SUMMARY Although the postoperative hemodynamic and echocardiographic features of idiopathic hypertrophic subaortic stenosis have been studied, the expected consistent postoperative thinning of the interventricular septum has not been reported. In this study, the short-term effects of septal myectomy were evaluated in 16 patients. All patients were assessed with pre- and postoperative hemodynamic studies and M-mode echocardiograms, and six of the 16 patients had pre- and postoperative two-dimensional echocardiograms. The mean resting preoperative gradient of 74 mm Hg (range 10-190 mm Hg), which fell to a mean resting postoperative gradient of 8 mm Hg (range 0-25 mm Hg), was associated with decreased end-diastolic interventricular septal thickness at the midventricular level in 14 of 16 patients and at the subaortic level in 16 of 16 patients by M-mode echocardiography. The group also demonstrated changes in left ventricular outflow tract configuration and dimension, mitral valve systolic anterior motion, mitral E-Fo slope and left ventricular percent fractional shortening by both M-mode and two-dimensional studies. In the two patients who did not show midventricular septal thinning on M-mode echocardiography, the two-dimensional echocardiograms revealed that the area of myectomy extended only through the subaortic region and not down to the midventricular septum. Thus, we have observed consistent postmyectomy septal thinning at both the midventricular and subaortic levels by M-mode echo. By defining the geometry of the septal myectomy in vivo with two-dimensional echocardiography, we can better interpret M-mode studies and identify factors that influence echocardiographic visualization of the region of myectomy.

ECHOCARDIOGRAPHY is a useful noninvasive tool for assessing the anatomical features of idiopathic hypertrophic subaortic stenosis (IHSS). These features have correlated well with angio graphic, hemodynamic and pathologic findings. Echocardiography also has been used to assess the effects of various interventions, including surgery, on IHSS. Although the hemodynamic effects of septal myectomy and myotomy have been impressive, thinning of the interventricular septum has not been documented by echocardiography in the early postmyectomy state, and this absence of septal thinning has not been explained.

M-mode echocardiography displays distance measurements and motion in an “icepick” view of the heart, without spatial orientation. Therefore, it is sometimes unclear exactly which portion of the interventricular septum is being examined (i.e., midventricular or subaortic portions). Wide angle, two-dimensional (2-D) ultrasonic sector scanning provides dynamic images of the heart in multiple cross-sectional planes, including long axis sections of the left ventricle that display the entire length of the interventricular septum. The purposes of this project were: 1) to study the effects of septal myectomy on the M-mode echocardiographic features of IHSS, with particular attention to the interventricular septum, and 2) to use 2-D echocardiography to further delineate anatomical changes resulting from septal myectomy in vivo.

Methods

Study Group

Sixteen consecutive patients, 12–62 years (mean 49 years), who had septal myectomy at Stanford University Hospital from 1973–1977 were studied. All patients had pre- and postoperative cardiac catheterization with measurements of left ventricular outflow tract gradients. Six of 16 patients had intraoperative measurement of left ventricular outflow tract gradients following septal myectomy; whereas the other 10 patients had routine cardiac catheterization within 30 days of surgery. Also, all patients had pre- and postoperative M-mode echocardiograms. Six of 16 patients had pre- and postoperative 2-D echocardiograms. All postoperative echocardiograms were performed within seven days of surgery. Fourteen of the 16 patients were on propranolol preoperatively in doses ranging from 80–320 mg/day. At the time of the postmyectomy hemodynamic and echocardiographic studies, none of the patients had resumed propranolol.

