Obstructive Lesions of the Left Ventricular Outflow Tract

Surgical Treatment

By Denton A. Cooley, M.D., Arthur C. Beall, Jr., M.D., Grady L. Hallman, M.D., and Donald L. Bricker, M.D.

For years successful surgical treatment of obstructive lesions of the left ventricular outflow tract lagged behind the often brilliant results obtained for more than 15 years in correction of inflow obstruction to the left ventricle at the mitral valve. Closed operations for relief of aortic valve obstruction gave early promise, but results were unpredictable, relief was usually temporary, and operative mortality was formidable. Open-heart procedures, first performed with hypothermia, and now with temporary cardiopulmonary bypass, have permitted accurate appraisal of the pathologic anatomy in obstructive lesions of the left ventricular outflow tract and have allowed precise correction under direct vision. Introduction of and progressive improvements in aortic valve prostheses have extended further the scope of operations in this area.

Indeed, at present with improved techniques of diagnosis by left heart catheterization and selective angiography, the left ventricular outflow tract has become a most fertile field for the cardiac surgeon.

The purpose of this paper is to review our experience with open surgical treatment of obstructive lesions of the left ventricular outflow tract between 1956 and 1964 in 296 patients with supravalvular, valvular, or subvalvular aortic stenosis. Congenital outflow obstructions include 105 patients with supravalvular, valvular, or subvalvular lesions, whereas the acquired category includes 191 patients with valvular stenosis. Thus, a total of 296 patients forms the basis for this report.

Method of Operation

Operation for all types of obstructive lesions of the left ventricular outflow tract are performed through a median sternotomy incision. Gravity venous outflow to the pump oxygenator is established by insertion of cannulae into the superior and inferior venae cavae through the right atrium. Arterial return is effected by proximal cannulation of a common femoral artery. The ascending aorta is cross-clamped proximal to the origin of the innominate artery after bypass begins. A small cannula is inserted in the apex of the left ventricle and secured with a purse-string suture and tourniquet device. During bypass an operative field unobscured by blood is maintained by gentle suction to this cannula. The apical stab wound in the ventricle also provides a means for removing any residual air at the conclusion of bypass.

For periods of bypass exceeding 15 to 20 minutes, particularly in adults with acquired disease, temporary coronary artery perfusion is utilized at a rate of 150 to 250 cm$^3$ per minute with control of rate of flow by monitoring of pressure in the line. In some instances both left and right coronary arteries are perfused, while in others only the left is cannulated. When an aortotomy is required for access to the obstructing lesion in mem-
The valve is primed with water. The patient's body temperature has been maintained as near normal as possible. This simplified technic of temporary cardiopulmonary bypass has been described in detail previously.1-3

**Congenital Lesions**

**Supravalvular Aortic Stenosis**

Supravalvular stenosis is a rare congenital lesion involving the aorta just above the annulus. Anatomically, it resembles a coarctation of the proximal ascending aorta (fig. 1a). The valve leaflets may be normal, but in some instances are thickened and deformed. Occasionally there may be partial obstruction to the coronary ostia. Varying degrees of intimal hypertrophy may be associated with the supravalvular stenosis (fig. 2a). Williams, Barratt-Boyes, and Lowe4 were the first to describe a characteristic facies and mental retardation, which are noted in some patients with supravalvular stenosis although the stenosis may occur as an isolated defect. Surgical repair originally was reported by McGoon et al.,5 and by Starr and associates.6

Five patients with isolated supravalvular aortic stenosis have undergone operation since 1956 (table 1). Two were 6 years old and the remaining three were 5, 13, and 15 years of age. Two patients had the characteristic facies and mental retardation occasionally seen with this lesion. One 6-year-old patient early in the series was treated by resection of the stenotic area and primary end-to-end aortic anastomosis. He died suddenly of cardiac arrest 20 hours after operation, and postmortem examination showed marked intimal thickening in the proximal portion of both coronary arteries. The only other death in this group (table 2) occurred in a 6-year-old girl whose obstruction was relieved by incision of the stenotic area and application of a Teflon patch. She remained hypotensive and died of sudden cardiac arrest 6 hours after operation. The remaining three patients all survived and had relief of stenosis after the application of a patch to an incision through the constricted

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Circulation, Volume XXXI, April 1965
area. One of these required an extensive endarterectomy of the ascending aorta and the proximal portions of both the innominate and carotid arteries. During the early postoperative period this patient had headaches and mental confusion suggesting cerebral edema and possibly cerebral ecchymoses due to increased blood flow, but recovery eventually ensued.

