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CLINICAL STUDIES

Benefits of Intraoperative Echocardiography in the Surgical Management of Hypertrophic Cardiomyopathy

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Objectives. The purpose of this study was to determine the role of intraoperative echocardiography in planning the site and extent of myectomy and in ensuring adequate control of the left ventricular outflow tract gradient.

Background. Although intraoperative echocardiography has been found to be beneficial in patients undergoing valve repair, its impact on surgical decisions in patients undergoing septal myectomy for hypertrophic cardiomyopathy has not been described.

Methods. In 50 patients undergoing septal myectomy over a 5-year period, epicardial echocardiography was performed before cardiopulmonary bypass to establish the extent of outflow tract obstruction, locate its site and plan the myectomy. In 30 patients, transesophageal echocardiography was also used to corroborate data on outflow tract anatomy and examine the mitral valve.

Results. In 40 patients (80%) the initial myectomy resulted in a reduction of the maximal outflow tract gradient from 88 ± 45 to 24 ± 11 mm Hg, measured by epicardial continuous wave Doppler echocardiography. Ten patients (20%) were shown by postbypass intraoperative echocardiography to have an unsatisfactory result, based on a persistent gradient >50 mm Hg (n = 7) or persistent mitral regurgitation of greater than moderate severity (n = 3). The postbypass two-dimensional echocardiogram was then used to direct the surgeon toward the most likely site of continued obstruction, and cardiopulmonary bypass was reinstituted to permit further myectomy (n = 9) or mitral valve repair (n = 1). After the second or subsequent period of cardiopulmonary bypass, the outflow tract gradient (26 ± 14 mm Hg) was substantially reduced and was not significantly different from the postbypass gradient (24 ± 11 mm Hg) in the group with initial surgical success. At postoperative follow-up (20 ± 37 weeks), the maximal measured outflow tract gradient (22 ± 21 mm Hg) showed no difference between patients with immediate surgical success and those requiring a second period of cardiopulmonary bypass for further resection.

Conclusions. Intraoperative echocardiography proved a useful tool to guide the site and extent of septal myectomy, leading to more adequate surgical resection and to persistence of satisfactory control of the outflow tract obstruction into the early follow-up period.

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In patients with hypertrophic cardiomyopathy, septal myectomy is efficacious for the relief of obstructive symptoms unresponsive to medical management (1–5). However, in a proportion of patients who have undergone myectomy, residual obstructive gradients that may cause persistent symptoms (6–9) have been noted at rest or with provocation. Recent data suggest that incomplete relief of left ventricular outflow tract obstruction is correlated with increased risk of early death after operation (10).

Intraoperative echocardiography has proved beneficial in the surgical planning and assessment of mitral valve repair (11–13). Previous studies (14) have shown that assessment of the left ventricular outflow tract gradient with intraoperative continuous wave Doppler echocardiography correlates with results of direct hemodynamic measurement of such gradients, as has also been shown during cardiac catheterization (15). In this study we review our experience with intraoperative echocardiography in patients undergoing septal myectomy to identify the contribution of this imaging technique to planning the site and extent of myectomy and to evaluating the effect of myectomy on the outflow tract gradient.

Methods

Patient selection. During the 5 years from December 1984 to January 1990, 64 patients underwent septal myectomy at the Cleveland Clinic Foundation. These patients had continued to report symptoms of left ventricular outflow tract obstruction despite maximal medical therapy, and generally

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constituted the most severely symptomatic patients with hypertrophic cardiomyopathy referred to our institution during this period. Fourteen patients had septal myectomy performed together with aortic valve surgery (n = 7) or resection of a subvalvular aortic membrane. Because the relative contributions of these other pathologic conditions to left ventricular outflow obstruction were variable and provided a heterogeneous patient group, these 14 patients were excluded from the analysis. This retrospective study therefore comprised 50 consecutive patients, 32 female, with a mean age of 53 ± 20 years.

Surgery. Septal myectomy was performed in accordance with the technique originally described by Morrow and Brockenbrough (1). However, the technique was modified to maximize the resection at the site of obstruction, as demonstrated by intraoperative echocardiography. Additional cardiac procedures were performed in five patients of this series, including coronary artery bypass grafting in four and mitral valve repair in one patient. Hypothermic cardiopulmonary bypass with cardioplegic arrest was utilized in all cases.

