Effects of Balloon Mitral Valvuloplasty on Left Atrial Function in Mitral Stenosis As Assessed by Pressure–Area Relation

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Objectives. This study sought to investigate the changes induced on the pressure–area relation of the left atrium in patients with mitral stenosis after percutaneous balloon mitral valvuloplasty.

Background. Left atrial (LA) function is influenced by changes in LA afterload. The latter is increased in mitral stenosis as a result of increased resistance to blood flow imposed by the stenotic mitral valve.

Methods. We studied the effects of acute alterations of LA afterload induced by retrograde nontransseptal balloon mitral valvuloplasty (RNBMV) on LA function in patients with mitral stenosis. LA pressure–area relations were obtained in 15 patients with mitral stenosis (8 with sinus rhythm, 7 with atrial fibrillation) before and after valvuloplasty, as well as in 15 normal subjects. LA pressure was recorded by a catheter-tipped micro-manometer introduced retrogradely into the left atrium while LA area was recorded simultaneously using acoustic quantification. The areas of the A and V loops of the pressure–area relation as well as the LA chamber stiffness constant were calculated.

Results. Balloon valvuloplasty resulted in a significant increase in mitral valve area (p < 0.001) and a substantial reduction of the mean transmitral pressure gradient (p < 0.001) and mean LA pressure (p < 0.001). The area of the A loop in patients with sinus rhythm and the area of the V loop in those with atrial fibrillation increased significantly after completion of the procedure (p < 0.001). Furthermore, LA stiffness decreased in both groups.

Conclusions. After RNBMV, there is a significant increase in LA pump function in patients with sinus rhythm, a significant increase in LA reservoir function in patients with atrial fibrillation and a significant reduction in LA stiffness in all patients. Marked alterations of the configuration of the LA pressure–area relation occur immediately after successful RNBMV in patients with mitral stenosis.

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Normal left atrial (LA) function consists of reservoir, conduit and pump function (1,2). Reservoir function occurs during left ventricular (LV) systole when the mitral valve is closed, the LA is relaxed, and the mitral annulus is temporarily displaced toward the apex (3). The left atrium acts as a conduit in diastole, when the mitral leaflets open and allow blood to enter the left ventricle. At end-diastole, the left atrium contracts, and the pump function occurs (4).

In mitral stenosis LA function may be disrupted because of increased LA afterload. Mitral stenosis resulting from rheumatic heart disease is associated with considerable fusion of the commissures and reduction of mitral valve apparatus and leaflet mobility (5,6). Moreover, there is a marked increase in LA dimension and, consequently, an impairment of the LA pump function (5). Finally, when atrial fibrillation ensues, complete loss of LA pump function occurs as a result of cessation of LA systole (7).

Percutaneous balloon mitral valvuloplasty has gained acceptance as a therapeutic alternative to surgical valvotomy in patients with mitral stenosis (8–10). Retrograde nontransseptal balloon mitral valvuloplasty (RNBMV) (11–14) using a steerable catheter that easily and consistently enters the LA retrogradely through the left ventricle is an effective and safe procedure that does not involve puncture and dilation of the interatrial septum. Successful RNBMV results in a significant increase in mitral valve area and reduction of LA pressure and transmitral gradient (11,14). Avoidance of transseptal puncture and subsequent creation of an interatrial communication with this technique provides a suitable setting for the investigation of the effects of acute decrease of LA afterload on LA function.

The LA pressure–area relation is an accurate method of estimating LA function. To our knowledge, there have been no
previous reports using this methodology to assess alterations of LA function in patients with mitral stenosis immediately after balloon mitral valvuloplasty. The LA pressure–area relation consists of two loops: the counterclockwise A loop, which expresses the LA pump function, and the clockwise V loop, which expresses the LA reservoir function (1,2,4,7). We used this methodology in the present study to investigate acute alterations of LA function induced by RNBMV. Two techniques were combined for the study of the LA pressure–area relation: automatic boundary detection (ABD) two-dimensional echocardiography for the measurement of LA area changes and a 7F Millar double-tip micromanometer for the measurement of LA and LV pressures.