Operative Techniques

All operations were performed through a median sternotomy. Standard techniques for cardio-
pulmonary bypass, using a bubble-type oxygenator, were used. After institution of cardiopulmonary bypass, ventricular fibrillation was induced with a brief DC current; the ascending aorta was cross-clamped and a small caliber (14F) left ventricular vent was inserted through the apex. An oblique aortotomy was made, extending into the noncoronary sinus of Valsalva. The right aortic valve cusp was then retracted with a cloth covered retractor, exposing the upper portion of the hypertrophied interventricular septum. A flat ribbon retractor was then passed through the aortic annulus to the apex of the heart in order to retract and protect the anterior mitral leaflet and anterolateral papillary muscle. The interventricular septum was incised with a #10 knife blade, attached to a 30° angled handle. This incision was begun just below the base of the right coronary cusp, slightly to the right of its midportion, and extended vertically toward the apex of the left ventricle approximately two-thirds of the distance between the aortic valve annulus and apex. This incision was completed by withdrawing the blade in a downward cutting motion onto the surface of the ribbon retractor. A second incision was made in the same manner slightly more than 1 cm to the left of and parallel to the first incision. In the most prominent portion of the hypertrophic ridge, the depth of both incisions was approximately 1.5 cm. The intervening bar of muscle between the two parallel myotomies was then excised sharply with scissors, using counterpressure on the anterior surface of the heart to rotate the midportion of the interventricular septum into a more accessible location. Following removal of the primary bar of muscle, a third incision was made 0.5-1.0 mm to the left of the first myectomy, directed toward the base of the anterolateral papillary muscle. This incision was therefore necessarily shorter than the primary incision and passed only through the immediate subaortic region. The second bar of muscle created by this third incision was then excised sharply and the interior of the ventricle was lavaged thoroughly to remove debris.

Because of the spiral configuration of the interventricular septum in three dimensions, septal myectomy performed in this manner results in a longitudinal trough that extends obliquely across the septum approximately two-thirds of the distance from the aortic valve to the left ventricular apex. The myectomy is deepest in the subaortic region and becomes progressively shallow beyond the midventricular location. This method for interventricular septal myectomy is a modification of the technique described by Morrow and coworkers.4

Echocardiographic Methods

All M-mode echocardiographic studies were performed using a Smith Kline Ekoline 20A ultrasonoscope and a 0.50-inch diameter, 2.25 MHz or 3.50 MHz transducer with 5 cm beam collimation. Recordings were made with an Irex 101, Ekoline 21, or Honeywell 1856 strip chart recorder. All examinations were conducted with the patient rotated 30° into a left lateral decubitus position. All M-mode echocardiograms were made with the transducer in the fourth or fifth intercostal space, with close attention given to standard transducer placement, as previously described10 to position the transducer perpendicular to the chest wall above the mitral valve. Also, efforts were made to direct the M-mode beam to the more medial regions of the interventricular septum.

A Varian model V3000 phased array 80° ultrasonic sector scanner was used to perform the 2-D echocardiographic studies. This instrument has been previously described by Anderson et al.11 Two-dimensionial echocardiographic studies were recorded on 1-inch reel-to-reel video tape. Simultaneous M-mode and 2-D recordings were made in all patients who had 2-D studies, as previously described.11 This method permitted anatomically precise M-mode recordings under direct 2-D visualization. Analysis of the 2-D images was made by replaying the recorded studies in real time, slow motion, and stop action modes.

The 2-D echocardiographic illustrations used in this article are made from stop action, single frame television images, using a Polaroid camera system. There is significant degradation of the stop frame image quality as compared with the dynamic display, since only one field of a two field video frame is displayed in each photograph. Therefore, only half of the image information is displayed by this stop action process and there is some blurring by the optical system.

The 2-D echocardiographic studies were performed by initially orienting the sector plane parallel to the long axis of the left ventricle (fig. 1). The transducer was rotated 90° clockwise to obtain the short axis view (fig. 1). The short axis sweep was then performed by keeping the transducer in a fixed location on the chest wall and slowly angling the image plane from aorta (cephalad) to apex (caudad), similar to the method previously described by Kisslo (fig. 1).12