Echocardiography. Preoperative transthoracic echocardiography was performed in standard fashion with commercially available echocardiographic equipment. Left ventricular dimensions and septal and posterior wall thickness were evaluated and found to be consistent with the diagnosis of hypertrophic cardiomyopathy (16). The peak left ventricular outflow tract gradient was recorded by continuous wave Doppler echocardiography (14,15).

All patients underwent intraoperative echocardiography. This procedure included measurement of the left ventricular outflow tract gradient by continuous wave Doppler echocardiography using the epicardial aorta-superior vena cava transducer position with the transducer against the ascending aorta pointing down into the left ventricular outflow tract and with the beam parallel to the direction of blood flow (17,18). Transesophageal imaging became available during the latter part of the series and was performed in addition to epicardial echocardiography in 30 patients for closer inspection of the mitral valve and left ventricular outflow tract. However, the outflow tract gradient could not be measured reliably with the transesophageal approach. These imaging data were used to estimate 1) the distance from the midportion of the aortic valve to the upper portion of the septal bulge, 2) the distance from the midportion of the aortic valve to the most apical point of septal contact with the mitral valve, and 3) the maximal thickness of the septum in any view. These measurements, performed in the beating heart, were extrapolated to the cardioplegic state, to determine the site of myectomy and the length and depth of the resection. The severity of mitral regurgitation was assessed preoperatively with spatial distribution criteria (19) modified for use in the operating room (13).

After completion of the resection, cardiopulmonary bypass was discontinued, and the arterial and left ventricular filling pressures and volumes were restored as closely as possible to physiologic levels to avoid underfilling of the ventricle. Intraoperative echocardiography was repeated before removal of the arterial and venous cannulas to facilitate early resumption of cardiopulmonary bypass if results were unfavorable. Particular attention was paid to reassessment of the severity of mitral regurgitation and measurement of the left ventricular outflow tract gradient (Fig. 1). In addition, intravenous isoproterenol was administered in 33 patients at the discretion of the surgical and anesthesia teams as a hemodynamic challenge, and the gradient was remeasured after this attempt to provoke latent obstruction. The operation was considered successful if the peak left ventricular outflow tract gradient at rest or with isoproterenol was <50 mm Hg and if mitral regurgitation resolved or was of moderate (grade 2/4) or lesser severity. The choice of a 50 mm Hg cutoff is the maximal instantaneous gradient at an outflow tract velocity >3.5 m/s in the situation where the Doppler beam is parallel to flow. This cutoff is arbitrary but has been used extensively as a clinical criterion for significant obstruction.

In patients with an inadequate initial operation established by these physiologic criteria, careful two-dimensional echocardiographic imaging was directed toward identifying the mechanism of outflow tract obstruction or mitral regurgitation. The site of outflow tract obstruction was defined by the relation of systolic anterior mitral valve motion to the site and size of the resection site, and these data were used to plan additional surgical procedures. Thus, systolic anterior motion on the medial side of the resection site led to the extension of the resection further medially, whereas that occurring distal (apical) to the myectomy site led this to be extended distally. In the 10 patients requiring a second bypass period, postbypass imaging and measurements of the outflow tract gradient were repeated after this additional operation.

Postoperative transthoracic echocardiograms obtained in 42 patients included measurement of the left ventricular outflow tract gradient and estimation of mitral regurgitation severity. Provocative testing with amyl nitrite was performed in 35 patients at the discretion of the cardiologist performing the echocardiogram.

Statistical analysis. Clinical, echocardiographic and Doppler variables for the patients with an immediately successful operation and those requiring a second bypass period were expressed as mean value ± SD. These groups were compared with use of a *t* test for continuous variables, whereas a chi-square or Fisher exact test was performed, depending on the sample size, for noncontinuous variables.