Methods

Study subjects. RNBMV was attempted in 15 patients with symptomatic mitral stenosis (4 men, 11 women; mean ± SD age 49 ± 7 years, range 34 to 55). Patients with any degree of mitral regurgitation detected by color flow Doppler echocardiography after valvuloplasty were excluded from the study. This criterion was met after RNBMV was initially attempted in 20 patients. Seven patients had atrial fibrillation, and the remainder had sinus rhythm. All patients with atrial fibrillation received anticoagulation for at least 2 months before valvuloplasty. Cardiac surgery standby was available in every instance.

An additional 15 age- and gender-matched subjects (4 men, 11 women; mean age 48 ± 7 years, range 36 to 54; 7 with lone atrial fibrillation [i.e., patients without structural heart disease]) who underwent cardiac catheterization for evaluation of chest pain and presented no evidence of heart disease after a complete clinical, electrocardiographic (ECG), echocardiographic and hemodynamic workup were selected as control subjects for obtaining the LA pressure–area relation.

In all patients, the LA cavity and walls were adequately visualized from conventional apical four-chamber echocardiographic views. This criterion was met after 21 patients and 16 control subjects were initially screened. The research protocol was approved by the ethics committee of the institutional review board of the department of cardiology at Hippokration Hospital, University of Athens Medical School. Written informed consent was obtained from all patients before the procedure.

Echocardiographic study. All echocardiographic examinations were performed by the same senior echocardiographer (E.T.) using a Hewlett-Packard Sonos 2500 imager equipped with a 2.5-MHz transducer and ABD application. Each subject was placed in a mild recumbent position, and the two-dimensional imaging was performed in the conventional parasternal long-axis and apical four-chamber views. Transmitral Doppler flows were recorded by placing the sample volume at the tip of the mitral valve leaflets so as to obtain the highest velocity in early diastole (E) and at atrial contraction (A). The mitral valve area and degree of mitral regurgitation were determined by continuous wave and color flow Doppler analysis (15). The presence of LV hypertrophy was assessed by M-mode and two-dimensional echocardiography according to the criteria of the American Society of Echocardiography (16).

Recently, an accurate method for the assessment of area changes was developed by means of ABD two-dimensional echocardiography. This method is reproducible in measuring LA area (17,18). In all patients, LA area was measured with the established conventional off-line measurements of two-dimensional echocardiographic images before the ABD application. After obtaining the best possible two-dimensional image of the LA with the optimal gain and compress, ABD echocardiography was engaged. Lateral gain control (LGC) allowed the two-dimensional image to be the same as the regular two-dimensional image when ABD borders were turned off. Time gain compensation (TGC) adjusted the gain horizontally across a given depth of the image. Using LGC and TGC, the gain of the ultrasound LA image was adjusted in small precisely selected sectors, allowing increased attenuation of ultrasound signals in myocardial tissue without affecting gain in the blood pool (17,18). To generate a region of interest that accurately conforms to the blood pool, a circle or half-ellipse was positioned around the LA, and the system quickly and automatically generated a region of interest. We then automatically proceeded to on-line graphical display of the instantaneous LA area (in cm²) (Fig. 1).

LA maximal areas (measured at the time of mitral valve opening) and LA minimal areas (measured at the point of mitral valve closure) obtained instantaneously by ABD were compared with the areas measured off-line by planimetry of the conventional two-dimensional echocardiographic images using nonsimultaneous beats. For comparisons, 5 or 10 consecutive beats were averaged in patients with sinus rhythm or atrial fibrillation, respectively. The ABD-derived LA area was accepted for analysis if its maximal and minimal values deviated by <8% from the respective mean values derived by conventional echocardiography.

A special effort was made to take LA area from exactly the same position during repeated measurements. This was achieved by directing the LA area to the position where the tracing of the ROI was kept constant. Moreover, the LA was echoed in exactly the same place with exactly the same angulation between conditions. All measurements were made at end-tidal volume apnea.
Procedure. Right and left heart catheterization and left ventriculography were performed before and immediately after RNBMV in patients with mitral stenosis and at baseline in control subjects. Grading of mitral regurgitation and measurements of cardiac output were performed as previously described (19). Coronary arteriography was also performed in all patients.

