Assessment of Left-to-Right Atrial Shunting After Percutaneous Mitral Valvuloplasty by Transesophageal Color Doppler Flow-Mapping

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To evaluate left-to-right shunts after percutaneous balloon mitral valvuloplasty, we studied 15 consecutive patients by using transesophageal color Doppler flow-imaging system. Transesophageal color Doppler examinations were performed five times in each patient (before valvuloplasty and 1 day, 1 week, 1 month, and 6 months after valvuloplasty). No shunt flow was observed before valvuloplasty. On 1 day after mitral valvuloplasty, transesophageal color Doppler echocardiography demonstrated left-to-right shunts in 13 (87%) of 15 patients. However, a significant oxygen step-up was present in the right heart in only one patient. The mean diameter of the interatrial septal defect detected by transesophageal two-dimensional echocardiography was 1.8±1.0 mm. The mean velocity of left-to-right shunting flow measured by high-pulse repetition frequency Doppler technique was 0.83±0.38 m/sec. One week after the procedure, left-to-right shunt flow was detected in 11 (73%) patients. One month after valvuloplasty, left-to-right shunting flow was detected in seven (47%) of 15 patients. There was a significant decrease in the diameter of an interatrial septal defect between 1 day and 1 week (p<0.01), between 1 week and 1 month (p<0.01), and between 1 month and 6 months (p<0.05). Six months after valvuloplasty, left-to-right shunting flow remained in three (20%) patients. By using transesophageal color Doppler echocardiography, we detected left-to-right shunting flow in two patients on 1 day after the procedure. In these patients, no shunting flow was detected 1 month after mitral valvuloplasty from the transthoracic approach. Oximetry demonstrated left-to-right shunts of pulmonary-to-systemic flow ratio of 1.3:1 in one patient immediately after mitral valvuloplasty. Thus, transesophageal color Doppler echocardiography is useful in the detection of left-to-right shunts after percutaneous mitral valvuloplasty, and most of the patients undergoing percutaneous mitral valvuloplasty had small left-to-right shunts that were not detected by oximetry. (Circulation 1989;80:1521–1526)

The technique of percutaneous balloon mitral valvuloplasty in patients with mitral stenosis was first reported by Inoue et al,1 who used a transseptal approach with a single-balloon technique. Catheter balloon valvuloplasty with a double-balloon technique2,3 has been shown to be more effective in dilatation of stenotic rheumatic mitral valves in adult patients. Although small left-to-right shunts after percutaneous mitral valvuloplasty may occur when the transseptal approach is used, there are few reports regarding interatrial communication created by percutaneous balloon mitral valvuloplasty.2-5 The purpose of this study was to evaluate with transesophageal color Doppler echocardiography the left-to-right shunting flow dynamics after percutaneous mitral valvuloplasty.

Methods

Patients
The study consisted of 15 consecutive patients with mitral stenosis who underwent percutaneous mitral valvuloplasty by the single-balloon technique. There were 12 women and three men who ranged in age from 41 to 76 years old (mean, 52±11

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years). Twelve patients were in New York Heart Association functional class II, and three were in class III. Seven patients were in normal sinus rhythm, and eight had atrial fibrillation.

**Medication**

All patients were anticoagulated with warfarin for 4 weeks before the procedure. The patient’s usual oral medication (including β-blockers, if prescribed) was given together with premedication (10 mg oral diazepam).

**Percutaneous Mitral Valvuloplasty**

Percutaneous mitral valvuloplasty was performed with a single-balloon catheter that was 4.7 mm in diameter at deflation as previously described by Inoue et al. Right heart catheterization was performed percutaneously from the right femoral vein with a thermodilution Swan-Ganz catheter. Transseptal left heart catheterization was performed from the right femoral vein with an 8F transseptal Mullins sheath and dilator (USCI, Billerica, Massachusetts) and a modified Brockenbrough needle. Systemic anticoagulation was achieved by administration of 100 units/kg heparin. Immediately after percutaneous balloon mitral valvuloplasty, we repeated all hemodynamic measurements. A complete right heart oximetry series was performed to look for evidence of an atrial shunt from left to right.

