The Surgical Treatment of Calcific Aortic Stenosis: *

Operative Methods and the Results of the Pre- and Postoperative Hemodynamic Assessments

ANDREW G. MORROW, M.D., W. GERALD AUSTEN, M.D., EUGENE BRAUNWALD, M.D.

From the Clinic of Surgery and Cardiology Branch, National Heart Institute Bethesda, Maryland

WITHIN recent years it has become apparent that relief of calcific aortic stenosis can be accomplished with maximum safety and effectiveness by means of an open operation. In some patients valve function may be restored by debridement of the valve and division of its fused commissures; in others partial, or total prosthetic replacement of the valve is found to be necessary.

The effectiveness of these technics in the relief of symptoms and disability is attested by numerous recent reports.[1, 5-7, 9, 11, 13] There has been relatively little published information, however, indicating the extent to which these procedures affect the hemodynamic abnormalities present before operation. Between January 1961 and December 1962, 52 consecutive patients with calcific aortic stenosis underwent open operation at the National Heart Institute. Left heart catheterization was carried out in each patient before operation, and in 39 surviving patients afterward. The operative methods employed in the treatment of these patients and the results of their pre- and postoperative hemodynamic studies are described in the report which follows.

Clinical and Hemodynamic Findings

The 52 patients ranged in age from 19 to 63 years; the median age was 48 years. Forty-six were men and six were women. In 43 patients the valvular lesion was considered to be an acquired one; 16 had a definite history of rheumatic fever, and in the other 27 the absence of a murmur in childhood and the operative findings indicated an acquired etiology. In the remaining nine patients a calcified congenitally bicuspid valve was found at operation. All but one of the patients had experienced dyspnea on effort. Thirty-one of them also complained of angina pectoris, 14 had had syncope, and 18 had been treated for congestive heart failure.

The usual physical findings of aortic stenosis were evident on examination in every patient and this was considered to be the predominant hemodynamic lesion in every instance. In 42 patients a blowing diastolic murmur was present at the base of the heart, indicating the presence of associated aortic regurgitation. In 29 of them regurgitation was considered to be of only trivial magnitude. In the remaining 13, however, regurgitation was probably of hemodynamic significance, as indicated by a systemic diastolic arterial pressure of 60 mm. Hg, or less, and a pulse pressure in excess of 60 mm. Hg. Cardiac enlargement of variable degree was always seen radiographically and calcification of the valve was apparent by x-ray in 48 patients. With one exception, the electrocardiograms revealed left ventricular hypertrophy, and in 17 patients prominent T-wave and ST-segment abnormalities were present as well. In four patients the tracings clearly indicated previous myocardial infarction and three had left bundle branch block. Two patients had atrial fibrillation.

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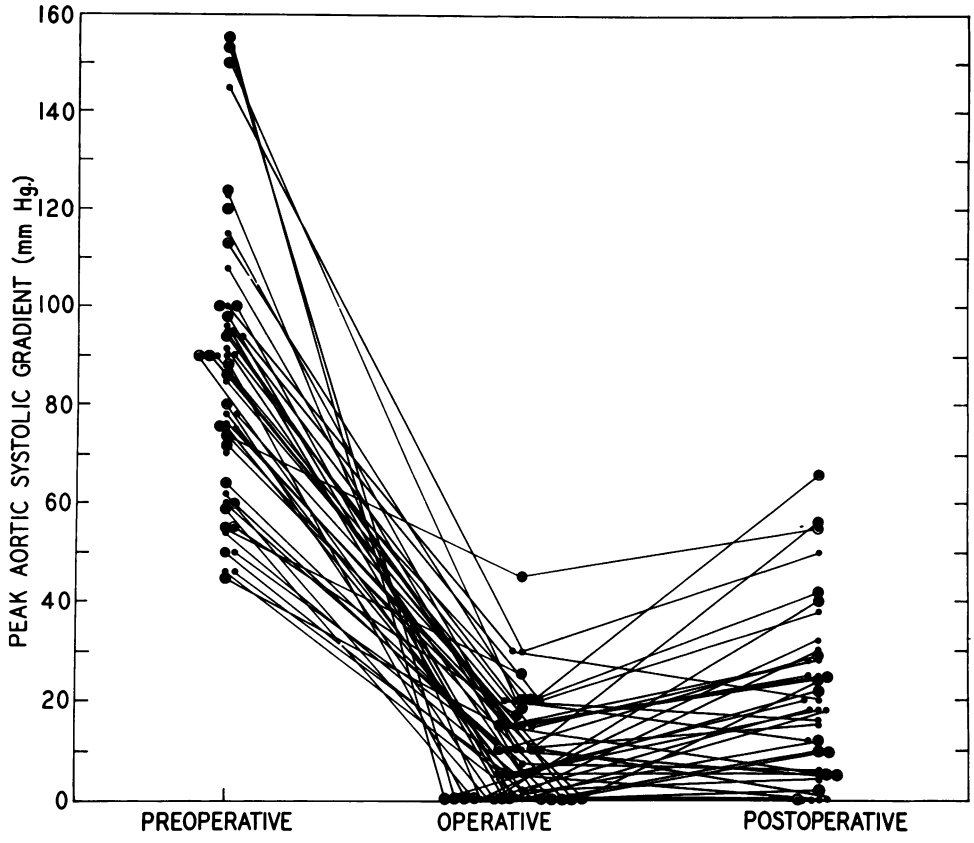

FIG. 1. Measurements of the peak systolic pressure gradients between the left ventricle and brachial artery recorded preoperatively, at the conclusion of the operative procedure (operative), and at the time of postoperative study. The solid circles designate patients in whom a debridement and commissurotomy was performed; the open circles designate patients in whom partial or total valve replacement was carried out.

In every patient the presence of aortic stenosis was confirmed by the demonstration of a systolic pressure gradient between the left ventricle and brachial artery at the time of left heart catheterization. This study was usually performed by the transseptal technic [2] (47 patients), while percutaneous left ventricular puncture,[3] or retrograde arterial catheterization was carried out in the remaining five. The pertinent preoperative hemodynamic data in all patients are summarized graphically in Figures 1–5.

The peak systolic pressure gradients measured preoperatively ranged from 45 to 155 mm. Hg and the average gradient was 87 mm. Hg (Fig. 1). The left ventricular end-diastolic pressure was higher than normal (12 mm. Hg) in 30 of the 52 patients (Fig. 2). This pressure ranged from 4 to 38 mm. Hg and averaged 16 mm. Hg. The left atrial mean pressure exceeded the normal value (12 mm. Hg) in 11 of the 41 patients in whom it was determined. The diastolic pressures directly recorded from the brachial artery are tabulated in Figure 3.