All patients received 10,000 U of intravenous heparin before retrograde LA catheterization. A 7F Millar double-tip micromanometer (model 804-8169, pigtail), with its sensors 7 cm apart, was used for pressure measurements. The transducers were calibrated electronically against mercury at the beginning of each study. Retrograde LA catheterization was performed according to our usual practice, as previously reported (11,20,21). By means of a steerable LA catheter (Stefanadis-Toutouzas, Special product, 5RE-692 by Cordis Europa), a guide wire was advanced into the LA under continuous fluoroscopy. The steerable catheter was then exchanged for the Millar catheter, and the guide wire was removed. The distal sensor was located in the left atrium and the proximal sensor in the left ventricle. A pacing wire was advanced through a right femoral vein sheath and was positioned at the high lateral right atrial wall for atrial pacing.

In patients with mitral stenosis, RNBMV was performed as has been previously reported (11–14). In brief, after the LA pressure and area had been simultaneously recorded, a stiff guide wire (0.038 in [260 cm], J tip, heavy duty) was inserted into and stabilized in the left atrium. The balloon catheter was introduced over the guide wire and was positioned across the mitral valve under fluoroscopy. The balloon was then inflated by hand according to standard steps (11,22,23). The single-balloon technique was used in all procedures in the present study. A small balloon (23 or 25 mm) was used initially, and if the immediate result was assessed as suboptimal, redilation was performed with a larger balloon (up to 30 mm). The procedure was defined as successful if an increase in mitral valve area $\geq 50\%$ with final mitral valve area $\geq 1.5 \text{ cm}^2$ and no final mitral regurgitation were achieved. After RNBMV, the Millar catheter was repositioned in the left atrium, and measurements were repeated.

Study design (Fig. 2). In all patients, baseline measurements were recorded at rest during a steady state period. Measurements at baseline in control subjects and in patients with mitral stenosis before and after RNBMV were repeated with right atrial pacing at standard heart rate (10 beats/min above the rest heart rate). The pacing rate was selected to eliminate competing rhythms and to permit separation of active (booster pump) from passive atrial emptying. Thus, the possible effect of heart rate on LA function was overcome in subsequent comparisons between variables before and after RNBMV. In patients with atrial fibrillation, a cardiac cycle was accepted for comparison if the cycle duration deviated by $\leq 2\%$ from the median cardiac cycle in the sampling period, which consisted of 10 consecutive cardiac cycles, and if the LV pressure amplitude of that cycle exceeded 95% of the maximal value obtained during the same period.

Measurements of the transmitral pressure gradient and assessment of the degree of mitral regurgitation by Doppler echocardiography were performed both before and after positioning of the catheter through the mitral valve, so as to exclude alterations of those variables induced by its presence.

Repeatability of the method. To test the repeatability of the method, we investigated control subjects at two separate times. The repeatability coefficient (RC) was calculated as defined by the British Standard Institution (24) according to
the formula $RC^2 = (\Sigma Di^2)/N$, where $N$ is the sample size and $Di$ the relative difference between each pair of measurements.

**Data collection.** Millar micromanometer and ECG cables were connected to a VF-1 mainframe (Crystal Biotech). LA and LV pressure, LA area and ECG signals were fed into a personal computer (IBM Pentium, 100 MHz) and were simultaneously displayed in real-time mode using a multichannel 12-bit analog to digital converter (Data Translation Inc.) and commercially available data acquisition software (Dataflow, Crystal Biotech), as previously reported (25). The sampling rate was 3 ms. Plots of simultaneous pressure and area were obtained using commercially available software (Microsoft Excel for Windows) (Fig. 3).