**Two-dimensional Echocardiography and Doppler Ultrasound**

All patients had both transthoracic and transesophageal Doppler and two-dimensional echocardiograms within 24 hours before percutaneous mitral valvuloplasty. After balloon valvuloplasty, both transthoracic and transesophageal Doppler and two-dimensional echocardiographic studies were performed four times in each patient (1 day, 1 week, 1 month, and 6 months after valvuloplasty). The echocardiographic Doppler systems used in this study were Toshiba SSH-65A or Aloka SSD-870. Transesophageal echocardiographic Doppler studies were performed by using an Aloka SSD-870 system with the use of a 5-MHz transducer. With the patient in the left decubitus position, the endoscope was introduced into the esophagus. After the orientational landmark of the aortic valve had been passed at a distance of 35 cm from the patient’s teeth, the left and right atrium and interatrial septum were identified by clockwise rotation of the endoscope. A complete scan of the atrial septum was performed by tilting and alternating withdrawing and advancing the tip of the endoscope.

A recording of the interatrial shunting flow velocity was obtained by using a high-pulse repetition-frequency Doppler ultrasonography with an Aloka SSD-870 system from the transesophageal approach. The diameter of the interatrial defect was measured with transesophageal two-dimensional echocardiography. Real-time images were recorded in cine loop, permitting frame-by-frame review. Imaging and recording time averaged 10–15 minutes per patient. Stop frame images were analyzed by two independent observers who were unaware of other patient data. The diameter of the interatrial defect was digitized manually from stop-frame images that were blinded to timing of the examination. For measurements of the left-to-right shunting flow velocity and diameter of the interatrial septal defect, the values of three and five measurements were averaged in patients with sinus rhythm and atrial fibrillation, respectively. We made no angle correction in evaluation of the velocity of left-to-right shunts because the angle between the left-to-right shunting flow detected by color Doppler and the ultrasonic beam was less than 20° in all cases.

**Statistical Analysis**

Mean values and SDs were computed for continuous variables. Evaluations of changes over time were made with a matched-pair t test. Incidence of left-to-right shunts was analyzed by the χ² test. A p value of 0.05 or less was considered significant. Observer variability in the assessment of the presence or absence of left-to-right shunting flow and for measurement of the diameter of the defect in our laboratory has been determined. From the accumulated data, there was no interobserver or intraobserver variability in the subjective assessment of the presence or absence of left-to-right shunting flow. The average intraobserver variability for measurement of the diameter of the atrial septal defect was 3.1% of the mean value, and the average interobserver variability was 4.8% of the mean.

**Results**

Transesophageal color Doppler echocardiography demonstrated no left-to-right shunts before percutaneous balloon mitral valvuloplasty. One day after the procedure, transesophageal color Doppler echocardiography demonstrated left-to-right shunts in 13 (87%) of 15 patients (Table 1, Figure 1). The mean diameter of the interatrial septal defect detected by transesophageal two-dimensional echocardiography was 1.8±1.0 mm. The mean velocity of left-to-right shunting flow (Figure 2) measured by high-pulse repetition-frequency Doppler technique was 0.83±0.38 m/sec. One week after the procedure, left-to-right shunt flow was detected in 11 (73%) patients. One month after balloon valvuloplasty, left-to-right shunting flow was detected in seven (47%) of 15 patients. There was a significant decrease in the diameter of an interatrial septal defect from 1 day to 1 week after valvuloplasty (1.8±1.0 vs. 1.5±1.1 mm, p<0.01). The diameter decreased from 1 week to 1 month after the procedure (1.5±1.1 vs. 1.2±0.8 mm, p<0.01) and also decreased between 1 month and 6 months (1.1±0.8 vs. 0.02±0.05 mm, p<0.05). Six months after valvuloplasty, left-to-right shunting flow remained in
Table 1. Detection of Left-to-Right Shunts After Percutaneous Mitral Valvuloplasty

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TEE, transesophageal echocardiography; TTE, transthoracic echocardiography.