Surgical Technic

After institution of temporary cardiopulmonary bypass the aorta is clamped just proximal to the innominate artery and a vertical incision is made along its right posterolateral aspect. This incision is extended through the constricted area down into the sinus of the noncoronary aortic cusp (fig. 1a). If the intima is excessively thick in the region of obstruction, it is removed by endarterectomy provided that this is feasible (fig. 2). An elliptical patch of Teflon or woven Dacron then is sutured into the vertical aortic incision to widen the area of previous constriction (figs. 1b and 2b).

Valvular Aortic Stenosis

Congenital aortic valvular stenosis first was relieved by valvulotomy with closed technics. Hypothermia next permitted surgeons to perform this procedure under direct vision. Cardiopulmonary bypass recently has allowed a prolonged period during which the aortic root can be exposed.

Sixty-nine patients have undergone valvulotomy for congenital aortic stenosis since 1956 (table 1). This group includes only those patients without secondary changes of extensive fibrosis and calcification, and all were treated by simple incision of fused commissures. Fourteen were less than 1 year of age, 16 were between 1 and 10 years old, 34 were between 10 and 20 years, four were between 20 and 30 years, and one patient was 51 years old. There were four deaths in this group (tables 2 and 3). Three were infants ages 1, 3, and 5 months with severe cardiac failure, requiring emergency operation. Two of these procedures were performed shortly after cardiac massage and resuscitation for cardiac arrest in the catheterization laboratory.

Surgical Technic

Caval occlusion at normothermia, frequently with partial pump-oxygenator bypass from the right atrium to the femoral artery during the recovery period following release of caval tourniquets, is utilized in small infants less than 1 year of age. In older patients temporary cardiopulmonary bypass is employed without coronary perfusion. The most common finding is a bicuspid valve with a small eccentric opening at one extremity of a fused commissure (fig. 3a). Satisfactory relief of obstruction can be obtained by incising the fused commissure to within 1 mm. of the an-

Table 1

<table>
<thead>
<tr>
<th>Site of obstruction</th>
<th>No. patients</th>
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<tbody>
<tr>
<td>Supravalvular</td>
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<tr>
<td>Valvular</td>
<td>69</td>
</tr>
<tr>
<td>Subvalvular</td>
<td>25</td>
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<tr>
<td>Membranous</td>
<td>21</td>
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<tr>
<td>Muscular</td>
<td>4</td>
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<tr>
<td>Combined</td>
<td>6</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>105</strong></td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th>Site of obstruction</th>
<th>No. patients</th>
<th>No. deaths</th>
<th>Per cent mortality</th>
</tr>
</thead>
<tbody>
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<td>40</td>
</tr>
<tr>
<td>Valvular</td>
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<td>6</td>
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<tr>
<td>Subvalvular</td>
<td>25</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Membranous</td>
<td>21</td>
<td>1</td>
<td>17</td>
</tr>
<tr>
<td>Muscular</td>
<td>4</td>
<td></td>
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</tr>
<tr>
<td>Combined</td>
<td>6</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>105</strong></td>
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Circulation, Volume XXXI, April 1965
Table 3

<table>
<thead>
<tr>
<th>Age in years</th>
<th>No. patients</th>
<th>Deaths</th>
<th>Per cent mortality</th>
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<td>3</td>
<td>20</td>
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<td>1-10</td>
<td>31</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>10-20</td>
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<td>0</td>
</tr>
<tr>
<td>20-30</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>30-40</td>
<td>2</td>
<td>0</td>
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<td>50-60</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Totals</td>
<td>105</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

nulus (fig. 3a). The raphe representing the rudimentary third commissure, if present, is not incised for fear of producing aortic insufficiency. Rarely, a tricuspid valve with a small central opening is present, and three incisions can be made in the fused commissures stopping 1 or 2 mm. short of the annulus to avoid unhinging the leaflets and producing insufficiency (fig. 3b).