Results

Preoperative echocardiography. The peak left ventricular outflow tract gradient at rest on the preoperative transthoracic echocardiogram averaged 74 ± 43 mm Hg. In nine patients the gradient at rest was <50 mm Hg and it was remeasured after inhalation of amyl nitrite. Thus, the maxi-

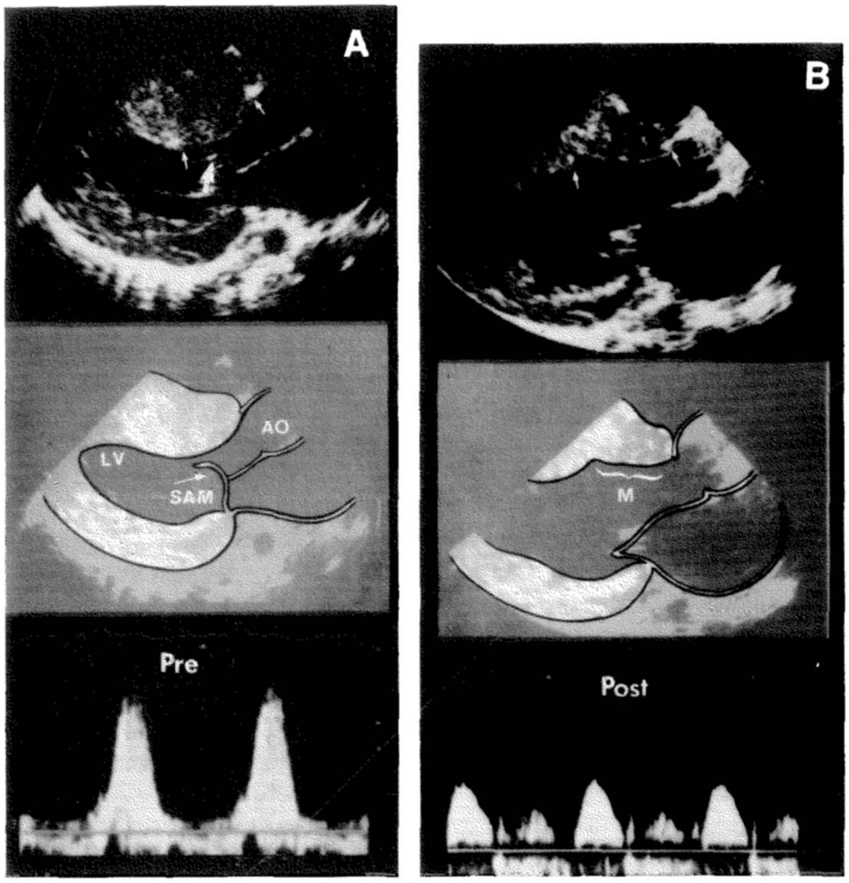

Figure 1. **A** and **B** show an epicardial parasternal long-axis equivalent image (**top**) and artistic diagram (**middle**) in systole and a continuous wave Doppler spectrum (**bottom**) recorded from the aorta-superior vena cava transducer position on the ascending aorta. **A**, The intraoperative images obtained before cardiopulmonary bypass used to plan the extent and location of resection included measurement of the distance (**small arrows, top**) between the most apical point of systolic anterior motion (**large arrow, top**; SAM) and the aortic valve ring. **B**, After (Post) successful myectomy (M), systolic anterior motion of the anterior mitral leaflet resolved. Continuous wave Doppler spectra (**bottom, A** and **B**) demonstrate reduction of the left ventricular outflow tract velocity from 3.9 before myectomy to 1.8 m/s after myectomy, indicating a reduction of the maximal outflow tract gradient from 61 to 13 mm Hg. AO = aorta; LV = left ventricle; pre = before myectomy.

mal measured gradient for all of 50 patients averaged 88 ± 42 mm Hg. Seven patients had moderately severe to severe (3+ to 4+) mitral regurgitation preoperatively; one of these also had marked myxomatous degeneration of the mitral valve.

Prebypass intraoperative echocardiography. Intraoperative two-dimensional echocardiographic images obtained before institution of cardiopulmonary bypass were used to determine the maximal thickness of the septum (22 ± 6 mm), the location of the hypertrophy and the site of systolic anterior motion of the mitral valve. The most basal site of systolic anterior motion was 24 ± 6 mm from the aortic valve and the most apical site of obstruction was 34 ± 10 mm from the valve. These data were made available for surgical planning at the time of the initial resection (Fig. 1).

Postbypass intraoperative echocardiography. Patients were classified into two groups according to the presence or absence of a persistent left ventricular outflow tract gradient (>50 mm Hg) with systolic anterior motion of the mitral valve or residual mitral regurgitation of moderate or greater severity after the initial myectomy (Table 1). The initial procedure was successful in 40 patients (80%) who had an average peak outflow tract gradient of 24 ± 11 mm Hg. Ten patients (20%) were considered to have an unsuccessful initial resection and required further myectomy during the same operative procedure because of a persisting left ventricular outflow tract gradient (average 64 ± 8 mm Hg) in seven and because of continuing mitral regurgitation of greater than moderate severity in three. The latter group comprised two patients with persistent systolic anterior motion causing regurgitation of a structurally normal mitral valve and one patient with persistent regurgitation due to intrinsic mitral valve disease.