Three (20%) patients. The incidence (Figure 3) of left-to-right atrial shunting at 6 months was significantly lower than that on 1 day after valvuloplasty ($p<0.001$). By using transthoracic color Doppler echocardiography, left-to-right shunting flow was detected in two patients 1 day after valvuloplasty.

Figure 1. Transesophageal two-dimensional echocardiogram (left panel) and transesophageal color Doppler echocardiogram (right panel) 1 week after percutaneous mitral valvuloplasty. Interatrial septal defect (left panel) clearly demonstrated (arrow). Mosaic signals in right atrium (right panel) indicative of left-to-right shunt flow are observed. LA, left atrium; RA, right atrium.
In these patients, no shunting flow was detected 1 month after valvuloplasty from the transthoracic approach.

Oximetry demonstrated left-to-right shunts of pulmonary-to-systemic flow ratio of 1.3:1 in one patient immediately after the procedure.

Discussion

Recently, percutaneous balloon mitral valvuloplasty through a transseptal approach has been developed as a less invasive alternative to surgical treatment.\textsuperscript{1-5} The occurrence of small left-to-right shunts is expected in some patients after transseptal catheterization.\textsuperscript{6} After septal dilatation, larger openings are created in the interatrial septum. Therefore, production of left-to-right shunts in some patients after percutaneous balloon mitral valvuloplasty is not surprising. As a matter of fact, this is the desired therapeutic effect of balloon atrial septostomy in infants with d-transposition of the great arteries, tricuspid atresia, pulmonary atresia with an intact ventricular septum, and total anomalous pulmonary venous return.\textsuperscript{7} Although there are some reports in regard to left-to-right shunts after percutaneous balloon mitral valvuloplasty using oximetric methods, the primary limitation of the oxygen step-up method in the detection of intracardiac shunt is that it lacks sensitivity.\textsuperscript{8}

Our present study with transthoracic Doppler color flow imaging suggests that most of the patients undergoing percutaneous balloon mitral valvuloplasty have small left-to-right shunts that are not detected by oximetry. We observed a small left-to-right shunt by oximetry with a pulmonary-to-systemic flow ratio of 1.3:1 in one of our 15 patients immediately after balloon valvuloplasty. No left-to-right shunts were demonstrated in the remaining 14 patients by oximetry. It is possible that these shunts may decrease over time as has

\textbf{FIGURE 2.} High-pulse repetition-frequency Doppler echocardiogram 1 week after percutaneous mitral valvuloplasty. Mean velocity of left-to-right shunt flow measured by high-pulse repetition-frequency Doppler technique is 1.20 m/sec.

\textbf{FIGURE 3.} Bar graph showing incidence of left-to-right shunt flow detected by transesophageal color Doppler flow-imaging. Detection rate of left-to-right atrial shunting at 6 months is significantly lower than that on 1 day after valvuloplasty.
been documented in infants who have had successful balloon atrial septostomies with use of small inflated balloon volumes.9

Doppler techniques now permit noninvasive evaluation of intracardiac blood flow and have a widely established record of accuracy in the detection of valvular regurgitation and intracardiac shunts.10-18 Doppler interrogation of the left-to-right shunt flow has qualitatively and quantitatively been used in assessing the magnitude of the pulmonary-to-systemic flow ratios as well as the shunts. Color Doppler echocardiography, however, has been helpful in locating the defect more precisely (i.e., sinus venosus defect) and defining associated physiologic abnormalities such as mitral and tricuspid regurgitation. Furthermore, identification of multiple atrial septal defects or discriminating between high septum primum defects associated with a patent foramen ovale has been helped by color Doppler echocardiography. Recent development of transesophageal two-dimensional echocardiography permits recognition of site and size of an atrial septal defect accurately.19 In contrast to the transthoracic approach, the interatrial septum is imaged in total without echo dropouts from the transesophageal approach. This is because the ultrasonic beam hits the interatrial septum nearly perpendicularly from the esophageal transducer position. Thus, atrial septal defects themselves and shunt flows through the defects can be detected with high diagnostic accuracy with transesophageal color Doppler echocardiography.