In the course of left heart catheterization the cardiac output was determined, by the indicator dilution method, in 49 of the 52 patients (Fig. 4). In 20 of them the cardiac index was less than 2.4 L./min./M.^{2}, the value generally accepted as the lower limit of normal. In only 14 patients was the cardiac index 3.0 L./min./M.^{2} or

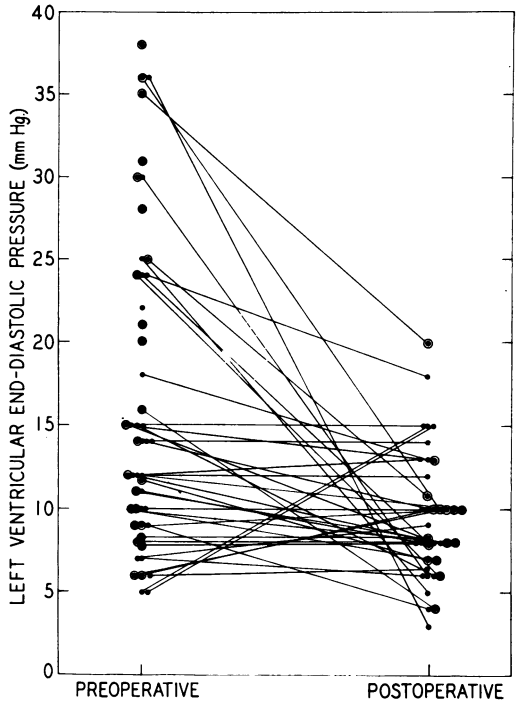

FIG. 2. Measurements of left ventricular end-diastolic pressure recorded preoperatively and at postoperative cardiac catheterization. Open and solid circles as designated in Figure 1.

greater; the average value was 2.5 L./min./M.^{2}. The mean systolic pressure gradient between the left ventricle and brachial artery was determined by planimetric integration of the pressure records after appropriate correction of the time delay in the brachial pressure pulse. Calculations of the effective orifice of the aortic valve were made in 45 patients.[4] The orifice areas ranged from 0.22 to 1.02 cm.^{2}, the average value being 0.58 cm.^{2} (Fig. 5). The effective orifice size was, of course, underestimated in those patients with associated aortic regurgitation since true aortic valve flow could not be measured.

In 47 patients right heart catheterization was also carried out at the time of preoperative study. Significant elevation of the right ventricular or pulmonary arterial systolic pressure (over 30 mm. Hg) was present in 16 of them.

Operative Methods

The operative methods utilized to expose the aortic valve during cardiopulmonary bypass were similar in each patient. After induction of anesthesia the patient is positioned supine and a complete median sternotomy is made. After wide incision of the pericardium, the aorta is freed from the pulmonary artery, and its base dissected anteriorly to the origin of the right coronary artery (Fig. 6). A single large venous drainage cannula is passed into the right atrium and the arterial return cannula into the common femoral artery. Cardiopulmo-

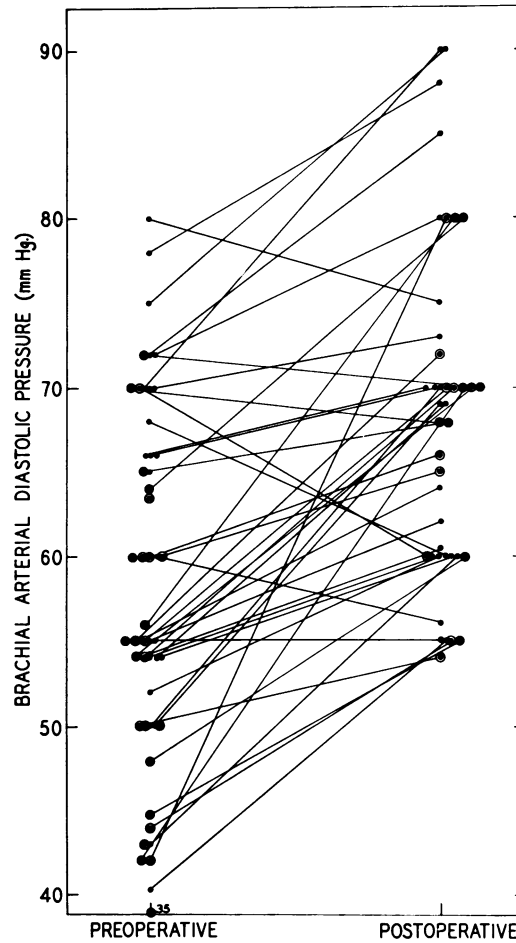

FIG. 3. Measurements of the diastolic pressure recorded directly from the brachial artery preoperatively and at the time of postoperative cardiac catheterization. Open and solid circles as designated in Figure 1.

nary bypass is then instituted at a flow rate of 2.0 L./min./M.^{2} and the main pulmonary artery is occluded. The patient's esophageal temperature is reduced to 30–31° C. by a heat exchanger in the extracorporeal circuit and when this temperature has been reached the flow rate is reduced to approximately 1.5 L./min./M.^{2}. During the cooling period a drainage cannula, passed into the pericardial space through a stab wound in the left precordium, is introduced into the apex of the left ventricle (Fig. 7). The cannula is attached to the intracardiac aspirating pump of the heart-lung machine.

When these preparations have been completed, the aorta is occluded near the origin of the innominate artery, and a vertical incision is made in it; a vertical aortotomy has, in this clinic, been found preferable to a transverse one. The incision is extended down to the aortic annulus in the noncoronary sinus of Valsalva and the flap of aortic wall which is created is retracted by suturing it to the pericardium. Throughout the period of aortotomy, the operative field is flooded with 100 per cent CO_2 (15 L./min.). The heart is maintained by constant perfusion of the left coronary artery, and usually the right as well, with arterial blood supplied from side arms of the arterial return line (Fig. 6). The coronary perfusion cannulae provide flows of 300 cc./min. against no resistance. This technic

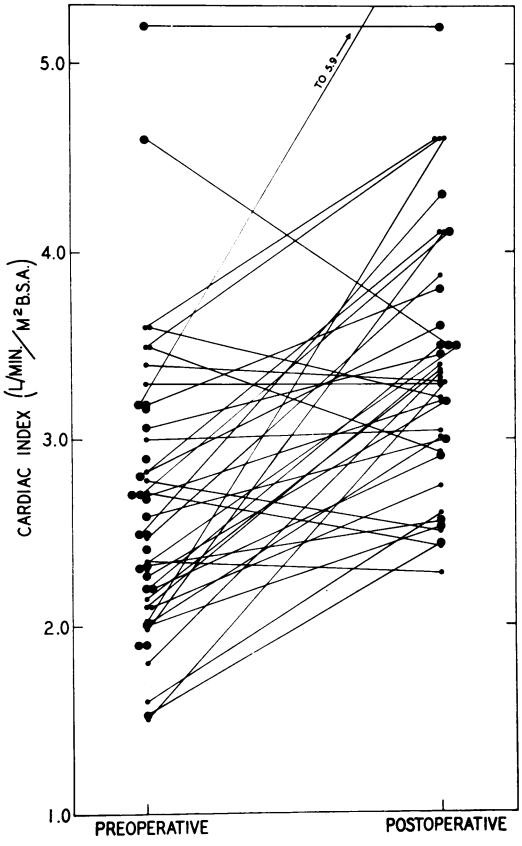

FIG. 4. Measurements of the cardiac index, by the indicator-dilution method, made preoperatively and postoperatively. Open and solid circles as designated in Figure 1.