**Data analysis.** The stored digitized data were analyzed by computer algorithm. For LA pressure and area values and subsequent calculations of derivative variables, 10 consecutive cycles in patients with sinus rhythm or 3 representative cycles in patients with atrial fibrillation were analyzed and the results averaged. There was a delay of the ABD image depending on the depth in which the echocardiographic study was performed (26). Thus, a correction (equal to $2 \times \frac{d}{v} = t + 1/f$, where $d =$ depth of examination; $v =$ velocity of sound; $t =$ flyback time; and $f =$ sweep frequency) for area data was made. The delay was also calculated as the time interval between recording of the minimal LA ABD area and the peak of the QRS complex of the digitized ECG to ascertain that LA area and LA pressure were simultaneously displayed and that the appropriate correction was made. The LA pressure–area curve was obtained at baseline and after RNBMV.

**LV variables.** LV high fidelity pressure contours were also analyzed by the Excel for Windows computer software. The following measurements and calculations were obtained: maximal rate of rise of LV systolic pressure (peak positive $dP/dt$), LV end-diastolic pressure, peak systolic blood pressure and time constant of relaxation (tau). Tau was calculated by the semilogarithmic method, allowing the pressure to decay to a zero asymptote $P_{B}$: $P(0) = P_{B}e^{-t/\tau} + P_{B}$. A nonlinear (27) least-squares technique was used to estimate the variables $P_{B}$ and tau. For the high fidelity pressure curve, the nonlinear least-squares fit was begun at peak negative $dP/dt$ and ended at 5 mm Hg above the LV end-diastolic pressure. Stroke volume index was calculated by the cardiac index divided by the heart rate. From the parasternal long-axis view using two-dimensional echocardiography, the LV mass index was calculated (28).

**LA function indexes.** LA systolic emptying index. The ABD-derived LA area at onset of LA systole measured at the peak of the P wave in the simultaneously recorded ECG ($A_{s}$) and end-systolic area ($A_{min}$) were used to compute the LA systolic emptying index, which was defined as the ratio of $(A_{s} - A_{min})/A_{s}$ (17,18).

LA stroke work index. The LA booster pump function was expressed by the $A$ loop, and the LA reservoir function was expressed by the $V$ loop (1). The LA stroke work index was defined as the area of the $A$ loop (2,4).

**LA stiffness.** The elastic characteristics of the LA chamber were assessed by analysis of data derived from the part of the pressure–area relation corresponding to the period between the nadir of the x wave and the peak of the V wave of the LA pressure waveform (clockwise ascending limb of the pressure–area loop). Pressure and area data during this period were fitted to the exponential function $P = be^{aA}$, where $P$ is the instantaneous LA pressure and $A$ the LA area (Fig. 3). The least-squares method was used for calculation of $a$ and $b$, where $a$ is the passive elastic chamber stiffness constant (in cm$^{-2}$), which determines the slope of the exponential curve (6), and $b$ is the elastic constant in mm Hg.

**Statistical analysis.** Two-way repeated measures analysis of variance (ANOVA) was applied to detect significant differences in LV and LA variables between the two groups over time. Bonferroni tests were used to perform pairwise comparisons between group means. Comparisons of discrete variables between patients and control subjects were made with one-way ANOVA. Correlations between LV stroke volume index and LA pressure–area $A$ and $V$ loops were determined by the Pearson correlation. A value of $p < 0.05$ was considered statistically significant.

**Results**

**Repeatability of the method.** Repeatability coefficient values for intraobserver repeatability (comparison of two deter-
LV variables

Diastolic BP (mm Hg) 75
Systolic BP (mm Hg) 116

mineralizations obtained at 30-min intervals representing repeated measurements by the same observer concerning LA area and its pulsatile changes were 0.91 and 0.37 cm², respectively. These values were small compared with the mean values of LA area and its pulsatile changes in this sample (12.9 and 5.6 cm², respectively). The same procedure was applied for LA pressure at the peak of A wave, stroke work index and stiffness constant. Repeatability coefficient values for pressure, A loop, V loop and stiffness constant were 0.3 mm Hg, 0.8 mm Hg cm², 0.3 mm Hg cm² and 0.063 cm², respectively. These values were small compared with the mean values of LA pressure, work index and stiffness constant in this sample (10.5 mm Hg, 7.5 mm Hg cm², 2.5 mm Hg cm² and 0.695 cm², respectively).