In the 10 patients with an unsuccessful initial resection attempt, intraoperative echocardiography after the first bypass period was used to evaluate the site and extent of myocardial resection, to direct the surgeon toward the site of continuing obstruction and to estimate the required size of the further resection (Fig. 2). The distance between the aortic ring and the basal site of systolic anterior motion of 26 ± 4 mm and between the aortic ring and the most apical site of systolic anterior motion of 35 ± 5 mm was unchanged from prebypass findings. After the second operation, intraoperative echocardiography demonstrated adequate relief of left ventricular outflow tract gradients in all patients (mean gradient 26 ± 14 mm Hg). Two patients who had persistent mitral regurgitation after the first bypass period had mild or trivial regurgitation after another myectomy. The patient with coexistent hypertrophic cardiomyopathy and myxomatous degeneration of the mitral valve had residual moderate

Table 1. Comparison of Patients With Successful Initial Myectomy and Those Requiring an Additional Surgical Procedure

	Initial Surgical Success (n = 40)	Initial Surgical Failure (n = 10)	p Value
Age (yr)	52 ± 21	58 ± 14	NS
Men	16 (40%)	2 (20%)	NS
LV diastolic dimension (mm)	42 ± 6	43 ± 4	NS
Max LV septal thickness (mm)	21 ± 7	23 ± 4	NS
LV posterior wall (mm)	15 ± 3	16 ± 3	NS
AoV–basal SAM site (mm)	25 ± 6	24 ± 8	NS
AoV–apical SAM site (mm)	36 ± 10	33 ± 9	NS
Max preop gradient (mm Hg)	88 ± 45	85 ± 29	NS
Max postop (first attempt)	24 ± 11	64 ± 8	0.001
(second attempt)	—	26 ± 14	—
Follow-up (TTE) gradient (mm Hg)	30 ± 28	19 ± 12	NS
Residual gradients (>50 mm Hg)			
At rest	3	0	NS
Provoked	3	0	NS
Complications			
Deaths	2	2	NS
Reoperation	1	0	NS

AoV = aortic valve; LV = left ventricular; Max = maximal; postop = postoperative; preop = preoperative; SAM = systolic anterior motion of the mitral valve; TTE = transthoracic echocardiography.

(2+) mitral regurgitation despite two further bypass periods during which measures were taken to repair the mitral valve.

The group with failure of the initial resection did not differ significantly from the group with initial surgical success. There was no significant difference in septal thickness or morphology, left ventricular dimensions, preoperative left ventricular outflow tract gradient or age (Table 1). However, a trend toward a higher proportion of women was noted in the group with initial failure.

Follow-up echocardiography. Follow-up echocardiograms were obtained in 42 patients at a mean of 20 ± 37 weeks postoperatively. Of the remaining eight patients, four were lost to follow-up and four died postoperatively. There was no significant difference in rest or peak left ventricular outflow tract gradient by transthoracic echocardiography during follow-up, between the groups with and without a successful initial operation (Table 1). For the total study group there was no significant difference between the final intraoperative gradient and gradients measured during follow-up (22 ± 21 mm Hg). However, three patients in the group with initial success had a residual rest transthoracic gradient (>50 mm Hg at rest) early postoperatively. Although these three patients did not have significant postmyectomy gradients intraoperatively; none of these three had been studied with isoproterenol in the operating room. One of these three patients later required another septal myectomy for persistent symptoms despite medical management. The other two with residual obstruction remained clinically well at follow-up. Three other patients in the group with an initially successful resection had nonobstructive outflow tract velocities at rest but had significant provokable gradients (>50 mm Hg) during amyl nitrite inhalation at late follow-up. All three of these patients have been managed medically. No patient in the initial failure group had a significant residual gradient at follow-up. No ventricular septal defects were observed on echocardiography either intraoperatively or at the follow-up study. Only one patient in the series developed complete heart block requiring a pacemaker.