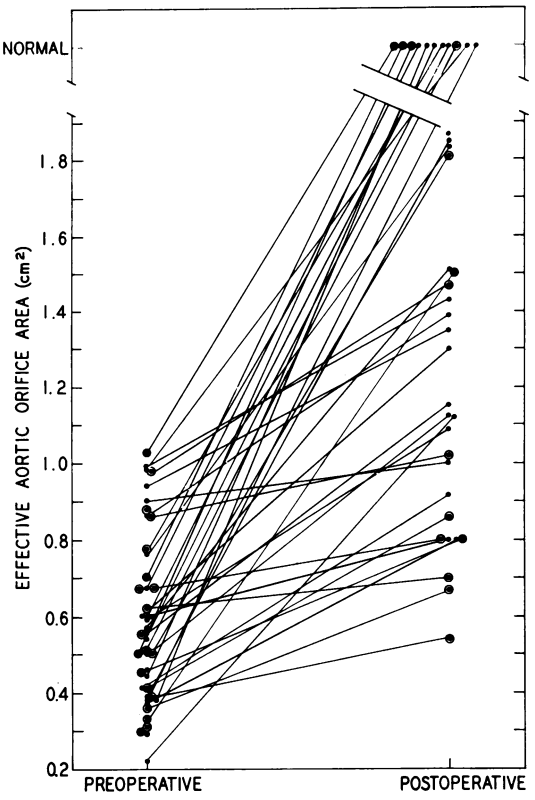

FIG. 5. Calculations of the effective orifice area of the aortic valve derived from measurements of pressure and flow made preoperatively, and at the time of postoperative cardiac catheterization. The *normal* postoperative values are those in which no valvular gradient was present or the gradient was too small for valid application in the Gorlin formula. Open and solid circles as designated in Figure 1.

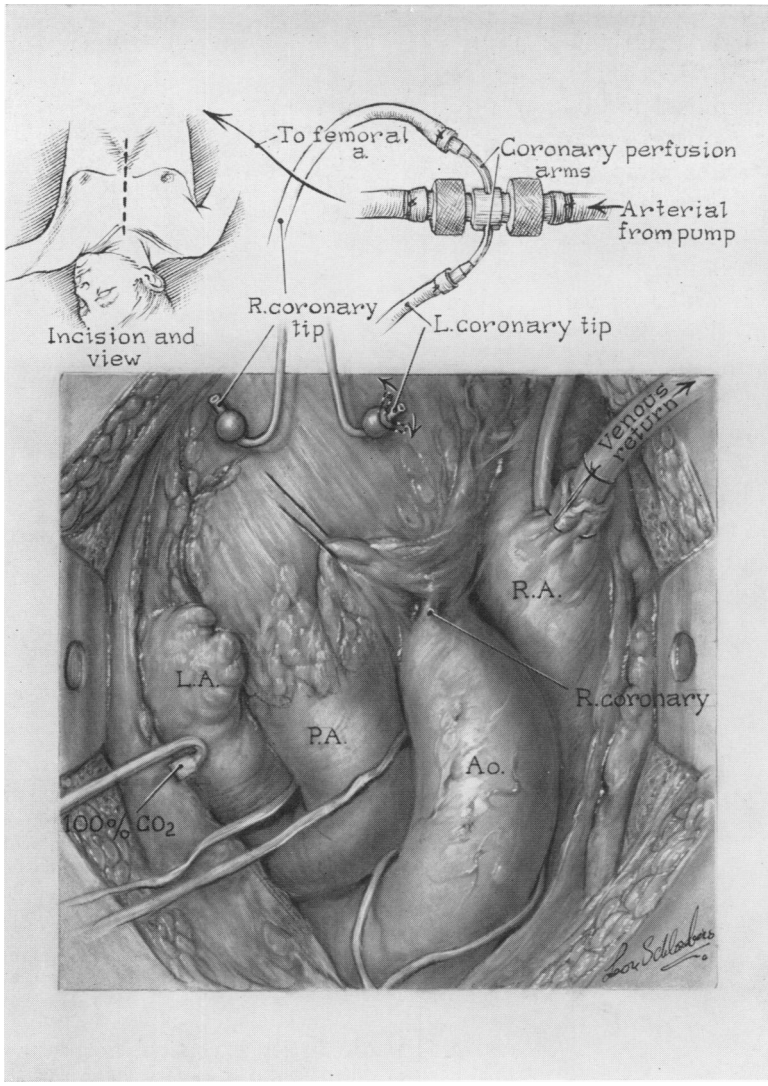

FIG. 6. The operative exposure and cannulations employed in the open correction of calcific aortic stenosis. The insert also shows the means by which oxygenated blood for coronary perfusion is supplied from side arms in the arterial return line.

of coronary perfusion, and the cannulae employed, are those described by Littlefield, Loweki, and Muller.[8] With coronary perfusion, the myocardium remains oxygenated at all times, and the impairment of left ventricular function, which follows a period of ischemia, at any temperature, is obviated.

Every patient was found to have a densely calcified aortic valve and in the majority of them an attempt was first made to restore valvular function by means of debridement. The calcific and atheromatous deposits on the upper surfaces of the leaflets are first removed; a round pituitary rongeur is most often employed for the larger and more discrete masses (Fig. 8) while curettes of various size are useful in loosening the flat plaques of calcium often present in the depths of the sinuses (Fig. 9). Only after the debridement has been completed are adherent commissures incised. The valve leaflets may then be elevated and additional calcium removed from their undersurfaces. It is frequently necessary to carry the debridement onto the

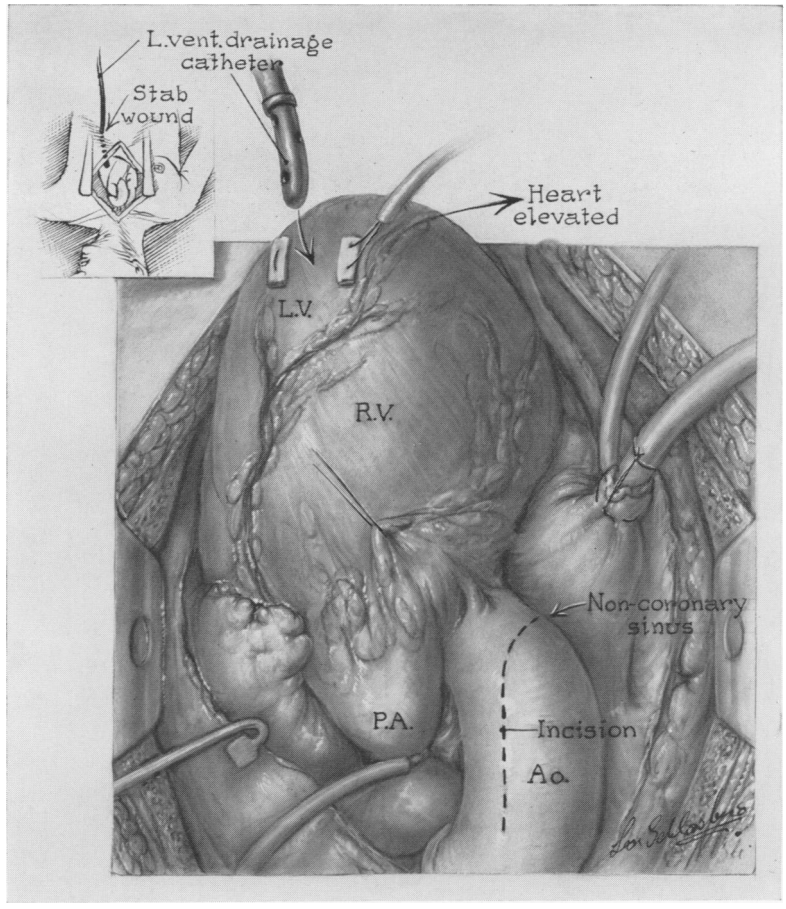

FIG. 7. The left ventricular drainage cannula is passed into the pericardial space from a stab wound in the left precordium. After the institution of bypass, the heart is delivered from the pericardium and the cannula passed through a re-inforced mattress suture in the apex of the ventricle. The site of the aortic incision is indicated by the dotted line.