Baseline characteristics. There were no significant differences between control subjects and patients with mitral stenosis with respect to age, gender, heart rate, systolic and diastolic blood pressures, LV ejection fraction, end-diastolic pressure, dP/dtmax and tau both in patients with sinus rhythm and in those with atrial fibrillation (Table 1). Stroke volume index was lower in patients with mitral stenosis both in those with sinus rhythm and in those with atrial fibrillation (p < 0.001). Among patients with mitral stenosis, there were three in New York Heart Association functional class II, nine in functional class III and three in functional class IV. The total echocardiographic score was 8.1 ± 2.1. Transmural flow velocities and LA dimensions and pressures were significantly greater in patients with mitral stenosis than in control subjects (p < 0.001). The LA systolic emptying index and the area of the A loop of the pressure–area relation (p < 0.001) were significantly decreased in patients with mitral stenosis with sinus rhythm compared with these variables in the control subjects. Furthermore, in patients with mitral stenosis with atrial fibrillation, the area of the V loop (p < 0.001) was increased compared with that in the control subjects. The LA stiffness constant was higher both in patients with sinus rhythm (p < 0.01) and in those with atrial fibrillation (p < 0.05) than in control subjects (Table 1).
Effects of valvuloplasty (Table 1). A technically successful procedure was achieved in all patients. Mitral valve area measured by hemodynamic variables increased significantly (from 0.9 ± 0.2 to 2.1 ± 0.5 cm² in patients with sinus rhythm and from 0.8 ± 0.2 to 2.0 ± 0.5 cm² in patients with atrial fibrillation, p < 0.001 for both) after the procedure. LV ejection fraction, end-diastolic pressure, dP/dtmax and tau were similar before and after the procedure. Stroke volume index increased in both the sinus rhythm and atrial fibrillation groups (p < 0.01). A significant reduction in transmitral flow velocities (p < 0.001) and LA dimensions (p < 0.05) and pressures (p < 0.001) was found after the procedure.

LA A loop. The LA systolic emptying index (p < 0.001) and LA stroke work index increased significantly after the procedure in patients with sinus rhythm (from 7.9 ± 4.6 to 15.1 ± 4.9%, p < 0.001 and from 5.46 ± 0.76 to 8.56 ± 2.31 mm Hg cm², p < 0.001, respectively) (Fig. 4).

LA V loop. The area of V loop did not change in patients with sinus rhythm (from 3.61 ± 0.66 to 3.72 ± 0.72 mm Hg cm², p = NS), whereas it increased significantly in patients with atrial fibrillation after valvuloplasty (from 5.68 ± 1.12 to 18.2 ± 4.5 mm Hg cm², p < 0.001) (Fig. 4).

LA chamber stiffness. The LA stiffness constant decreased significantly after valvuloplasty, both in patients with sinus rhythm (from 1.02 ± 0.38 to 0.75 ± 0.22 cm², p < 0.05) and in those with atrial fibrillation (from 0.98 ± 0.19 to 0.50 ± 0.14 cm², p < 0.001) (Table 1, Fig. 4). Furthermore, in both groups the pressure–area relation was shifted downward and leftward after RNBMV (Fig. 5).

Table 2 shows the results of the repeated measures ANOVA. All necessary conditions for the application of repeated measures ANOVA were satisfied. The interaction group by time was not found to be significant for all LA and LA variables, except for the area of the V loop.

Relation between stroke volume index and LA loops. There was a positive correlation between the LV stroke volume index and the A loop in the control group as well as in patients with mitral stenosis and sinus rhythm, both at baseline and after the procedure (p < 0.001 for all correlations). Furthermore, a positive correlation between the stroke volume index and the V loop was demonstrated in control subjects and patients with sinus rhythm and in those with atrial fibrillation, both at baseline and after RNBMV (Fig. 6).

Discussion

The results of the present study indicate that LA function estimated by the pressure–area relation is markedly altered in the presence of mitral stenosis. After RNBMV in patients with sinus rhythm there was significant increase in the LA A loop, whereas in patients with atrial fibrillation there was a significant increase in the LA V loop. There was significant decrease in LA stiffness in both groups of patients.