**Subvalvular Aortic Stenosis**

Obstruction below the level of the aortic valve may occur in the form of a fibrous membrane or as a hypertrophied mass of muscle:

Membranous subaortic stenosis has been well understood and adequately treated for a number of years. A fibromuscular diaphragm lies below an aortic valve that is usually normal (fig. 4a). Twenty-one patients with isolated membranous subaortic stenosis were treated with satisfactory results (table 1). There were no deaths in this group.

**Surgical Technic**

Temporary cardiopulmonary bypass without coronary perfusion is utilized. A transverse aortotomy is made and the valve leaflets are retracted. The fibrous membrane (fig. 5) is excised with knife or scissors with avoidance of the medial leaflet of the mitral valve on the left (fig. 4b).

Muscular subaortic stenosis has not been so clearly defined as has membranous stenosis,
and the best form of surgical treatment has yet to be elucidated. Patients with this lesion have hypertrophy of left ventricular muscle, primarily involving the upper septum and producing obstruction to left ventricular outflow (fig. 6). Brock\textsuperscript{10} is credited with first focusing attention on this lesion, and Braunwald and his associates\textsuperscript{11} delineated the diagnostic maneuvers for the detection and evaluation of muscular subaortic stenosis. Successful surgical treatment includes closed transventricular instrumented dilatation,\textsuperscript{12} open transaortic simple myotomy,\textsuperscript{13-15} and excision of obstructing muscle mass through the left atrium\textsuperscript{16, 17} or left ventricle.\textsuperscript{18}

Four patients with muscular subaortic stenosis have been operated upon in this center with no deaths (table 1). Three different technics have been utilized. Early in the series one 12-year-old girl had dilatation of the subaortic muscular stenosis with insufficient relief of the left ventricular to aortic gradient. More recently, a 23-year-old woman underwent transaortic wire-loop cautery excision of the obstructing muscle with dramatic results. The last two patients, a 48-year-old man and a 34-year-old woman were operated upon through a left ventriculotomy, and muscle (fig. 7) from the ventricular septum and the free wall of the left ventricle was excised with effective relief of obstruction. In the last three successful operations the electrocardiogram revealed left bundle-branch block after operation, and conduction tissue was noted on the muscle excised from the subvalvular zone.

**Surgical Technic**

After institution of temporary cardiopulmonary bypass the aorta is cross-clamped, but
not opened. A vertical left ventriculotomy is made parallel to the anterior descending branch of the left coronary artery, and a knife is used to excise obstructing muscle from the septum and the free wall of the left ventricle (fig. 8). The ventricular incision then is closed with continuous suture supplemented by several interrupted sutures.

**Combined Lesions**

Six patients had various combinations of congenital supravalvular, valvular, and subvalvular aortic obstruction (table 1). Two patients had supravalvular and valvular stenosis and one had the characteristic facies and mental retardation mentioned previously. Operative technics were similar to those utilized for stenotic lesions occurring as isolated anomalies. There was one death in this group (table 2). A 6-year-old girl died suddenly shortly after return to the recovery room following aortic valvulotomy and excision of a subaortic fibrous membrane. Autopsy failed to reveal the cause of death.

**Acquired Valvular Aortic Stenosis**

For many years, surgical therapy of acquired stenosis of the aortic valve was limited by the state of the diseased valve. These valves, unlike those with congenital stenosis, usually are not amenable to satisfactory plastic correction. Commissurotomy and debridement, even with use of currently available sophisticated instruments, frequently fail to produce adequate mobilization and competent closure of the leaflets. Furthermore, in a high percentage of cases these operations soon are followed by re-stenosis with need for subsequent surgical intervention. These facts have led us to believe that total prosthetic valve replacement is the only logical approach to acquired aortic valve stenosis.