aortic leaflet of the mitral valve since it is often involved as well. In some of the patients in this group, particularly the older ones, aortic stenosis was found to result entirely from loss of leaflet mobility due to calcification, and none of the commissures of the valve was fused. Such an anatomic picture suggests that primary atherosclerosis of the valve may sometimes occur without previous rheumatic valvulitis. In these patients the calcific and atheromatous deposits on the leaflets are often softer and less adherent than in younger patients and

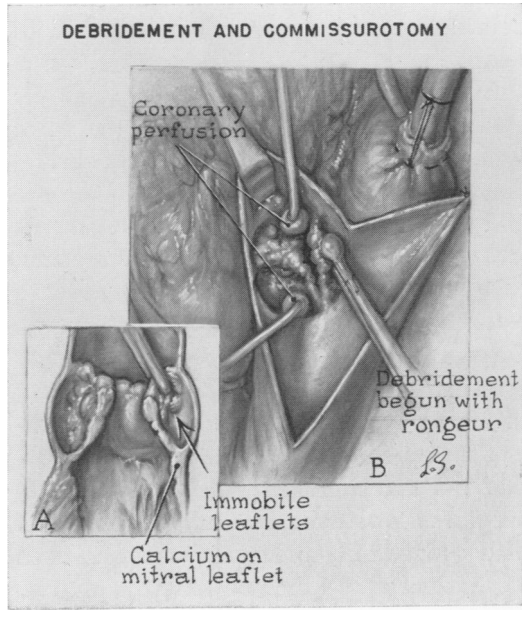

FIG. 8. An attempt is usually made to restore valve function by means of debridement and commissurotomy. Calcific deposits are first removed from the upper side of the leaflets, usually with a rongeur.

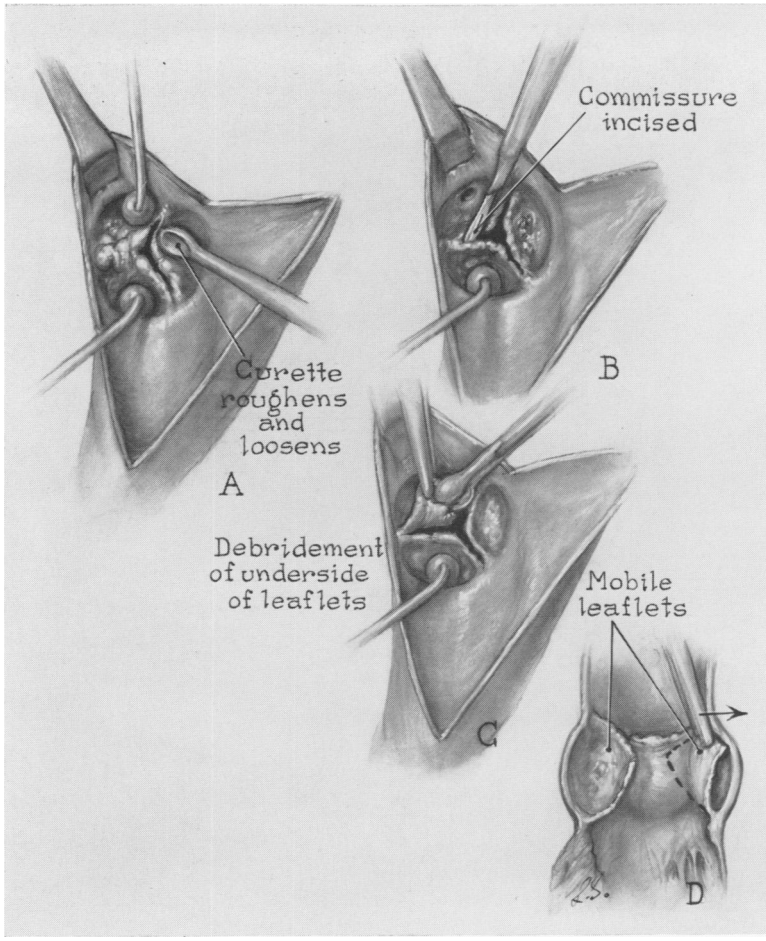

FIG. 9. Flat plaques of calcium are often loosened with a curette and the commissures are incised only after the upper surfaces of the leaflets have been debrided. finally, additional mobility is obtained by removal of calcium from the undersurfaces of the leaflets.

debridement may be accomplished with relative ease.

In certain patients the calcific deposits extend through the substance of the valve leaflets and attempts at effective debridement will result in fenestration at the base of a leaflet or loss of substance along its free margin. Under these circumstances, excision and prosthetic replacement of a leaflet, or the entire valve is necessary. Often a truly tricuspid valve is functionally a bicuspid one, as shown in Figure 10. In this case, two shrunken and deformed leaflets may be replaced with a single prosthetic one, rendering the valve actually bicuspid. In other patients total replacement of a congenitally bicuspid valve has been found necessary (Fig. 11). Here, only two sinuses of Valsalva are present and the valve is usually reconstituted with two prosthetic leaflets of equal size (Fig. 12). Individual leaflets of knitted Teflon fabric, as described by Bahnson,[1] are utilized for partial valve replacement or total replacement of congenitally bicuspid valves. When total replacement of a tricuspid valve is found to be necessary, the Teflon prosthesis designed by Muller and Littlefield[12] is most often utilized (Fig. 13–15). If the sizes of the sinuses of Valsalva are grossly discrepant, three individual Bahnson leaflets may be used.* The correct size of a prosthetic leaflet, or Muller valve is determined

* The Muller valve and Bahnson leaflets are manufactured by the U. S. Catheter and Instrument Company, Glens Falls, New York.

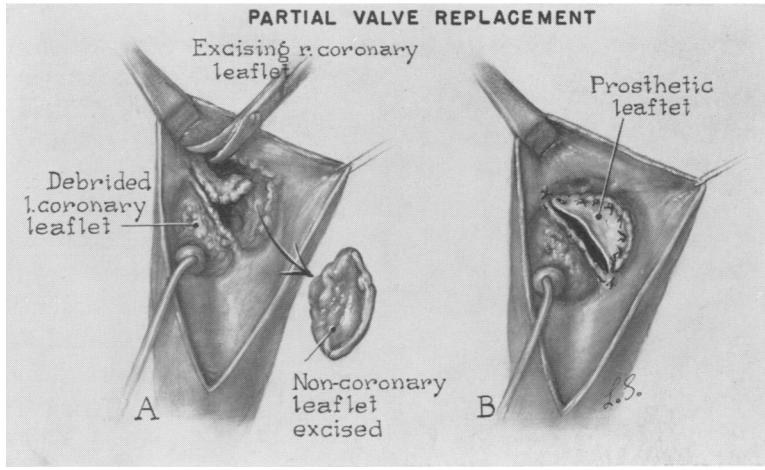

FIG. 10. Occasionally, in the *functionally bicuspid* valve, two irreparable leaflets may be replaced with a single prosthetic one as shown.

by measurement of the systolic diameter of the aorta before bypass and checked by direct measurements of the valve after the aorta has been opened. A valve, or leaflet 2 to 3 mm. larger than the indicated size is usually selected.

