Progress in Cardiovascular Diseases

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Progress in CARDIOVASCULAR DISEASES

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Progress in CARDIAC SURGERY

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Editorial Introduction

THIS ISSUE introduces a new quarterly publication *Progress in Cardiovascular Disease*. It is intended to contribute to postgraduate education in this field. Because of the frequency and importance of cardiovascular disease and the widespread interest in advances in our knowledge of the subject this publication is designed to appeal to the general physician as well as to the cardiovascular specialist.

Although cardiovascular disease is regarded as a single specialty it has been subdivided into so many fields of knowledge that even the cardiovascular specialist finds difficulty in keeping abreast of the vast number and variety of published reports of experimental, laboratory and clinical studies. Frequently these reports in his own specialty are too complex or too technical for him to evaluate their quality or to understand their significance. *Progress in Cardiovascular Disease* will endeavor not only to bring to its readers a clearly understandable exposition of advances in our knowledge of cardiovascular disease but also to provide a *critical appraisal* of reported research, proper orientation of isolated investigations to the general knowledge and persistent problems in the field, and an evaluation of the significance and possible application of new work to bedside diagnosis and treatment.

A vast number of journals now compete for the physician's available reading time. In part this is an indication of the swift pace of advancement of medical knowledge and the increasing volume of reports of clinical and experimental observations seeking publication. But in large measure, also, the rise in the number of medical journals is due to an unsatisfied need on the part of the physician-reader who more than ever before desires and is required to be well informed. This publication will endeavor to contribute to satisfaction of that need.

The first issue is devoted to Progress in Cardiac Surgery in recognition of the rapid advances in this field and its recent growth in importance. Succeeding issues will contain symposia on Progress in Coronary Heart Disease, in Pulmonary Function and Cor Pulmonale and in Diagnostic Methods. Thereafter the choice of teaching device for subject presentation and the choice of subject will be determined exclusively by the desire to inform the reader most clearly and accurately regarding progress in cardiovascular disease. The sponsors of this publication will make every effort to attain this objective.

Progress in Cardiac Surgery: General Survey—Indications for Surgery, Surgical Risk and Results

By CHARLES K. FRIEDBERG

THE SWIFT PROGRESS in the technics of cardiac surgery has been accompanied by equal advances in diagnostic methods and it is now possible to recognize preoperatively all of the lesions for which surgical treatment may be offered. This expansion of the therapeutic horizon by surgical advances has imposed additional responsibilities on the general physician, the internist and the cardiologist for they must now constantly consider the possible application of surgical as well as medical treatment for a host of cardiac diseases. They must be familiar with the diseases for which surgical procedures are available, they must possess the ability to diagnose these lesions by the conventional office methods of history, physical examination, fluoroscopy and electrocardiography or recognize the indications for more complex procedures such as cardiac catheterization, angiocardiography and indicator dilution studies. Finally they are responsible for the selection of patients for cardiac surgery which requires knowledge of the indications for surgical treatment of the individual cardiac lesions, the surgical risk involved and the likelihood of symptomatic and functional improvement. Such selection requires also knowledge of the life history of the various cardiac diseases without surgical therapy and skill in the assessment of the individual cardiac patient's present and future disability and his probable duration of life for these must be measured against the immediate surgical risk and the likelihood of functional and symptomatic improvement as well as prolongation of life.

This issue of *Progress in Cardiovascular Diseases* presents recent advances in a variety of selected areas of cardiac surgery described by surgeons who have been intimately concerned with these advances. In addition, Dr. Paul Wood has discussed the broad subject of rheumatic heart disease from the medical viewpoint with the objective of indicating the physician's responsibility toward the selection of patients for cardiac surgery. The present introductory survey proposes to round out this symposium on cardiac surgery by filling in some of the gaps imposed by limitations of space and to provide a brief check-list of the current status of cardiac surgery, the surgical risk, its therapeutic accomplishments and the indications for surgical treatment in the common acquired and congenital cardiac lesions. A discussion of the surgical treatment of coronary heart disease is presented in the next issue of this publication and progress in vascular surgery will be discussed in a subsequent issue.