Beginning in 1956 open commissurotomy
and debridement with temporary cardiopulmonary bypass were employed in this center for acquired stenosis of the aortic valve. Such a procedure was carried out in 95 cases with an operative mortality rate of 22 per cent (table 4). Subsequently, nine operations were performed in which one or more cusps were excised and replaced with leaflets made of compressed Ivalon, Teflon, or Dacron-reinforced Silastic. Original enthusiasm with such prostheses soon was dampened by early appearance of valvular incompetence, development of fatigue and tearing of the leaflets, or by recurrence of stenosis associated with fibrous tissue fixation of the leaflets. Development of caged-ball valves in which movement of a Silastic ball eliminated the need for material flexion at last provided an effective means for prosthetic replacement of the aortic valve. Since December 1962, we have used ball-valve replacement in the surgical treatment of all patients with acquired valve disease. The 87 cases with calcific aortic stenosis will be analyzed in some detail.

During this period of almost 2 years 87 patients have undergone prosthetic ball-valve replacement for acquired aortic valve stenosis (fig. 9). An additional 79 patients with aortic valve insufficiency have had ball-valve prostheses inserted during this same period, but these patients are not considered in this presentation. The majority of patients with aortic valve stenosis were in the fifth to seventh decades of life (table 5). Most of the lesions were known to be rheumatic in origin, and the etiology of a number of others probably was similar, even though a rheumatic history could not be obtained (table 6). In seven patients the original aortic valve lesion was thought to be congenital, but superimposed acquired changes necessitated valve replacement, for which reason these patients are included in the acquired category.

Starr-Edwards prostheses and Magovern sutureless prostheses were used in approximately similar numbers of instances, and surgical techniques for these operations are described in detail elsewhere. Cumulative results are summarized in table 7, which includes all deaths from all causes whether or not the death was related to aortic valve replacement. There were six hospital deaths, an
operative mortality rate of 7 per cent, and seven late deaths, resulting in an over-all mortality rate of 15 per cent. Most of the operative deaths were related to concomitant coronary artery disease as manifest by arrhythmias or myocardial infarction (table 8). The majority of late deaths were associated with prosthetic complications, thromboembolism causing death of one patient with a Starr-Edwards prosthesis, and one with a Magovern prosthesis. One early and three late deaths were related to prosthetic detachment, occurring once with a Starr-Edwards prosthesis and three times with Magovern prostheses. Due to this disparity in incidence of prosthetic detachment between the two types of valves, and a similar finding in patients undergoing prosthetic replacement for aortic valve insufficiency, our present tendency is toward use of Starr-Edwards prostheses in most patients.

Among 74 surviving patients, the majority are asymptomatic and have returned to gainful employment, unless previously retired due to advanced age. Most no longer require special diets or diuretics, and a number have discontinued use of digitalis preparations. As might be expected in patients in this age group, a few are incapacitated by manifestations of atherosclerosis and one patient by what was probably a cerebral embolus from the prosthesis. Over-all, the results have been most gratifying in view of the grave prognosis in these patients once they become symptomatic.

Discussion

In management of patients with congenital obstructive lesions of the left ventricular outflow tract, selection of candidates for surgery depends upon symptoms, pressure gradient across the stenotic area, and the nature of the altered anatomy as determined by angiocardiography. In most patients whose systolic pressure gradient across the stenotic region is less than 50 mm Hg operation is not recommended. Patients with pressure gradients greater than 50 mm Hg are accepted for surgery, depending on the severity of symptoms. In children with congenital stenosis of the aortic valve or supravalvular region, the onset of exertional dyspnea or syncope makes operative correction more urgent. Congenital aortic valvular stenosis may cause severe and intractable cardiac failure during the first year of life, and under these circumstances aortic valvulotomy will be necessary, frequently on an emergency basis.23, 24

Much of the controversy concerning muscular subaortic stenosis should be resolved by data in a recent report by Morrow, Lambrew, and Braunwald.25 On the basis of operative experience in 10 patients these authors concluded that simple incision of the hypertrophied subaortic septal muscle is sufficient for relief of left ventricular outflow obstruction. The exact mechanism by which cardiomyotomy relieves the obstruction has not been determined, but production of left