After repair or replacement of the valve, the left ventricle is thoroughly lavaged to remove any calcific, or thrombotic material which may have fallen into it (Fig. 16). The lowermost portion of the aortotomy is then closed with a continuous suture as the patient's temperature is restored to normal. The aspirating pump attached to the left ventricular drain is stopped, allowing the heart to fill with blood, and the remaining opening in the aorta is clamped. As the occluding clamp on the ascending aorta is released, the left ventricular drainage cannula is again opened, if necessary, to prevent distention of the heart (Fig. 17). A direct assessment of the competency of the valve may be made also at this time by measurement of the flow from the cannula when it is opened to the atmosphere.

Results of Operation

Among the 52 patients described, debridement and commissurotomy were carried out in 26, total valve replacement in 22, and partial valve replacement in four. There were nine operative deaths. Two followed incision and debridement; one of these patients died in congestive failure on the second postoperative day. The other developed ventricular fibrillation during the thoracotomy and was cannulated while the heart was being massaged. Although

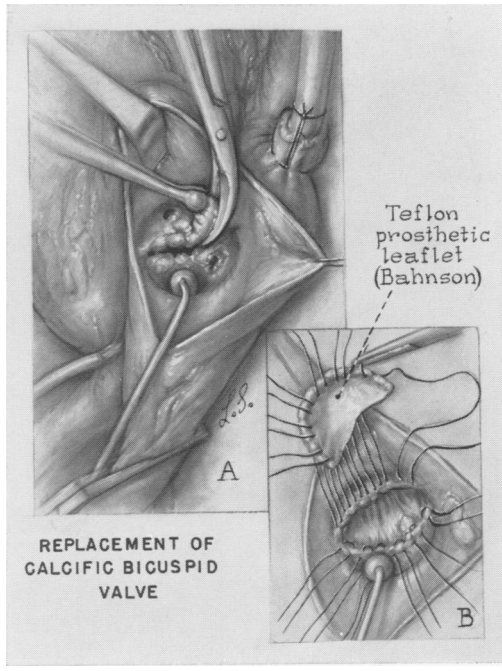

FIG. 11. When replacement of a calcified congenitally bicuspid valve is necessary it is accomplished with two Bahnson leaflets. After excision of the leaflets a series of mattress sutures is placed in the valve ring which is composed of only two sinuses of Valsalva.

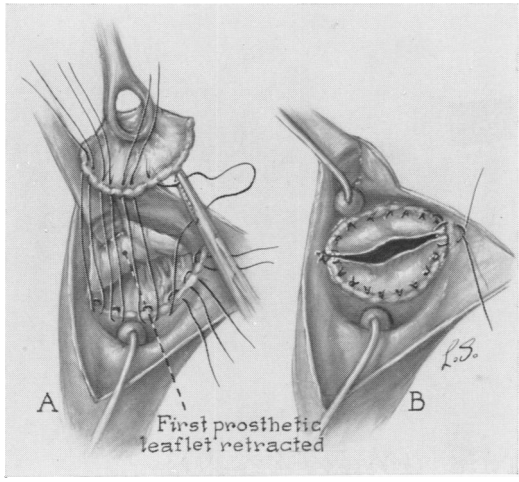

FIG. 12. The sutures are passed through the base of each prosthetic leaflet and tied above. The two commissures are anchored to each other.

the operation was completed, effective cardiac action could never be restored. One patient, who had had partial valve replacement, died of unrecognized bleeding from the left ventricular stab wound. Six patients died in the hospital after total valve replacement. In one, severe aortic regurgitation resulted from faulty insertion of the prosthesis. In three patients the valve replacement itself was satisfactory, but uncontrollable bleeding from a friable and diseased aorta led to death in the operating room. Two of these patients had developed ventricular fibrillation during the thoracotomy and were cannulated while the heart was being massaged. Another patient, a chronic asthmatic, died

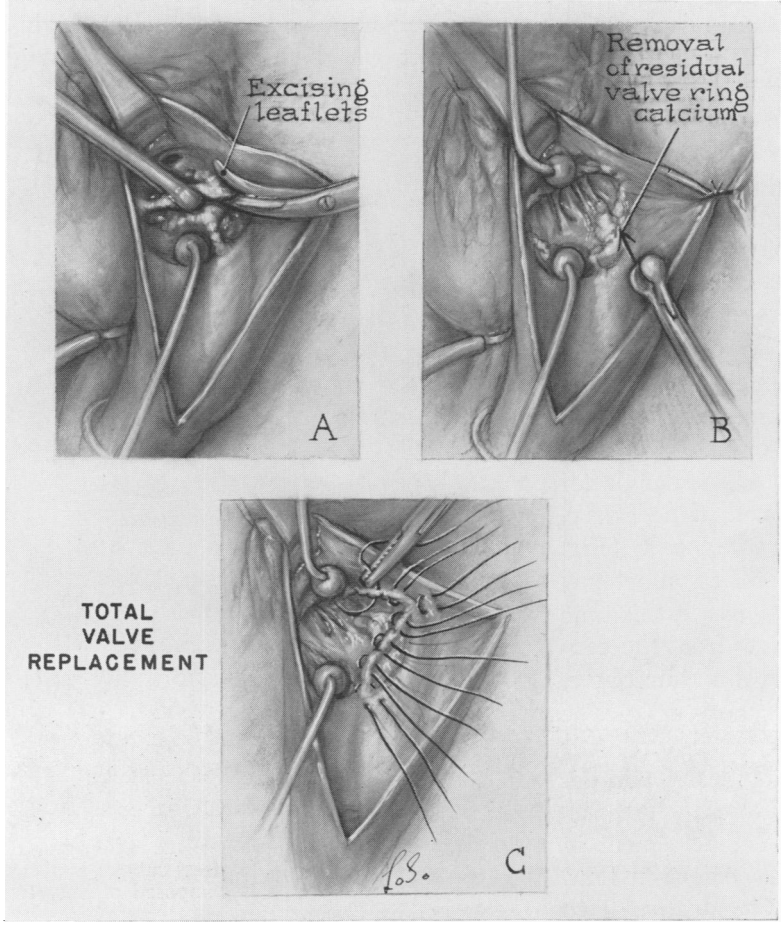

FIG. 13. Total replacement of a tricuspid valve is begun by excision of the leaflets. After the removal of residual calcium from the valve ring, 15 to 18 mattress sutures of 3–0 silk are placed in it as shown.