Of the four patients who died during the follow-up period, two died of cardiac and two of noncardiac causes. Three patients died perioperatively. Among the 10 patients requiring a second bypass period, one patient died intraoperatively and one died early postoperatively from sepsis. Of those with successful initial resection, one died perioperatively from left ventricular dysfunction and another died 1 year postoperatively of probable noncardiac causes.

Discussion

In most patients with hypertrophic obstructive cardiomyopathy, symptoms can be controlled satisfactorily with medical therapy (20,21). Septal myectomy, a procedure involving the transaortic resection of a portion of the interventricular septum, is usually reserved for those showing persistence of obstructive symptoms and left ventricular outflow tract gradients despite medical therapy (1). The major surgical complications of this operation are conduction defects and ventricular septal defects that may reflect excessive tissue resection. The hazards of excessive resection may prompt the surgeon to be more conservative, thus risking inadequate resection. Significant residual obstruction has been documented postoperatively in several previous studies (6–9). Although measurement of the outflow tract gradient by direct puncture has been available since the operation was developed, intraoperative echocardiography is a technically easier means of measuring the gradient and also helps to define outflow tract anatomy.

Intraoperative echocardiography. Transesophageal and epicardial two-dimensional and Doppler echocardiography have become well established in the evaluation of the presence, mechanism and severity of valvular lesions in the operating room (11–13,22–24). Echocardiographic imaging performed before operation and before institution of cardiopulmonary bypass offers several benefits to patients undergoing septal myectomy. 1) Physiologic data from the continuous wave Doppler measurement of the outflow tract gradient and color flow mapping of mitral regurgitation provide an on-line assessment of the hemodynamic effects of myectomy, allowing the team to perform additional surgical procedures during the same thoracotomy. 2) Anatomic data derived from the intraoperative echocardiogram facilitate surgical planning in relation to the length, depth and site of the septal resection, both before the initial myectomy (Fig. 1) and before the second period of cardiopulmonary bypass (Fig. 2). 3) Mitral regurgitation can be assessed at each phase

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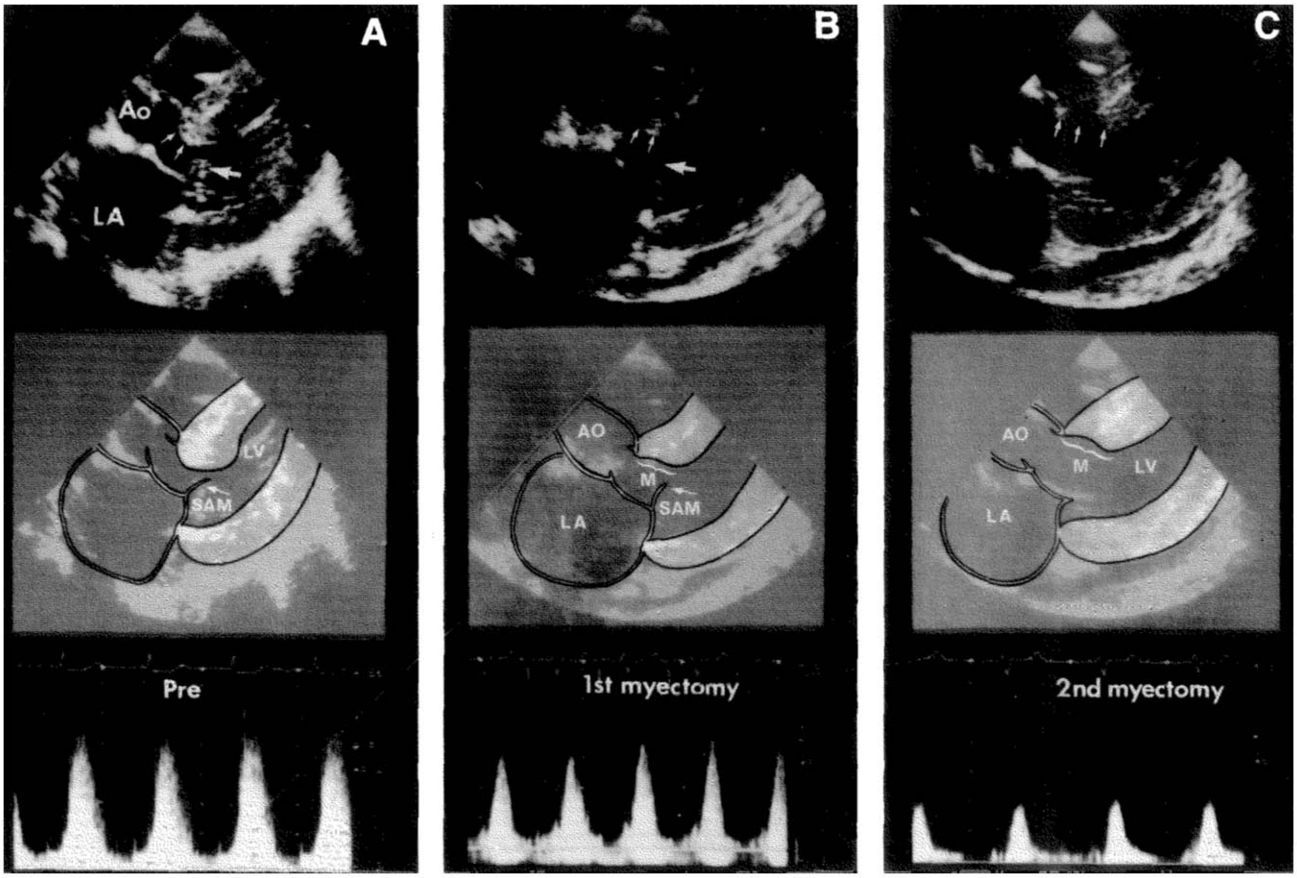