We are now at the close of a decade of progress in cardiac surgery in which

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the treatment of a variety of congenital and acquired cardiac lesions by so-called closed technics has approached its maximal potential for mechanical repair or cure with the least possible risk. Although symptomatic and functional improvement has been unequivocal in most cases, the cardiac repair has usually been incomplete, uncertain or palliative, significant associated lesions have been overlooked and sometimes irreparable or fatal damage has been induced. At the present moment progress in cardiac surgery is characterized by efforts to eliminate these deficiencies by the performance of cardiac surgery in the open heart under direct vision. This has been made possible first, in a limited sense, by the use of hypothermia with inflow occlusion[1] and later by the perfection of various devices for cardiac and pulmonary bypass, culminating in the pump-oxygenator.[2] Although hypothermia with venous inflow occlusion may continue briefly to be utilized for the repair of some cardiac lesions by surgeons experienced and skilled in its use, it appears probable that because of the 12-minute time limitation it imposes for surgical repair and because of the danger of ventricular fibrillation as well as other disadvantages this technic will shortly be replaced by the use of the pump-oxygenator. The value of complete cardiopulmonary bypass with the pump-oxygenator has been enhanced in selected cases by retroperfusion of the coronary sinus[3,8] and by induced cardiac arrest with the aid of potassium citrate[4,5] or acetycholine.[6,7] The immediate phase of progress in cardiac surgery consists of the widespread adoption of and training in the technic of employment of pump-oxygenators for cardiac surgery under direct vision, the application of direct vision surgery to the repair of a variety of cardiac lesions formerly treated by closed technics, to the repair of many other lesions which could not be treated by closed technics and especially to the attainment of such experience and skill in direct vision cardiac surgery that the maximal possible repair can be attained with minimal risk. This period of transition from closed to open cardiac surgical technics imposes a special difficulty for the physician who must determine whether the desirability or even urgency for cardiac surgery is such that he must recommend a safer but less certain or less curative closed procedure or whether he should recommend delay until his surgeon can perform a preferable open cardiac operation without significant additional risk. With increasing surgical experience cardiac surgeons are already beginning to report mortality rates which are as low as those with closed technics.

The physician must also peer ahead to the adjacent future when other surgical advances, already on the horizon, will outmode present methods of repairing certain cardiac lesions. If the use of prostheses for the correction of valvular deformities is a very near-term development, as it appears to be, then the physician must decide whether his patient should and can safely delay in availing himself of the beneficial cardiac surgical procedures now available in the hope of obtaining a more perfect therapeutic result at a later date. The possibility of partial or complete cardiac transplantation is engaging the efforts of a number of investigators but at present such an advance in cardiac surgery can be hopefully imagined but not yet realistically envisioned.

Acquired Cardiac Lesions

Mitral Stenosis

After 10 years the procedure variously termed commissurotomy, valvulotomy or valvuloplasty of the mitral valve is generally accepted as an effective surgical operation. The over-all surgical mortality, in the hands of surgeons who have performed more than a hundred such operations, is in the range of 5 to 10 per cent, but is less than 2 per cent if the earliest cases of a series and if patients with symptoms of advanced heart failure at rest are excluded.[9,10] A more thorough and effective correction of the mitral obstruction is being accomplished than in the early days of the operation. But in advanced lesions with extensive calcification and deformity of the valve, surgical repair is often unsatisfactory and may be complicated by serious or fatal mitral regurgitation. Because of these shortcomings it is probable that mitral commissurotomy will soon be performed by direct vision at least in cases with calcification of the mitral valve or complex anatomic alterations which demand direct vision for proper surgical repair, in cases in which it is difficult to reach the mitral valve because of the small size of the appendage or because of left atrial calcification, in cases requiring reoperation and in cases in which a left atrial myxoma or tumor[11,12] is found to have produced the signs of mitral stenosis. The possibility of correcting mitral regurgitation by open heart surgery, if a significant regurgitation is found to be associated with stenosis or if it is provoked by the commissurotomy, is another advantage favoring the adoption of direct vision surgery for mitral stenosis. An early objective is the perfection of a valvular prosthesis to replace either an insufficient or stenotic valve. For the present open heart surgery for mitral stenosis will probably be utilized only in selected cases until the mortality rate can be shown to be no higher than that with the current closed method of mitral commissurotomy.