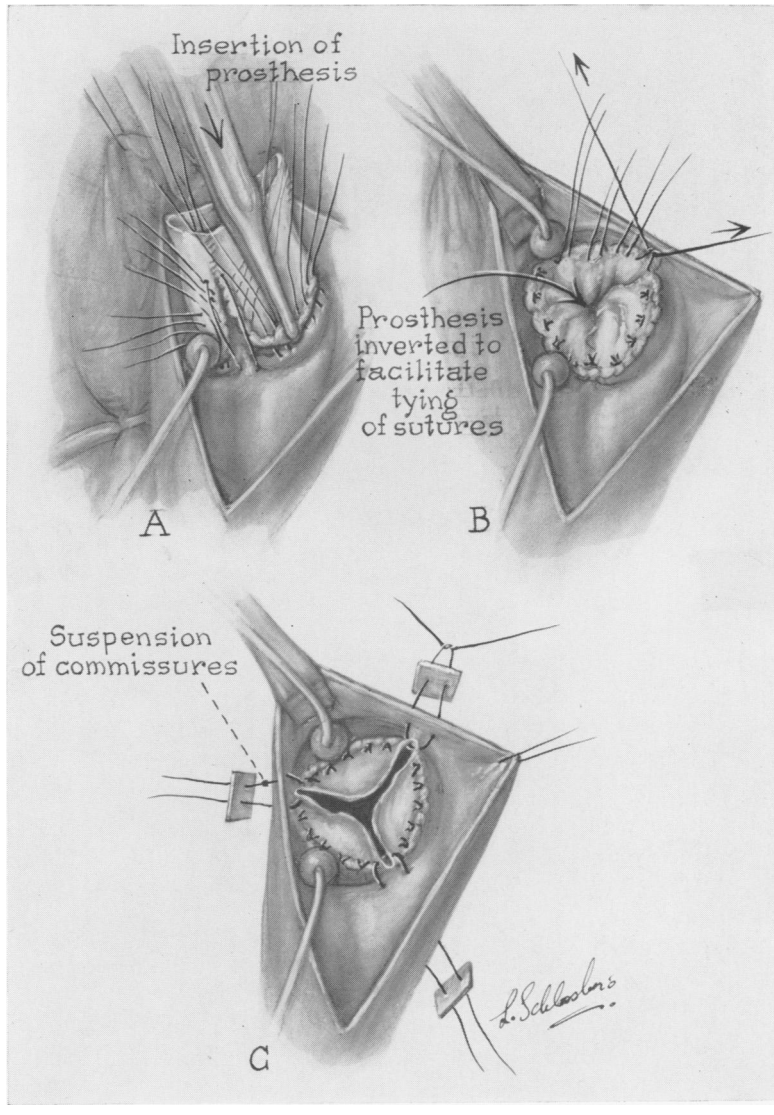

FIG. 15. The valve is then drawn into position and the sutures tied within the sinuses. Each commissures of the prosthetic valve is then anchored to the aortic wall with two heavy sutures tied externally over Teflon pledgets.

two weeks after operation in status asthmaticus. The final patient, who had severe pulmonary hypertension, developed right heart failure and died after a pulmonary embolus one month postoperatively.

Four patients have died at intervals after their discharge from the Clinical Center. Two had debridement and commissurotomy; one of them died after three months

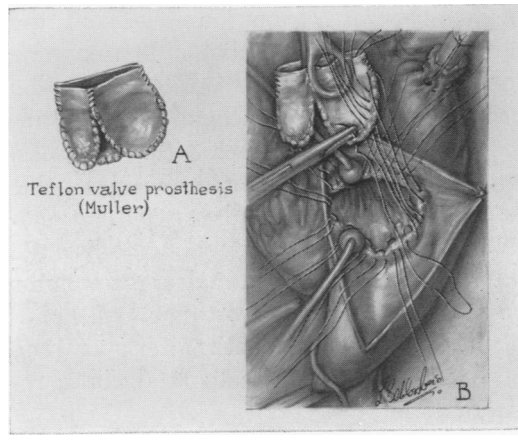

FIG. 14. The tricuspid Teflon valve (Muller) is shown in A. The sutures are passed through its selvedged sewing margin from below upward.

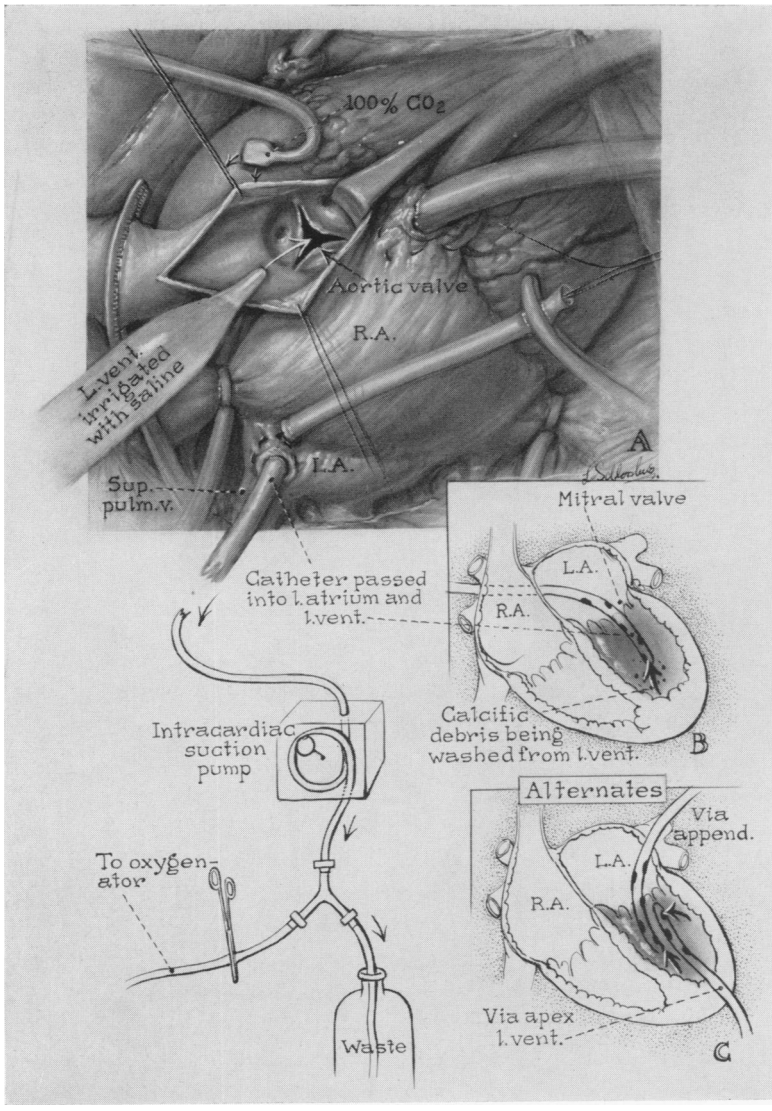

FIG. 16. Following repair or replacement of the valve, calcific debris is washed from the ventricle by quantities of irrigating solution poured into it and aspirated by the coronary return pump into a waste vessel. (Reproduced with permission of the publisher from Morrow, A. G. and Austen, W. G., Surg. Gynec. & Obst., **114**:634, 1962.)

of homologous serum jaundice, and the other of acute myocardial infarction nine months postoperatively. One patient, who had had partial replacement, died suddenly, of unknown causes, after six weeks. In the remaining patient a bicuspid valve had been replaced, and the patient evidenced striking clinical and hemodynamic improvement when studied eight months later. One of the two prosthetic leaflets became detached nine months after operation, however, and gave rise to fatal aortic regurgitation.

