = after mitral balloon valvuloplasty; Pre = before mitral balloon valvuloplasty; Pt = patient; SR = sinus rhythm.

$2.2\ cm^2$, the mean transmitral gradient decreased from 15 to 6 mm Hg and mild mitral regurgitation developed. Although Doppler echocardiographic studies performed before valvuloplasty showed an eccentric mitral valve orifice, a repeat study performed 24 h after the procedure revealed an unusual appearance suggestive of a double-orifice mitral valve (Fig. 2). Subsequently, as a result of symptoms, the patient underwent repeat valvuloplasty with the double-balloon technique, after which the double-orifice valve was no longer present. Thereafter, she remained considerably improved symptomatically in functional class II.

Case 3: rupture of chordae tendineae (Fig. 3). A 41-year old woman underwent percutaneous mitral valvuloplasty by the double-balloon technique, having had functional class III symptoms for some time. She had atrial fibrillation, an echocardiographic score of 7 and a prior mitral surgical commissurotomy. As a result of percutaneous mitral valvuloplasty, mitral valve area (by the Gorlin formula) increased from 0.9 to $2\ cm^2$, the mean transmitral gradient decreased from 14 to 5 mm Hg and mild angiographic mitral regurgitation developed (she had had no regurgitation before valvuloplasty).

On the next day, the patient was asymptomatic, but a Doppler echocardiographic study revealed a mobile, thickened ruptured chorda tendinea attached to the anterior mitral leaflet, with systolic anterior motion of the ruptured chorda into the left ventricular outflow tract (Fig. 3). There was no evidence of consequent left ventricular outflow tract obstruction on Doppler studies. No further intervention was required and the patient has remained asymptomatic in functional class I.

Cases 4 to 6: two distinct jets of mitral regurgitation (Fig. 4). Three patients (Cases 4 to 6) underwent percutaneous mitral valvuloplasty by the double-balloon technique with a satisfactory improvement in mitral valve area and transmitral gradient after the procedure (Table 1). All three patients had a prior surgical mitral commissurotomy and all had sinus rhythm. The balloon dilation procedure was uneventful in all three patients, with none noticing any deterioration in symptoms after the procedure. However, a Doppler echocardiographic study performed 24 h later demonstrated in each case two distinct jets of mitral regurgitation on both pulsed Doppler study and color flow mapping. These consisted of one regurgitant jet emanating from the main mitral valve orifice at the normal site of coaptation and a second discrete regurgitant jet that appeared to arise from the basal portion of the anterior mitral leaflet close to the mitral annulus (Fig. 4). The latter regurgitant jet was consistent with a tear or fenestration in the body of the anterior mitral leaflet and was not suggestive of disruption of the mitral anulus. Because after the procedure all three patients remained clinically stable and in functional class I, no further intervention was necessary.

Figure 1. Patient 1. Apical four-chamber view, with explanatory diagram showing a flail portion of the posterior mitral valve leaflet (PVML) on the atrial side of the coaptation during systole. This appearance was associated with severe mitral regurgitation on Doppler color flow mapping. AMVL = anterior mitral valve leaflet; LA = left atrium; LV = left ventricle; R = right atrium; RV = right ventricle.

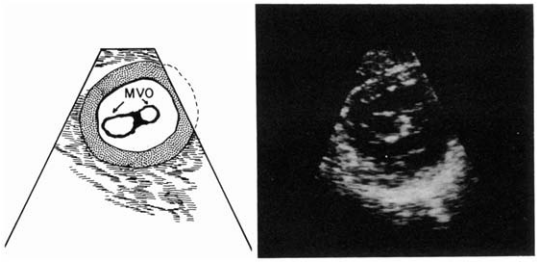

Figure 2. Patient 2. Parasternal short-axis view of the mitral valve leaflets with explanatory diagram showing a double mitral valve orifice configuration (MVO) after percutaneous mitral valvuloplasty. This configuration changed to that of a single orifice after a second balloon dilation procedure.