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**Table 7**

Prosthetic Valve Replacement for Acquired Lesions—Cumulative Mortality

<table>
<thead>
<tr>
<th>No. patients</th>
<th>No. alive</th>
<th>Deaths</th>
<th>Late</th>
<th>Over-all mortality rate</th>
</tr>
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<tbody>
<tr>
<td>87</td>
<td>74</td>
<td>6</td>
<td>7</td>
<td>15%</td>
</tr>
</tbody>
</table>

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**Table 8**

Prosthetic Valve Replacement for Acquired Lesions—Causes of Death

<table>
<thead>
<tr>
<th>Early (Less than 30 days)</th>
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</tr>
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<tbody>
<tr>
<td>Arrhythmia</td>
<td>3</td>
</tr>
<tr>
<td>Myocardial infarction</td>
<td>2</td>
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<tr>
<td>Detached prosthesis</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Late (30 days or more)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Detached prosthesis</td>
<td>3</td>
</tr>
<tr>
<td>Thromboembolism</td>
<td>2</td>
</tr>
<tr>
<td>Myocardial infarction</td>
<td>1</td>
</tr>
<tr>
<td>Infection</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>7</td>
</tr>
</tbody>
</table>

Total: 13
bundle-branch block or the interruption of muscle bundles of abnormal contractility may be responsible for the beneficial effect.25

Among patients with acquired aortic valve stenosis, those in class I or II of cardiac function are not accepted for operation. All of the 87 cases described were in class III or IV of the New York Heart Association Classification. When long-term results of aortic ball-valve prostheses are available, perhaps operation will be indicated in class-II patients, but at present this policy does not appear justified.

Conversely, patients with aortic stenosis and class II functional capacity should not be allowed to reach a far-advanced state of myocardial deterioration before being offered benefits of prosthetic valve replacement. Operative mortality rate is significantly increased under these circumstances. Predilection of patients with acquired aortic valve stenosis to sudden death also must be remembered. When the patient shows evidence of cardiac decompensation or develops angina or syncope, prosthetic replacement of the aortic valve should be recommended strongly to the patient because of the known poor prognosis of medical therapy under these circumstances.

Many of the gratifying results seen in this series of patients probably are related to the technic of cardiopulmonary bypass employed. Recent evidence strongly suggests that many complications considered to be innate in open-heart surgery actually are due to the large quantities of homologous blood required to prime the pump-oxygenator.26 For this reason, since April 1962, we have employed the previously described method of temporary cardiopulmonary bypass with disposable plastic bubble oxygenators primed with 5 per cent dextrose in distilled water under normothermic conditions.3 Results of this technic in more than 1,000 clinical cases of all types have demonstrated its superiority over other methods of open-heart surgery in almost every respect.1 Not only are the patients awake much sooner after operation and hemostasis more easily obtained than when a homologous blood prime is used, but also the incidence of pulmonary and renal problems associated with such operations has been reduced substantially.2 Among 364 patients undergoing prosthetic replacement of the aortic, mitral, or tricuspid valves, only one death from renal insufficiency occurred.27

Summary

Currently available diagnostic methods and surgical technics now allow accurate assessment and effective correction of the majority of lesions producing obstruction of the left ventricular outflow tract. On the basis of anatomic location these lesions can be divided into supravalvular, valvular, and subvalvular stenosis, and valvular lesions further can be subdivided into congenital and acquired categories. Temporary cardiopulmonary bypass with a pump oxygenator provides sustained support of the circulation for operation, while surgical technics employed are selected on the basis of etiology and location of the lesion. Experience gained in operations on 296 patients with obstructive lesions of the left ventricular outflow tract since 1956 now has demonstrated that these operations usually can be performed with acceptable risk and with excellent functional results.

References


Circulation, Volume XXXI, April 1965

Selective Intelligence

It is better to know a few things and to have the right use of them than to know many things which you cannot use at all.—Seneca.
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Circulation. 1965;31:612-621
doi: 10.1161/01.CIR.31.4.612
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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