Analysis

The M-mode echocardiograms were each assessed by three observers. The parameters measured in the M-mode studies were: right ventricular internal dimension at end-diastole; left ventricular internal dimension at end-diastole and end-systole; left atrial internal dimension at end-systole; aortic root dimension at end-diastole; left ventricular posterior wall thickness at end-systole and end-diastole as previously described by Popp.18 The comparison of interventricular septal and left ventricular posterior wall thickness was made at end-diastole and expressed as a ratio. In addition, the interventricular septal thickness was measured in the subaortic region as well as in the midventricular region at both end-systole and end-diastole. In this study, the subaortic region of the interventricular septum was defined as that region of the septum recorded anterior to the mitral valve (fig. 2). The midventricular region of the interventricular septum was defined as that region of the septum recorded anterior to the chordae tendineae which is the area between the free edge of the mitral leaflets and the tips...
of the papillary muscles (fig. 3) from which standardized right and left ventricular parameters are measured. Systolic anterior motion of the mitral valve was quantified by measuring the shortest distance between the maximum systolic anterior mitral motion and the line connecting adjacent C and D points of the mitral valve echocardiogram (fig. 4). The left ventricular outflow tract systolic size was measured as the distance from the point of maximum mitral systolic anterior motion to the interventricular septum similar to the method of Bolton (fig. 4). Percent fractional shortening of the left ventricle was determined by subtracting the end-systolic from the end-diastolic left ventricular dimension (measured at the peak of the R wave on the electrocardiogram), dividing this value by the end-diastolic dimension and expressing it as a percentage. The 2-D echocardiograms were assessed by at least two observers.
Figure 2. (Above) Pre- and postoperative M-mode echo of the left ventricle at the subaortic level showing postoperative interventricular septal (IVS) thinning. Arrow denotes preoperative systolic anterior motion of the mitral valve which disappears postoperatively. Note the coarse diastolic fluttering in the postoperative mitral valve echogram, especially of the posterior mitral leaflet. Also note the systolic murmur present on the phonocardiogram. This patient had a ruptured chordae tendinae which developed postoperatively. The left ventricular outflow tract may be larger than is usually seen postoperatively because of the volume overload due to the mitral insufficiency. PHONO = phonocardiogram; AL = anterior leaflet of the mitral valve; LVPW = left ventricular posterior wall; PREOP = preoperative; POSTOP = postoperative.
without knowledge of data from the M-mode echocardiograms, hemodynamic data, or patient identification. The cardiac catheterization data were independently analyzed by observers who had no knowledge of echocardiographic data.

**Results**

All 16 patients showed a postoperative marked decrease in the left ventricular outflow tract gradient from a mean preoperative resting gradient of 74 mm Hg (range 10–190 mm Hg) to a mean postmyectomy gradient of 8 mm Hg (range 0–25 mm Hg). The pre- and postoperative left ventricular outflow tract gradients are illustrated in figure 5.

The M-mode echocardiographic results are summarized in table 1. There was good internal consistency in pre- and postmyectomy M-mode parameter measurements which were not affected by operation, such as right ventricular internal diameter, left ventricular posterior wall dimension, and aortic root dimension. Pre- and postmyectomy M-mode echocardiographic measurements were compared by paired t test, which revealed the following:

1) There was a significant operative change ($P < 0.001$) in interventricular septal dimension at both end-diastole and end-systole in both the subaortic (fig. 2) and midventricular regions (fig. 3). The two patients (13 and 15) who did not demonstrate interventricular septal thinning postmyectomy at the midventricular level did demonstrate postoperative interventricular septal thinning at the subaortic level (see below for 2-D echocardiogram analysis).

2) The interventricular septal-to-left ventricular posterior wall ratio decreased postoperatively ($P < 0.001$).

3) Systolic anterior motion of the mitral valve decreased postoperatively ($P < 0.025$).

4) The interventricular septal to systolic anterior motion distance (a reflection of left ventricular outflow tract size) increased postoperatively ($P < 0.001$).

5) There was an overall increase in mitral E-Fo slope postoperatively ($P < 0.001$). Moreover, when the six patients (nos. 2, 3, 4, 7, 9 and 14) who had diastolic abutment of the anterior mitral leaflet against the interventricular septum were excluded from the total group, the 10 remaining patients also showed an increased E-Fo slope postmyectomy ($P < 0.05$). There was no postoperative change in mitral valve excursion ($P =$ not statistically significant).
TABLE 1. M-Mode Echocardiographic Data

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Abbreviations: IVS = interventricular septum; ED = diastole; MV = midventricular; ES = systole; SA = subaortic; LVPW = left ventricular posterior wall; SAM = systolic anterior motion; FS = fractional shortening; Pre = pre-myectomy; Post = post-myectomy; LVID = left ventricular internal diameter.