Discussion

Percutaneous mitral valvuloplasty is being increasingly utilized as an alternative approach to the surgical treatment of patients with mitral stenosis. Several studies (1–6) have now described favorable results with this technique and have reported a small incidence of predictable complications, including complete heart block (2–7), left to right shunting through an atrial septal defect (2,3,6,7,9), thromboembolic episodes (2,6,7), pericardial tamponade (6,7,16) and increased mitral regurgitation (2,3,5–8). Combined two-dimensional and Doppler echocardiography provide an excellent noninvasive method for evaluating the structure and function of the mitral valve apparatus before and after percutaneous mitral valvuloplasty and thus has the ability to detect other unusual or clinically unsuspected complications of the procedure. This report describes four such complications, affecting six patients in a large consecutive series.

The process of rheumatic mitral stenosis involves commissural fusion, with some degree of thickening and tethering of the leaflet tips and the subvalvular apparatus. As the disease process becomes more severe, marked leaflet thickening, calcification, immobility and chordal thickening and shortening can occur. Thus, in the setting of severe mitral stenosis, mechanical dilation of the valve orifice by either surgical or percutaneous balloon techniques has a theoretic risk of producing tears and even complete rupture of the diseased leaflets and subvalvar apparatus. Although open surgical commissurotomy allows direct inspection and assessment of such phenomena, the techniques of closed

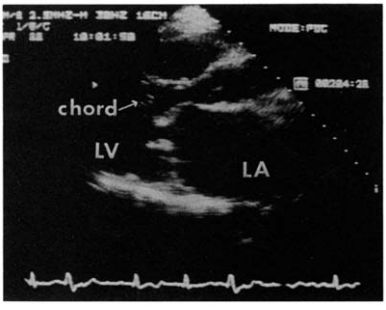

Figure 3. Patient 3. Parasternal long-axis view demonstrating a thickened ruptured chorda tendinea (chord) freely mobile in the left ventricular cavity (LV) in diastole and moving anteriorly into the left ventricular outflow tract in systole. This chordal structure was never seen to prolapse into the left atrium (LA) and was not associated with significant mitral regurgitation or outflow tract obstruction.

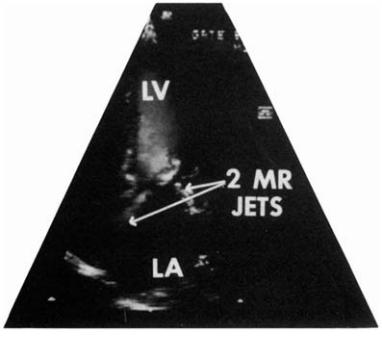

Figure 4. Patient 4. Apical four-chamber view from a Doppler color flow mapping study, showing two discrete jets of mitral regurgitation (MR) after percutaneous mitral valvuloplasty. One jet arises from the main orifice; the second jet originates from the basal portion of the anterior mitral leaflet close to the mitral anulus. Other abbreviations as in Figure 1.

JACC Vol. 19, No. 1
January 1992:186–91

surgical mitral commissurotomy and percutaneous balloon mitral valvuloplasty do not have this advantage and hence require either clinical signs or other imaging modalities such as Doppler echocardiography to assess the result of intervention. It is noteworthy that in the current series, five of the six patients described were clinically stable after percutaneous mitral valvuloplasty and thus the unusual complications described would presumably have remained undetected had the patients not undergone a routine Doppler echocardiographic study within 24 h of the procedure.

Mechanisms of the Complications

Several possible mechanisms can be suggested for the unusual complications described in this report.

Partial rupture of the distal portion of the mitral valve leaflet. With the rheumatic thickening of the mitral valve leaflets, it is possible that the balloon inflation procedure may lead to disruption and tearing of portions of either the anterior or the posterior mitral leaflet. Such a rupture may be a function of balloon size or, in particular, the ratio of balloon size to specific patient variables such as body surface area and mitral anulus diameter. In one recent study (17) in a canine model of surgically created mitral stenosis, tearing of the mitral leaflets was commonly induced by inflation of relatively oversized balloons. In our Patient 1, a relatively large ratio of balloon-dilating area to body surface area (ratio 5.1) was utilized, whereas more recent practice in our institution is to select balloon size so as to produce a ratio of about 3.5. This practice is based on data suggesting that the latter ratio produces an optimal increase in mitral valve area without leading to a significant increase in mitral regurgitation (6).