Indications for Mitral Commissurotomy

Asymptomatic patients and those who can perform all ordinary activities without discomfort, i.e. those in Class I according to the classification of the New York Heart Association, are not recommended for operation. But careful questioning of the patient or her spouse may disclose that symptoms have occurred despite previous denials. In other cases patients classified as asymptomatic are free of symptoms only because they have been protected from or avoid activities which have caused distress in the past. Following operation they have come to realize their previous limitations and their increased capacity for activity.

Mitral commissurotomy is also an elective operation in patients with mitral stenosis in Class II, i.e. patients comfortable at rest but with symptoms such as dyspnea, fatigue or palpitation during ordinary activity. After considerable experience a surgeon's mortality rate with this group of patients should probably not substantially exceed 1 per cent.[9] The decision as to operation or medical treatment is determined by the severity of the symptoms and the extent to which the symptoms and consequent restrictions hamper the in-

dividual patient's way of life. Progression of disability under observation frequently justifies surgical intervention.

Mitral commissurotomy is most frequently indicated in patients with mitral stenosis in Class III, i.e. those patients who are asymptomatic at rest but are markedly limited in their way of life because they experience symptoms with less than ordinary activity. Even in this group a mortality rate of less than 1 per cent was reported by Ellis and Harken,[13] with only two deaths in a series of 500 cases.

Patients in Class IV experience symptoms of cardiac failure even at rest, but in more intense form with any exertion. They are unable to carry out any activity without distress. Operation in these cases is an effort at salvage and the mortality is relatively high and remains high at a level of approximately 20 per cent even in the hands of experienced surgeons.[13] Therefore, surgery should be undertaken before the patient reaches this advanced stage. But even among these late cases more than 60 per cent of those who survive are reported to be significantly improved.

Contraindications

Predominant associated *mitral regurgitation* remains a contraindication unless the surgeon is prepared to correct this as well as the stenosis by open heart surgery. *Aortic regurgitation* is no contraindication if there are no peripheral dynamic signs of this lesion and if the diastolic pressure exceeds 50 mm. Hg. If free aortic regurgitation coexists or the diastolic pressure is below 50 mm. Hg a mitral commissurotomy should be performed only if the surgeon is prepared to insert an aortic valve prosthesis by open heart surgery. *Bacterial endocarditis* should be cured by antibiotic therapy for at least three months before mitral commissurotomy is undertaken. But low-grade fever in patients with congestive heart failure requiring digitalis therapy, sodium restriction and mercurial diuretics long before the onset of the fever, is rarely due to bacterial endocarditis and should not be the reason for undue delay in operating. Periods of fever without frank polyarthritis in the patients with mitral stenosis beyond the age of 25 are often mistakenly interpreted as indicating active clinical rheumatic fever and are responsible for unnecessary and sometimes dangerous delay after the need for mitral commissurotomy has been generally accepted.

Age appears to be no contraindication, the surgical risk depending on the severity of symptoms and functional incapacity, as described above, rather than by age. But in patients past the age of 60, especially in males, there is a high probability of calcification of the valve with consequent increased difficulty in restoring valvular function.

Functional *tricuspid regurgitation* is not a contraindication to mitral commissurotomy but usually represents a late stage in the course of mitral stenosis. It may be diminished after mitral commissurotomy but the probability of a good functional result is less than in patients operated earlier in the course of mitral stenosis.

Coexistent *tricuspid stenosis*[14-16] should be sought in all cases of pre-

dominant mitral stenosis and should be corrected at the time of mitral commissurotomy.