6) There was no significant change in the postoperative left ventricular internal diameter at end-diastole as compared with the preoperative values (P = not statistically significant).

7) A high preoperative percent fractional shortening of left ventricular internal diameter decreased postmyectomy (P < 0.01).

Two-Dimensional Echocardiography

In all six patients who had pre- and postoperative 2-D echocardiographic studies, the postoperative region of septal thinning could easily be appreciated. Figures 6 and 7 depict pre- and postoperative, respectively, 2-D echocardiographic studies from the same patient in different views and phases of the cardiac cycle. On the short axis cross-sectional view of the left ventricle, the area of septal myectomy was approximately 2 cm wide and could be seen extending from the 10–12 o'clock position on the left ventricular circumference, and it did not involve the papillary muscles (fig. 7B). As suggested by the M-mode echocardiographic studies, systolic enlargement of the left ventricular outflow tract could be readily appreciated on the 2-D images (compare figs. 6B and 7A). In four of six patients the septal thinning extended all the way down to the midventricular level (fig. 7A), correlating with the finding of interventricular septal thinning at the midventricular level by M-mode echocardiography. Two patients (nos. 13 and 15) had postmyectomy septal thinning only in the subaortic region by M-mode echocardiography; 2-D studies also confirmed this. As seen in fig. 8, the septal myectomy involved only the subaortic region and not the midventricular level, indicating a less extensive septal myectomy in these two patients. As measured from the short axis left ventricular view, all myectomies were at least 1.8 cm wide (fig. 7B).

Discussion

Changes in some of the echocardiographic features of IHSS following septal myectomy have been described in previous studies. As in this group, changes have been correlated with marked decreases in left ventricular outflow tract gradient compared with preoperative catheterization. This study adds new information on the geometry of the myectomy in vivo and documents changes in the other echocardiographic parameters.

The postoperative interventricular septal thinning and decrease in the interventricular septal-to-left ventricular wall thickness ratio found by echocardiography in this series has not been reported in previously published studies. The interventricular septal thinning found in this study may be explained by multiple factors, including: 1) the depth of the myectomy into the ventricle toward the apex extend-
ing down through the subaortic area and into the midventricular region of the interventricular septum; 2) the region of the septal thinning being accessible to the ultrasound beam; 3) attention to directing the M-mode beam to the more medial regions of the septum to find the area of myectomy; and 4) the width of the myectomy exceeding the width of the ultrasound beam at the level of the interventricular septum.

It is clear that in 14 of 16 patients in this study, interventricular septal thinning extended through the subaortic septum down to the midventricular region, as detected by M-mode (figs. 2 and 3) and further confirmed by 2-D echocardiography (fig. 7A). After examining the 2-D images, the reason for lack of evident midventricular septal thinning in the other two patients was that the myectomy extended only as far as the subaortic septum and not down to the midventricular region of the septum (fig. 8). Perhaps in previous studies as well, the lack of documented interventricular septal thinning at the standard midventricular level was due to the limited longitudinal extension of the myectomy. According to Roberts, an adequate septal myectomy should include surgical excision of myocardium located in the midventricular region of the septum and not just excision of that portion of the septum in the subaortic region. Whether our 14 patients who demonstrated postoperative midventricular septal thinning will sustain superior surgical results compared with the two patients who had only subaortic septal thinning in this study, or no septal thinning postmyectomy as in other studies, will be determined by long-term follow-up.