LA function in mitral stenosis. In the present study, patients with mitral stenosis and sinus rhythm had a decreased A loop, an increased V loop and increased stiffness compared with that in normal subjects. In patients with atrial fibrillation, the LA pressure–area relation consisted only of the V loop,
which was significantly increased in mitral stenosis compared with that in control subjects.

The LA pump function in mitral stenosis was characterized by an increase in LA dimension at the onset of atrial systole (29), a decrease in the LA systolic emptying index and a decrease in LA stroke work. Two factors may account for the decreased LA active emptying phase in patients with mitral stenosis: 1) the LA dilation and fibrosis that are present in mitral stenosis, and 2) the obstruction to blood flow during the active emptying force by the stenotic mitral valve, which increases the LA afterload.

LA reservoir function in mitral stenosis was characterized by a large LA maximal area and an increase in the area of the V loop of the pressure–area relation. LA reservoir function determines the blood flow from the left atrium to the left ventricle during the passive emptying phase (30).

LA stiffness, as determined by changes in the pressure–area relation, is markedly altered in patients with mitral stenosis, and sinus rhythm or atrial fibrillation. The passive stiffness constant is increased in patients with mitral stenosis, which leads to an increase in LA pressure that is partially compensated for by increased maximal LA dimension.

It is known that LA function is influenced by both atrial and ventricular factors (5,6,31). The atrial factors include LA contractility and relaxation, LA pressure and compliance and rhythm abnormalities. The ventricular factors include mitral annular displacement, LV compliance and relaxation. Mitral stenosis alters physiology and influences LA function. During

Table 2. Results of Repeated Measures Analysis of Variance

<table>
<thead>
<tr>
<th>Variable</th>
<th>Between Subjects</th>
<th>Within Subjects by Time</th>
<th>Within Subject Group by Time</th>
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<tr>
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<td>LA chamber stiffness constant</td>
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<td>&lt; 0.01</td>
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Abbreviations as in Table 1.
atrial contraction, resistance is increased at the mitral valve, causing elevated LA pressure. In addition, there is increased atrial afterload (at the mitral valve level) during atrial contraction, which may account for the decreased LA pump function. We found that stroke volume index was lower both at baseline and after the procedure in the atrial fibrillation group. Moreover, a positive correlation between stroke volume index and the A and V loops of the LA was found. The data suggest that increased stroke volume promotes LA performance. Such an effect may result from increased pulmonary venous return and LA preload, through the Frank-Starling mechanism.

Finally, an increase in LV contractility due to increased LV preload after mitral valve dilation may also influence favorably the LA performance, through the increase of mitral annular displacement and subsequent increase of LA reservoir capacity and passive emptying.

In patients with atrial fibrillation, atrial contraction and relaxation is lost, resulting in the absence of the A loop of the pressure–area relation (7,32). Thus, the pressure–area relation consists only of the V loop. LA filling during systole depends, at least in part, on the descent of the base of the heart, which may already be affected by the anatomic derangement accompanying mitral stenosis. Without atrial relaxation (in atrial fibrillation), LA pressure and LA stiffness constants are higher than in patients with sinus rhythm (33,34).

**Effects of balloon mitral valvuloplasty on LA function.** The present study demonstrates that in patients with sinus rhythm after balloon mitral valvuloplasty there was significant increase in the area of the A loop of the LA pressure–area relation. In patients with atrial fibrillation, a significant increase in the area of V loop was found. There was a significant increase in mitral valve area accompanied by a substantial reduction in the mean transmirtal pressure gradient. The improved hemodynamic variables as a result of RNBMV were accompanied by the restoration of the LA pump function as well as by a reduction in LA stiffness.

The A loop in the sinus rhythm group improved because of relief of afterload. One interesting finding of this study was that LA contraction improved because LA systolic function is still preserved when sinus rhythm is present.