Figure 2. A, B and C show an epicardial subcostal long-axis equivalent image (**top**) and artistic diagram (**middle**) in systole and a continuous wave Doppler spectrum (**bottom**) recorded from the aorta-superior vena cava transducer position on the ascending aorta. A, Marked septal hypertrophy (**small arrows, top**) and systolic anterior motion of the anterior mitral leaflet (**large arrow, top**) are present (with an outflow gradient of 55 mm Hg) before operation. B, After unsuccessful initial myectomy (M, **middle**), with reduction in the septal bulge, systolic anterior motion of the mitral valve (SAM) persists. C, After the second myectomy, the myectomy site (M) extends deeper and longer and the systolic anterior motion is eliminated. Left ventricular outflow tract gradients at each stage (**bottom panels A, B** and C) demonstrate persistent obstruction (with a 61-mm gradient) after the initial operation, with resolution (to a gradient of 19 mm Hg) after additional myectomy during the second period of cardiopulmonary bypass. Calibrations are 1 m/s. Ao = aorta; LA = left atrium; other abbreviations as in Figure 1.

of the operation. Coexistent intrinsic mitral valve disease has been reported in up to 20% of patients with hypertrophic cardiomyopathy (25). The presence of this combination in only one patient in this series reflects our exclusion of those in whom mitral valve replacement was the primary operation for this disorder (26).

Previous studies of intraoperative echocardiography in hypertrophic cardiomyopathy. In early studies, M-mode echocardiography was used at septal myectomy to measure septal thickness and guide the depth of myectomy (27). Despite this guidance, rest or inducible gradients were still found frequently in patients undergoing follow-up cardiac catheterization (27). The use of epicardial two-dimensional echocardiographic imaging of septal thickness to guide the decision to perform septal myectomy versus mitral prosthetic valve insertion was reviewed by McIntosh and Maron in 1988 (28). Transesophageal echocardiography has recently been reported (29) to elucidate the anatomic characteristics of the mitral valve and to characterize mitral regurgitation in patients undergoing myectomy. Although these studies provided anatomic and flow information, Doppler measurements of the outflow gradient were not reported. Thus, no previous report has shown the impact of intraoperative echocardiography on surgical decision making in this disorder.

The correspondence between intraoperative continuous wave Doppler-derived and invasively measured gradients was documented by our group in 1987 (14) and has been confirmed by others (15,30). We sought to apply these data clinically by judging the functional adequacy of myectomy (based on the presence of significant rest or inducible gradients) and, in patients with an unsuccessful initial resection, adjusting the subsequent surgical procedure on the basis of the site of persistent obstruction.

Incidence of second resections for inadequate initial myectomy. In our study unfavorable results requiring further surgical treatment were present in 20% of patients after an initial septal myectomy, a frequency exceeding the 5% to 12% rate experienced with valve repair (13,22–24). In the present series, those patients who would require a second period on cardiopulmonary bypass could not be predicted from the preoperative assessment of the degree of hypertrophy or outflow tract gradient. Measurements of the distance from the aortic anulus to the septal-mitral contact and the septal thickness obtained before institution of cardiopulmonary bypass were used to guide the extent of resection, but these data did not prevent a relatively high incidence of initially unsuccessful operations.