With use of transthoracic pulsed Doppler and contrast echocardiography, Mackay et al4 reported left-to-right shunts after valvuloplasty in five of 15 patients immediately after valvuloplasty. However, they had no follow-up study in regard to the shunts after valvuloplasty. In our present study, although left-to-right shunts were demonstrated in only two of 15 patients immediately after valvuloplasty by transthoracic color Doppler echocardiography, they were no longer detected at 1 month after valvuloplasty. On the other hand, transesophageal color Doppler echocardiography demonstrated left-to-right shunts in 13 of 15 patients immediately after balloon valvuloplasty. One month after valvuloplasty, left-to-right shunts were present in seven of 15 patients. The accurate determination of the diameter of an interatrial defect by transthoracic two-dimensional echocardiography is technically difficult because of normal “septal dropout” and because of the high resolution required to display the true edges of a defect. Imaging from the esophagus overcomes difficulties in obtaining good image quality from the chest wall that are encountered in obese patients and those with emphysema. Transesophageal color Doppler echocardiography is extremely sensitive in the detection of valvular regurgitation and intracardiac shunts.19-22 Indeed it has been reported that regurgitation through a 1-mm orifice can be detected by Doppler color flow mapping.23 The advantage of the transesophageal over the transthoracic approach in the detection of left-to-right shunt flow are 1) absence of anatomic obstacles between the ultrasound transducer and interatrial septum, 2) nearly parallel alignment of ultrasound beam with the shunting flow through the defect, and 3) better resolution characteristics with higher-frequency (5-MHz) transducers. These result in a superior recording quality and greater sensitivity in demonstrating atrial septal defects themselves and left-to-right shunt flows through the defects. Therefore, it is possible that transesophageal color Doppler echocardiography can detect small interatrial shunts that cannot be detected by transthoracic color Doppler echocardiography and by oximetry.

In the experimental study with dogs, persistence of a 5-mm atrial septal defect has been reported after transseptal puncture with a 7-mm catheter.1 Mackay et al20 reported one case in which the transseptal technique was performed wherein there was only a moderate improvement in the valve area, and right heart oximetry series showed no evidence of a significant oxygen step-up immediately after valvuloplasty. Repeat right heart oximetry series at 2 months after valvuloplasty, however, demonstrated a significant oxygen step-up with a calculated pulmonary-to-systemic blood flow ratio of 1.8:1. Palacios et al21 presented four patients in whom a small left-to-right shunt was demonstrated by oximetric studies. However, in all of these patients the shunt could not be demonstrated 24 hours later.

Although the amount of left-to-right shunts might be small in most of the patients undergoing percutaneous balloon mitral valvuloplasty, acute creation of interatrial communication could be particularly deleterious in patients with longstanding pulmonary hypertension secondary to mitral stenosis because the added volume overload on the patient’s right ventricle could theoretically lead to worsening hemodynamic consequences. Furthermore, a persistent left-to-right shunt may hinder the hemodynamic assessment of mitral stenosis. Reid et al24 reported that there was a discrepancy between the mean mitral valve area as assessed by the Gorlin method and as assessed by the Doppler half-time method immediately after the procedure; the mitral valve area by Gorlin method is larger than that calculated by half-time method. In their study, the correlation of the valve area between the half-time method and the Gorlin method improved at 6 months after the procedure. Abascal et al25 also reported the same results. This may be because there were small left-to-right shunts not detected by oximetry. Although further investigation is necessary to understand more clearly the mechanisms responsible for this phenomenon, it may be possible that small left-to-right shunts affect the hemodynamics in patients with mitral stenosis.
Our study suggests that most of the patients undergoing percutaneous balloon mitral valvuloplasty had small left-to-right shunts undetectable by oximetry. The diameter of the interatrial defect decreased over time and left-to-right shunts disappeared within 6 months after valvuloplasty in most cases.

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References

KEY WORDS • valvuloplasty • echocardiography, Doppler