Although Patient 1 rapidly developed the clinical findings of acute pulmonary edema that usually require an urgent mitral valve reconstruction or replacement, she responded very well to conservative medical therapy and surgical intervention was deferred. Remarkably, she has tolerated the increased mitral regurgitation satisfactorily during follow-up observations of >2 years. This case illustrates that although increased mitral regurgitation occurs in a proportion of patients undergoing percutaneous mitral valvuloplasty (2,3,5,6,8), it is unusual to require urgent mitral valve surgery in this setting, even in relatively severe cases such as the one described.

Double-orifice mitral valve. Patient 2 had eccentric disease of the mitral valve orifice before percutaneous mitral valvuloplasty, raising the possibility that the initial guiding catheter placed across the mitral valve orifice may have perforated the leaflets at the site of relative fusion, rather than passing through the orifice. In this setting, it is conceivable that balloon inflation may produce a second orifice by splitting the leaflet tissue adjacent to the original valve orifice. The disappearance of the double-orifice configuration after repeat percutaneous mitral valvuloplasty suggests that there may have been minimal central fusion of anterior and posterior leaflets between the two "orifices," allowing easy separation with repeat balloon inflation.

Rupture of chordae tendineae. In a similar manner to mitral leaflet rupture, the presence of thickened matted chordae tendineae may predispose to chordal rupture, depending on the precise position of the inflating balloons in relation to such chordae. Patient 3 also had a prior surgical mitral commissurotomy, raising the possibility of additional scarring of the mitral valve leaflets and subvalvular apparatus leading to an increased propensity to chordal rupture. However, a recent series reported from our institution (5) of 14 patients who underwent percutaneous mitral valvuloplasty after a prior mitral commissurotomy contained no cases of chordal rupture so this explanation would not appear to apply in most cases. Although the patient remained asymptomatic after percutaneous mitral valvuloplasty, the echocardiographic appearance on the day after the procedure was remarkable for a flail, thickened chordal mass moving freely in the left ventricular cavity and in systole moving up into the left ventricular outflow tract. There was no evidence of left ventricular outflow tract obstruction from this mobile mass, however, and only mild mitral regurgitation. Again, in the setting of stenotic mitral leaflets, as in this case, it is notable that chordal rupture may be associated with no significant clinical deterioration, possibly as a result of the thickened leaflets not allowing a significant amount of regurgitation (as opposed to the situation with normal leaflets, in which chordal rupture frequently leads to severe mitral regurgitation).

Three distinct jets of mitral regurgitation. Three patients demonstrated this unusual phenomenon after percutaneous mitral valvuloplasty, the explanation for which is uncertain. The Doppler color flow studies in these patients consistently showed a color flow jet at the mitral coaptation site in addition to a second color flow jet, arising from the basal portion of the anterior leaflet made inadvertently while positioning the catheters. Fortuitously, the mitral regurgitation this induced was always only of mild severity and caused no significant clinical sequelae.

Clinical characteristics. In this small number of patients with unusual phenomena documented by Doppler echocardiographic studies after percutaneous balloon mitral valvuloplasty, there were no clinical characteristics that identified the six patients described as more likely to have such complications. Although four of the six patients had had a previous surgical commissurotomy, the small sample size makes it difficult to draw any conclusions from this observation. Certainly, no unusual sequelae of the kind described in this series were identified in a previous larger series from our institution (5) in patients who underwent percutaneous mitral valvuloplasty after a previous mitral commissurotomy. Five of the six patients described underwent balloon valvuloplasty by the use of the double-balloon technique, but it was also true that in the majority of patients who have had this procedure in our institution, it was done with the double-balloon technique.

Conclusions. Percutaneous mitral valvuloplasty may result in a number of unusual sequelae in a relatively small percent of cases. The sequelae reported in this series are usually benign in terms of clinical outcome, but may on occasion lead to acute symptomatic deterioration, requiring consideration of urgent surgical or other intervention. Doppler echocardiographic assessment after percutaneous mitral valvuloplasty represents an ideal method for detecting such sequelae and monitoring their progress over time.