Thus, there are limitations in the use of anatomic guidance alone. One problem is that measurements made in the filled, beating heart may not correlate with those in the flaccid heart under conditions of cardioplegia. Another difficulty is that systolic anterior motion is a complex, dynamic process; thus in patients with this condition, obstruction involves a more complex physiology than that of hypertrophy alone and would not resolve with excision of the same amount of tissue in all patients.

Having defined patients with initially unsuccessful myectomy, intraoperative echocardiography enabled the adequate control of outflow tract gradient and mitral regurgitation by performance of additional myectomy or valve repair during the same operation in all 10 patients without having to resort to valve replacement. In this situation qualitative information regarding the site of residual obstruction (for example, medial or distal to the initial myectomy) appeared to be influential in the success of the second set of interventions.

Postoperative follow-up. At late follow-up, the mean left ventricular outflow tract gradient did not differ significantly between patients with and without a successful initial resection. Only three patients (6%) had a significant gradient at rest measured at postoperative follow-up; one of these required reoperation. Limited reported data are available for comparison with these results. In a follow-up study of 20 patients operated on between 1960 and 1972, Beahrs et al. (9) found only 1 patient (5%) to have a gradient at rest >50 mm Hg. Similarly, Siegman et al. (8) found that none of their 12 patients had a gradient at rest of this severity and only 1 of 9 had a provokable gradient. In contrast, Fighali et al. (7) reported an inducible gradient in 4 of 5 patients after septal myectomy and Morrow et al. (6) found obstructive gradients in 7 of 32 patients (22%). Our incidence of both rest and inducible gradients at follow-up was low, which may relate to better relief of outflow tract obstruction by more aggressive resection, given the knowledge that complications such as ventricular septal defect, persistent obstruction and mitral regurgitation could be detected by postbypass intraoperative echocardiography. The availability of echocardiography may also have contributed to a very low incidence of surgical complications (including complete heart block) in this series, because the surgeon had on-line information regarding the size of the septum and the extent and location of the excision.

Limitations of the study. This study group comprised patients requiring surgical treatment for clinical indications in whom management constraints imposed limitations on the uniform application of trial interventions and investigations. Thus, several factors in this clinical series were heterogeneous and could not be controlled. In particular, although we consider provocation of left ventricular outflow tract gradients (14,15) to be very important both in the operating room and at follow-up, no uniform policy was employed in this study regarding the use of provocation, the decision obviously being influenced by safety considerations. The importance of looking for provokable gradients in the operating room is supported by the occurrence of a persistent gradient at follow-up in three patients who did not undergo isoproterenol provocation during their postbypass intraoperative studies. It is possible that these patients would have had a provokable gradient in the operating room had we tested them, and that further resection would have eliminated a persistent gradient at follow-up study.

Two practical considerations in the performance of intraoperative echocardiography are important constraints. First, mitral regurgitation needs to be assessed in a semiquantitative fashion (13) because the data are used for on-line decision making. Although such assessment is necessarily subjective, a similar approach used in a recent study of mitral valve repair was shown to be prognostically important (31). Another limitation is that exact reproduction of preoperative hemodynamic conditions is not feasible because of the time constraints of completing the echocardiogram promptly.

In addition, there was no control group of patients either without intraoperative echocardiography or with inadequate initial resection but no further intervention. It is conceivable that the latter group would have a satisfactory clinical result, with amelioration of symptoms despite the persistence of a significant gradient after the septal myectomy. However, on hemodynamic grounds, the objective demonstration of a persisting left ventricular outflow tract gradient in these patients represents an inadequate operation, which appears to carry a less favorable prognosis (10). The low rate of recurrence of significant gradients in this group appears to support this position.

Conclusions. Intraoperative echocardiography benefits the surgical care of patients undergoing septal myectomy in several ways. Because of the echocardiographic findings, the site and extent of the resection may be planned more effectively. The physiologic results of the initial resection attempt may be determined by intraoperative echocardiography, and further operations may be performed if the initial hemodynamic response is unsuitable. Intraoperative echocardiography is a useful adjunct to the performance of septal myectomy in patients with hypertrophic obstructive cardiomyopathy.

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