As can be seen in figure 7B, the septum was thinned at approximately 10–12 o’clock on the short axis left

**FIGURE 6.** A) Photograph and diagram of a preoperative long axis sector scan in diastole of a patient with IHSS (patient 10). Note the thickened interventricular septum (IVS) in relation to the left ventricular posterior wall (LVPW). Also note the bright postero-medial papillary muscle (PMP) and the calcified mitral annulus (CMA) as landmarks. B) Photograph and diagram of a preoperative long axis sector scan in systole of the same patient as in figure 6A. Note the narrowed left ventricular outflow tract (LVOT). C) Photograph of preoperative short axis view at the level of the papillary muscles in diastole of the same patient. Note the thickened interventricular septum in relation to the left ventricular posterior wall. R = right; L = left; RV = right ventricle; AV = aortic valve; Ao = aortic root; AL = anterior leaflet of the mitral valve; LA = left atrium.
FIGURE 7. A) Systolic long axis view of same patient as in figure 6, postoperatively. The arrow denotes region of interventricular septal thinning at both the subaortic and midventricular levels. Also note the increase in postoperative left ventricular outflow tract (LVOT) size as compared with the systolic long axis view in figure 6B. B) Postoperative diastolic short axis view at the level of the papillary muscles of the same patient. The arrow denotes the area of postoperative septal thinning. Compared with figure 6C, the left ventricular outflow tract has enlarged following septal myectomy. PMP = postero-medial papillary muscle; LVPW = left ventricular posterior wall; IVS = interventricular septum; RV = right ventricle; Ao = aortic root; MV = mitral valve; CMA = calcified mitral annulus; LV = left ventricle; LA = left atrium; A = anterior; Ap = apex; Ba = base; P = posterior.

ventricular circumference. This position easily allows accessibility of the M-mode beam to this region of the septum. However, if the area of myectomy were more medial and posterior at 8–10 o’clock on the left ventricular circumference (fig. 9), the area of septal thinning might not be accessible to the ultrasound beam, because this region of the septum is roughly parallel to the M-mode beam. However, even if this region were accessible to the ultrasound beam, only a thorough examination of the medial portion of the interventricular septum would reveal septal thinning. The region of septal thinning could easily be overlooked if only the more lateral and anterior portions of the interventricular septum were studied by M-mode echocardiography (fig. 10). One of the advantages of wide angle, 2-D echocardiography is that the entire septum can be imaged, with preservation of spatial orientation, so that the exact area and extent of septal thin-
FIGURE 8. Postoperative long axis view in diastole of a patient with IHSS. Note that the area of septal thinning (arrow) is only in the subaortic region and not at the midventricular level. This patient had a bioprosthetic mitral valve (BPV) replacement for severe mitral regurgitation in addition to the septal myectomy. LA = left atrium; ALP = anterolateral papillary muscle. Other abbreviations as in figure 6.

ng can be visualized and M-mode findings can be explained.

In most patients, the interventricular septum is approximately 5–7 cm from the anterior chest wall. At this depth the width of a single ultrasound beam is 0.5–0.6 cm. Because the lateral resolution deteriorates as the beam width increases, closely related structures may not be separable by ultrasound. In the case of septal myectomy, if the muscle bar removed were less than 0.5–0.6 cm wide, the ultrasound beam probably would not be able to detect septal thinning. Because the septal muscle defects in this study were all at least 1.8 cm wide by 2-D echocardiography, they were easily detected by M-mode echocardiography. Conversely, if the area of septal thinning were quite narrow in previous studies, limited lateral resolution

FIGURE 9. Diagram of postoperative left ventricular short axis view with myectomy in the 8–10 o’clock position on the left ventricular wall circumference as denoted by the arrow. Even when the M-mode echo beam (A) is aimed to the right (medially) through the region of myectomy, the interventricular septal (IVS) thinning cannot be appreciated. When the beam (B) is directed more to the left (laterally), the area of septal thinning still cannot be detected. ALP = anterolateral papillary muscle. Other abbreviations as in figures 6 and 8.
could have accounted for the failure to detect postmyectomy septal thinning.