References

1. Lock JE, Khalidullah M, Shivastava S, Bahal V, Keane JF. Percutaneous catheter commissurotomy in rheumatic mitral stenosis. N Engl J Med 1985;313:1515–8.
2. Palacios IF, Block PC, Brandi S, et al. Percutaneous balloon valvotomy for patients with severe mitral stenosis. Circulation 1987;75:778–84.
3. McKay RG, Lock JE, Safian RD, et al. Balloon dilation of mitral stenosis in adult patients: postmortem and percutaneous mitral valvuloplasty studies. J Am Coll Cardiol 1987;9:723–31.
4. Palacios IF, Lock JE, Keane JF, Block PC. Percutaneous transvenous balloon valvotomy in a patient with severe calcific mitral stenosis. J Am Coll Cardiol 1986;7:1416–9.
5. Rediker DE, Block PC, Abascal VM, Palacios IF. Mitral balloon valvuloplasty for mitral restenosis after surgical commissurotomy. J Am Coll Cardiol 1988;11:252–6.
6. Herrmann HC, Wilkins GT, Abascal VM, Weyman AE, Block PC, Palacios IF. Percutaneous balloon mitral valvotomy for patients with mitral stenosis: analysis of factors influencing early results. J Thorac Cardiovasc Surg 1988;96:33–8.
7. Palacios IF, Block PC, Wilkins GT, Weyman AE. Follow up of patients undergoing percutaneous mitral balloon valvotomy: analysis of factors determining restenosis. Circulation 1989;79:573–9.
8. Abascal VM, Wilkins GT, Choong CY, Block PC, Palacios IF, Weyman AE. Mitral regurgitation after percutaneous mitral valvuloplasty in adults: evaluation by pulsed Doppler echocardiography. J Am Coll Cardiol 1988;11:257–63.
9. Casale P, Block PC, O'Shea JP, Palacios IF. Atrial septal defect after percutaneous mitral balloon valvuloplasty: immediate results and follow up. J Am Coll Cardiol 1990;15:1300–4.
10. Tuzcu EM, Block PC, Palacios IF. Comparison of early versus late experience with percutaneous mitral balloon valvuloplasty. J Am Coll Cardiol 1991;17:1121–4.
11. Reid CL, McKay CR, Chandraratna PAN, Kawanishi DT, Rahimtoola SH. Mechanisms of increase in mitral valve area and influence of anatomic features in double-balloon, catheter balloon valvuloplasty in adults with rheumatic mitral stenosis: a Doppler and two-dimensional echocardiographic study. Circulation 1987;76:628–36.
12. Wilkins GT, Weyman AE, Abascal VM, Block PC, Palacios IF. Percutaneous mitral valvotomy: an analysis of echocardiographic variables related to outcome and the mechanism of dilatation. Br Heart J 1988;60:299–308.
13. Abascal VM, Wilkins GT, Choong CY, et al. Echocardiographic evaluation of mitral valve structure and function in patients followed for at least 6 months after percutaneous balloon mitral valvuloplasty. J Am Coll Cardiol 1988;12:606–15.
14. Carabello BA, Grossman W. Calculation of stenotic valve orifice area. In: Grossman W, ed. Cardiac Catheterization and Angiography. Philadelphia: Lea & Febiger, 1986:143–54.
15. Abbasi AS, Allen MW, Decristofaro D, Ungar I. Detection and estimation of the degree of mitral regurgitation by range-gated pulsed Doppler echocardiography. Circulation 1980;61:143–7.
16. Chen C, Wang Y, Qing D, Lin Y, Lau Y. Percutaneous mitral balloon dilatation by a new sequential single- and double-balloon technique. Am Heart J 1988;116:1168–9.
17. Rediker DE, Guerrero JL, Block DS, Southern JF, Falion JT, Block PC. Limits of mitral valve apparatus distensibility: observations from balloon mitral valvotomy in a canine model. Am Heart J 1987;114:1513–5.