Patients with mitral stenosis and sinus rhythm were not directly comparable to those with atrial fibrillation at baseline because the arrhythmia was associated with a more dilated chamber despite similar mean anatomic and pressure measurements. These two groups showed differences in the V loop at baseline. The V loop response after RNBMV was more pronounced in patients with atrial fibrillation than in those with sinus rhythm, as a result of the fact that LA compliance and, consequently, LA passive filling and subsequent emptying were more increased in the former group than in the latter.

The present study proved that the mitral valve apparatus greatly influenced LA pressure–area relation. The main obstacle to LA blood flow was the stenosed mitral valve (6,29). Also, there is impaired descent of the atrioventricular ring during systole (3). The mechanism to explain the increase in reservoir function in patients with atrial fibrillation after RNBMV could be the substantial decrease in LA pressure and dimension at the onset of atrial filling. With the reduction in mean LA
pressure to nearly normal values, blood flow from the pulmonary veins during systole accelerates, and thus reservoir function is bound to increase.

The most interesting aspect of the present study is the fact that the pressure–area relation of the atrium rapidly returns to normal after relieving the increased LA afterload impedance by valvuloplasty. This finding suggests that the changes in LA contraction and LA chamber stiffness are not due to structural alterations of the LA because these changes would take time to resolve. Whether the change in LA stiffness after valvuloplasty really indicates the shift of the LA pressure–area curve or the mere shift to the lower portion of the same pressure–area curve as a result of the reduction of LA pressure was not demonstrated in the present study. Ideally, LA pressure should be varied by inferior vena cava occlusion to the normal range; thus, the pressure–area curve would be accurately evaluated and determine whether the curve is really shifted.

Study limitations. Use of ABD two-dimensional echocardiography requires a considerable learning phase. As described, the operator must compare the conventional echocardiographic image in real time to ascertain that the areas derived by ABD are not different from the former. The settings of the TGC and LGC have to be carefully adjusted to avoid overestimation or underestimation of the true cavity areas (17). In the present study, LA area was calculated only from the apical-four chamber view because it is impossible to have simultaneous recordings of two echocardiographic views. Ideally, the LA pressure–volume relation would be more accurate than the pressure–area relation. However, no validated method is presently available for using ABD for LA volume measurement; conversely LA area measurements by ABD echocardiography have been previously validated (17,18). This is a limitation of the study because dimensional changes during atrial contraction may be dissimilar in different planes. However, this limitation is counterbalanced by the fact that the methodology was identical during measurements in different phases of the protocol. Furthermore, it was recognized that the timing of cardiac events did not match the ECG or pressure signals because of the inherent delay in obtaining and processing the ABD signal. However, because matching of the timing of the two signals is critically important when attempting to analyze pressure–area relations, in the present study we corrected the aforementioned delay by aligning the minimal LA area with the peak of the QRS complex of the ECG.

Despite its shortcomings (17,18), this echocardiographic technique may provide improved indexes of LA function if specific instructions are taken into account.

Clinical implications. Percutaneous balloon mitral valvuloplasty can be performed either by the transseptal or the nontransseptal technique. The former is by far the most widely used approach; however, the latter represents an effective and safe alternative (11,35,36). In the present study by using retrograde LA catheterization we avoided complications of the alternative transseptal procedure and, moreover, we had the advantage of assessing an intact LA chamber and avoiding any possible wall dysfunction due to transseptal catheterization. Furthermore, no functional (not even trivial) mitral regurgitation was observed as the Millar catheter was passed through the mitral valve leaflets (20).

Although not included in the scope of the present study, echocardiographic measurements of pulmonary vein flow may provide additional information, particularly with regard to LA filling before and after RNBMV. Therefore, it would be reasonable to include such an investigation in future studies.

Conclusions. Patients with mitral stenosis have increased LA size and decreased LA pump function, as indicated by the decreased LA systolic emptying index and the decreased LA stroke work index. The LA pressure–area relation is accurate in evaluating the alterations in LA function after RNBMV. After RNBMV there is significant increase in the LA A loop in patients with sinus rhythm and in the LA V loop in patients with atrial fibrillation. In mitral stenosis, the increased LA stiffness before valvuloplasty returns to normal immediately after the procedure, which increases the mitral valve area.

References