One might postulate that the reason for symptomatic improvement following septal myectomy (besides relief of left ventricular outflow tract gradient) is improved left ventricular compliance facilitating left ventricular diastolic filling. Mitral valve E-Fo slope has been used as an index of left ventricular filling rate and diastolic left ventricular compliance. When analyzing the entire group, we found a significant increase in E-Fo slope in the postoperative state compared with the preoperative state. However, in six of 16 patients the E-Fo slope was very close to zero (all < 0.9 cm/sec), since the anterior mitral leaflet appeared to abut the interventricular septum during the early part of diastole when the E-Fo slope is measured. Because of this interference with measurement of the E-Fo slope, we could not consider the E-Fo slope as being a reliable index of left ventricular diastolic compliance in these six patients. When these patients were excluded from analysis, however, there was still a significant increase in the E-Fo slope in the remaining 10 patients postmyectomy. This suggests that diastolic left ventricular filling rate and perhaps diastolic left ventricular compliance had increased postoperatively. These echocardiographic findings are consistent with hemodynamic studies which have shown a postoperative decrease in left ventricular end-diastolic pressure and also suggested an increase in left ventricular diastolic compliance.

The preoperatively increased percent fractional shortening of the left ventricular internal dimension decreased significantly in the postoperative state. Although posterior wall hyperkinesis and increased percent fractional shortening in IHSS have been reported in previous studies, a decrease following septal myectomy has not been reported. Hyperkinesis in IHSS appears to be associated with left ventricular outflow tract gradients as inotropic agents augment the gradient and negative inotropic agents decrease the gradient. Criley has even suggested that the gradient may be relieved because surgery creates myocardial damage that results in decreased contractility of the left ventricle. Although both contractility and left ventricular outflow tract gradients decreased postoperatively in our patients, a cause and effect relationship cannot be inferred from our studies.

The zone of pressure change in the left ventricle has been found about 2.5 cm below the aortic valve. Our data show a clear postoperative increase in left ventricular outflow tract dimension during systole by both M-mode and 2-D techniques in this region coincident with reduction of gradient. Because the interventricular septum did thin postoperatively in our group, augmentation of outflow tract dimension was not entirely dependent on alleviation of mitral systolic anterior motion.

Assessing the effects of septal myectomy by echocardiography in patients with IHSS is a difficult task involving complex anatomic and ultrasonic factors. Four such factors emphasized by this study are: 1) the longitudinal extent of the septal myectomy; 2) the width of the septal myectomy in relation to the lateral resolution capability of the ultrasonic beam; 3) accessibility of the excised portion of the interventricular septum to the ultrasonic beam; and 4) meticulous exploration of the medial part of the interventricular septum with the ultrasound beam to search for the area of myectomy. Our data indicate that: 1) reduction of septal thickness significantly increased left ventricular outflow tract dimensions somewhat independently of the decrease in mitral valve systolic shortening.

**Figure 10.** Diagram of postoperative short axis view with myectomy (arrow) in the 10–12 o’clock position on the left ventricular wall circumference as found in the patients in this study. When the M-mode beam is directed medially (right) (A), the area of septal thinning can be readily appreciated and compared to the thickness of the left ventricular posterior wall (LVPW). However, with more lateral (leftward) beam orientation (B), the region of septal thinning is missed. Abbreviations as in figures 6 and 8.
anterior motion; 2) left ventricular outflow tract gradient decreased significantly as a result of operation; 3) left ventricular diastolic compliance may have been increased by septal myectomy; and 4) left ventricular percent fractional shortening decreased postmyectomy. As suggested by Roberts, we must assess the postmyectomy septum in order to determine adequacy of myectomy. Assuming that the area of excised septum is large enough to be detected, the adequacy of septal myectomy usually be assessed if proper attention is given to the physiologic, anatomic, and ultrasonic factors described in this report. However, correlation of the long-term clinical effects with the anatomic configuration and physiologic modification of the septal myectomy must await further follow-up studies. Although the effects of septal myectomy on left ventricular compliance and contractility are somewhat speculative, further investigation is warranted to determine their possible role in decreasing left ventricular outflow tract gradient.

We conclude that M-mode and 2-D echocardiography are useful in assessing postmyectomy interventricular geometry. Moreover, two-dimensional echocardiography can be synergistically combined with M-mode echocardiography to aid in the interpretation and understanding of M-mode records.

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