Significant postoperative complications occurred in seven of the surviving patients; postoperative bleeding necessitated the evacuation of hemothorax in four patients, and three others developed homologous serum jaundice, but made uneventful recoveries. In no patient of the entire group was there evidence of early or late arterial embolization.

All of the surviving patients have evidenced striking symptomatic improvement and none has experienced anginal pain or syncope. A number of them describe vary-

ing degrees of exertional dyspnea, but this symptom is less troublesome than before operation in all. No patient manifested a diastolic murmur for the first time postoperatively and diastolic murmurs were no longer heard in 12 patients in whom they had been present preoperatively.

Postoperative Hemodynamic Assessments

As described above, the severity of aortic stenosis was assessed before operation by means of left heart catheterization. At the conclusion of the operation, before the thoracotomy was closed, the left ventricular and radial artery pressure were again measured simultaneously to provide an immediate assessment of the operative result. Such intra-operative records were made in 47 patients, and the preoperative and operative pressure gradients may be compared in Figure 1. In 46 of the 47 patients a substantial immediate reduction in the peak systolic gradient was apparent; in only four instances did the gradient measured at this time exceed 20 mm. Hg, and it was totally abolished in 20 patients.

Detailed postoperative hemodynamic assessment was carried out in 39 patients. These studies were made at intervals of two weeks to one year after operation, and the average time between operation and

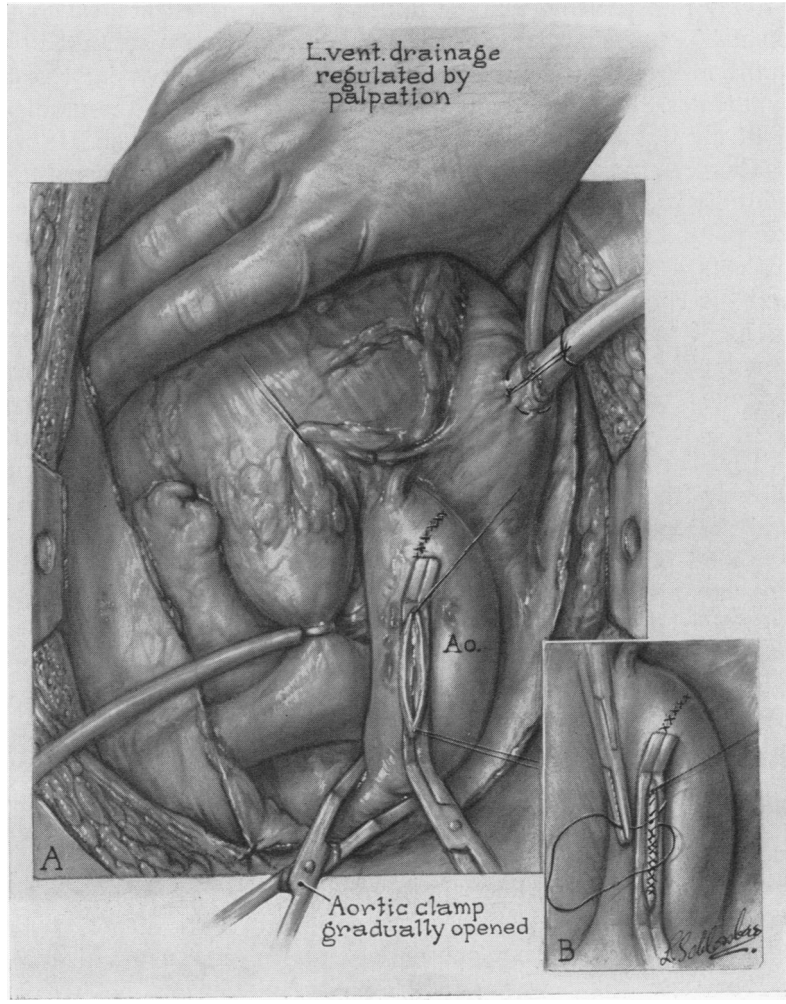

FIG. 17. Air is evacuated from the heart and the upper portion of the aortotomy is closed with a clamp. As the occluding clamp on the ascending aorta is released the ventricle is palpated and distension of the heart is prevented by regulation of the flow from the drainage cannula.

postoperative study was five months. The left ventricular pressure was determined postoperatively in every patient by means of percutaneous puncture of this chamber.

The systolic pressure gradients recorded at postoperative catheterization are compared to the preoperative and operative ones in Figure 1. A reduction in the gradient, as noted at operation, was confirmed at late postoperative study in every patient. In general, however, the gradients measured late were higher than those obtained in the operating room. In 21 patients the peak systolic gradient was 20 mm. Hg or less and in 14 additional ones a less satisfactory but acceptable result was indicated by gradients of 24 to 42 mm. Hg. In only four patients was the residual gradient 50 mm. Hg, or more, the level generally utilized in the selection of operative candidates. The average gradient postoperatively was 20 mm. Hg.

The changes in left ventricular end-diastolic pressure observed after operation are plotted in Figure 2. In the majority of patients a significant decrease was noted and the end-diastolic pressure was normal in 13 of the 18 patients in whom it was abnormally high prior to operation. The average end-diastolic pressure postoperatively was 10 mm. Hg.

The diastolic arterial pressures recorded directly from the brachial artery both pre- and postoperatively are plotted in Figure 3. In 33 of the 39 patients the diastolic pressure recorded at postoperative catheterization was higher than that measured before operation. Aortic regurgitation was no longer of hemodynamic significance in 10 of the 12 patients who had had low diastolic arterial pressures and wide pulse pressures preoperatively.

The cardiac index was higher postoperatively in 29 of the 36 patients, unchanged in three, and lower in the remaining seven (Fig. 4). The index was normal after operation in all but one patient, and the average value was 3.4 L./min./M.^{2}. The effective area of the aortic valve was increased by operation in every patient in whom it was measured and the comparative values are plotted in Figure 5.

An analysis of the electrocardiograms, recorded preoperatively and two to 12 months postoperatively, was made in 30 patients. In 17 of them the amplitude of the R wave in lead V_5 was found to have decreased significantly (5 mm. or more), and the average reduction in amplitude was 13 mm. In these 17 patients the average reduction in the systolic pressure gradient between the left ventricle and brachial artery was 59 mm. Hg. In 11 other patients the amplitude of the R wave was essentially unchanged although a similar reduction in gradient (average 55 mm. Hg) was achieved. In the two remaining patients the R wave increased by 5 and 17 mm. although the gradients were reduced by 108 and 31 mm. Hg respectively.

There was also poor correlation between the change in the size of the heart, as determined by x-ray, and the hemodynamic result. Appreciable reduction in over-all heart size was apparent in 15 patients, and in them the pressure gradient had been reduced by an average of 59 mm. Hg. In 13 patients the heart size was unchanged although an average reduction in systolic gradient of 62 mm. Hg was apparent in their postoperative assessment. Two patients evidenced increases in heart size postoperatively although the hemodynamic result in each was satisfactory.

Comment

All physicians who have the responsibility of managing patients with calcific aortic stenosis have come to recognize the frequency with which sudden death may occur as a result of this lesion. In addition to the 52 patients described above, seven other symptomatic patients with calcific aortic stenosis underwent hemodynamic assessment and were scheduled for operation during the two year period embraced by

this report. Three of these patients died in the hospital and another at home before the necessary arrangements for operation could be made. Another patient suffered a massive, but not fatal, myocardial infarction during this time. The other two patients were brought to the operating room where one of them developed irreversible ventricular fibrillation with the induction of anesthesia. The other fibrillated during the thoracotomy, and was successfully resuscitated only after more than one hour of cardiac massage; although the contemplated valvular repair was not carried out, the patient survives.

The fate of these seven patients emphasizes the ominous outlook for the symptomatic patient who is denied operation and indicates the rationale for the policy of selection of operative candidates which has been adopted in this clinic: *Operation is always recommended to the patient with aortic stenosis when he is symptomatic and the presence of significant obstruction can be proved hemodynamically.* Although the risk of operative correction may be increased when advanced age, gross cardiomegaly, persistent left ventricular failure, pulmonary hypertension, or coronary artery disease is present, a significant number of patients with these unfavorable signs have survived operation and have evidenced striking improvement. We have also come to believe that the treatment of the patient with calcific aortic stenosis should not be considered an elective operation, but one which must be carried out at the earliest possible time after the decision as to operation has been made and the patient has derived maximal benefit from preoperative preparation.

The above comments concerning patient selection are, of course, reflected in the high immediate mortality, 17 per cent, among the 52 patients operated upon. Five of the nine early deaths resulted from technical problems while the others were, in large measure, attributable to the patients' cardiac disease. The two late deaths from myocardial infarction and jaundice seem unrelated to the status of the aortic valve. The death of the patient in whom a prosthetic leaflet became detached must be attributed to faulty surgical technique since the leaflet itself was found to be intact. The total mortality and morbidity among the present patients are comparable to those experienced by McGoon in the exceptionally well documented series of patients which he has recently reported.[9]

The comparative hemodynamic studies described above indicate that satisfactory relief of outflow obstruction can be achieved in the vast majority of patients with calcific aortic stenosis without the creation of significant valvular incompetence. In the present series, valves amenable to debridement and commissurotomy were encountered in 26 of 52 patients. Twenty-three of these patients were studied postoperatively, and the average residual systolic gradient was found to be 17 mm. Hg. and in 20 of them the residual gradient was less than 30 mm. Hg. Fourteen patients with total prosthetic replacement of either bicuspid, or tricuspid valves were studied postoperatively and residual gradients of 2 to 56 mm. Hg were found to be present; the average value was 25 mm. Hg. In the two patients in whom a single leaflet was replaced gradients of 0 and 66 mm. Hg were found.

On the basis of these hemodynamic data, as well as the comparative operative risks, it would appear that debridement and commissurotomy is preferable to valve replacement whenever this technic is applicable. On the other hand, the 22 patients who had total valve replacement represent the authors' initial experience with this method, and in patients operated upon subsequently more acceptable clinical as well as hemodynamic results have been obtained. The mechanisms responsible for the residual pressure gradients following total valve replacement are not yet ap-

parent. Those observed immediately after the insertion of the valve may result from a valve of improper size or one inserted incorrectly. In the first total replacements for example, the commissures of the prosthetic valve were closed by sutures for 1 to 2 mm., a technic since abandoned. The gradients noted at postoperative study may reflect only higher cardiac output, but may also be attributable to stiffening of the uncoated Teflon fabric of which all the prosthetic valves or leaflets were fabricated. The Muller prosthetic valve presently used is coated with a Teflon dispersion and the possible advantage of this coated fabric over the plain one must await the test of time. Alternatively, the immediate and complete relief of valvular obstruction which usually follows total valve replacement may allow the hypertrophic outflow tract of the left ventricle to become the site of secondary subvalvular obstruction. If such hypertrophic stenosis occurs, it will, of course, resolve as the ventricular hypertrophy regresses. This sequence of events has been previously documented in patients with congenital aortic stenosis [10] and was also proved to occur in one patient of the present series. This patient, a 61-year-old woman, had no significant aortic regurgitation and a gradient of 155 mm. Hg across the aortic valve when her cardiac index was 2.8 L./min./M.^{2}. At the operating table, immediately following total valve replacement, no gradient was evident, but when she was studied three weeks postoperatively a gradient of 112 mm. Hg was apparent with a cardiac index of 2.08 L./min./M.^{2}. At this time the contour of her brachial artery pulse showed the rapid upstroke characteristic of hypertrophic subaortic stenosis. Significant resolution of obstructive ventricular hypertrophy was indicated by another study three months later when the gradient was found to be only 22 mm. Hg and the cardiac index 3.6 L./min./M.^{2}.

It must be emphasized that the conclusions concerning the hemodynamic benefits derived by these patients are based on a relatively short period of observation. One wonders what may be the ultimate fate of the various prosthetic materials which are utilized in the construction of prosthetic aortic valves. The permeable fabrics, such as knitted Teflon, presumably allow tissue ingrowth. Will this prove to be a desirable, or undesirable characteristic? Will such fabrics stiffen and lead to recurrence of stenosis? Will the impermeable prosthetics, such as silicone rubber, promote a similar, or a different reaction? Will calcification of the prosthetic valve occur with time? Similar questions must also be raised concerning the valve which has been debrided. It is seldom that entirely normal function can be restored by debridement and turbulent flow across the valve certainly persists. Will this lead to recurrence of calcification and after what period of time? The answers to all of these questions will be provided only by careful and continuing hemodynamic studies of patients who have been treated by the various methods and future plans of management will be dictated by the results which are obtained.

Summary

Fifty-two patients are described in whom open operations for the relief of calcific aortic stenosis were carried out. Detailed hemodynamic evaluation was performed in every patient preoperatively and in each surviving patient afterward. In 26 patients the calcified valve was found to be amenable to debridement and commissurotomy while in the remainder partial, or total valve replacement was found to be necessary. These operative methods are described; there were nine operative and four late deaths.

The experience indicates that satisfactory relief of outflow obstruction can be achieved in the vast majority of patients without the creation of valvular incompe-

tence. The comparative hemodynamic assessments, as well as the operative risks, indicate that at the present time debridement and commissurotomy appears to be the surgical procedure of choice when it is found to be applicable. In many patients, however, function can be restored only by means of valve replacement, and questions are posed concerning the ultimate fate of the prosthetic materials presently utilized for this purpose.

Both debridement and valve replacement provide relief of symptoms, and it is hoped that they will be found to prolong life in the symptomatic patient with aortic stenosis. The question as to which operative technic will ultimately prove to be the most satisfactory one will only be answered by the results of continuing hemodynamic assessments.

Addendum

Since this manuscript was submitted for publication further follow up has been possible in the 15 surviving patients in whom total valve replacement with the Muller valve was carried out. Severe aortic regurgitation has appeared in six patients. One of these six patients died before re-operation and the valve was found detached along two of the sinuses. In the other five, re-operation has been carried out and the teflon valve has been found perforated or torn. An additional patient died with satisfactory function of his valve apparently from arrhythmia.

This experience indicates that teflon fabric is unsatisfactory for reconstruction of the aortic valve. Since February 1963 the Starr-Edwards prosthesis has been utilized in this Clinic for aortic valve replacement in 32 patients.

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