Mitral Commissurotomy in Pregnancy

Mitral commissurotomy is indicated when serious or progressive heart failure develops in the course of pregnancy in a patient with mitral stenosis or if such a patient is first seen in congestive heart failure after the third month of pregnancy and medical therapy does not satisfactorily control heart failure. Fortunately, if the procedure is thus indicated, the operative risk does not appear to be substantially greater during pregnancy than in the non-gravid state.[17] In a series of 18 pregnant women with mitral stenosis and heart failure,[18] which was extremely advanced in some cases, mitral valvotomy was performed without any maternal deaths or serious postoperative complications, but there were two premature births with mortality in one of them.

Effectiveness of Mitral Commissurotomy

Symptomatic and functional improvement has been reported in approximately 75 per cent of patients surviving operation.[19-20] Furthermore, this improvement is maintained, as indicated by five-year or longer follow-up periods,[22] although regression has been noted in a small percentage of cases. The effect of the operation on longevity is difficult to assess because of the absence of satisfactorily controlled studies and the uncertain and variable natural history of mitral stenosis.[23] Donzelot et al. studied the life expectancy of patients with mitral stenosis with and without operation. Of 165 who were operated there was a mortality of 9.7 per cent and improvement in 81 per cent. During the same period of observation there was a mortality rate of 49 per cent among 120 patients who were not regarded as operable and a 58 per cent mortality among 19 patients who were not operated, though they were regarded as operable.

Assessment of improvement after operation is notably hampered by the occasional postoperative euphoria associated with faith in the surgeon and confidence that the operation has effected the anticipated cure even when, occasionally, no manipulation of the valve was possible and even when significant mitral regurgitation was induced. But this improvement rarely, if ever, persists after the first few months. In some instances there is apparent improvement only because of more rigorous medical treatment or better cooperation of the patient or because disability was largely due to physicians' restrictions or patients' fear of activity, both of which are shed after the operation.

There is need for a more accurate evaluation of the patients preoperative symptoms and functional capacity by detailed history and observation and by the use of objective tests.[25] Objective measurements have been provided by left heart catheterization or by combined left and right heart catheterization before and at intervals after operation to determine whether the diastolic left atrio-ventricular gradient has been virtually abolished or substantially diminished.[26] In general such studies in small series of cases have shown a sig-

nificant increase in flow across the mitral valve with a significant reduction in the left ventricular filling pressure gradient across the mitral valve.[27] Measurements of left atrial and ventricular pressures at the operating table immediately after the commissurotomy with due regard for blood flow, may serve as an aid to estimating the effectiveness of the mitral commissurotomy.[28,29] Standard exercise tolerance tests have been recommended as a guide to operative indication as well as a measurement of effectiveness of the operative procedure.[30] Such exercise tests, performed serially before and after operation, have shown sustained improvement in 22 of 30 patients followed for two to five years after mitral commissurotomy.[31] No such improvement was recorded in those patients with mitral stenosis who had refused the operation or in those whom there was thought to be some contraindication to operation.

Restenosis of the Mitral Valve

Clinical deterioration, after a period of improvement following mitral commissurotomy, has been attributed to refusion of the valve cusps with restenosis of the mitral orifice. Estimates of the frequency of such occurrence range from isolated instances to 2 per cent or more.[32-34] Criteria for restenosis are poorly defined. This is due in part to the unreliability of clinical symptoms and patients' reported functional capacity as the basis for assessing improvement. Objective evidence by left heart catheterization that the left atrioventricular diastolic gradient was largely eliminated some months after operation and that the preoperative gradient was restored at a still later date, concomitant with clinical regression, would be more convincing. As a rule, clinical regression attributed to mitral restenosis is due to (1) inadequate relief of the mitral obstruction because of insufficient separation of the commissures, especially the posteromedial commissure, or because of uncorrected shortening and adhesion of chordae tendineae; (2) unrecognized associated lesions such as aortic or tricuspid stenosis; (3) the operative production or increase of mitral regurgitation; (4) irreversible pulmonary hypertension and heart failure; (5) coexistent bronchopulmonary disease.

Need for Catheterization

Right and left heart catheterization have enhanced our understanding of the hemodynamics of mitral stenosis and other valvular lesions, improved our ability to diagnose pure mitral stenosis by conventional means, helped to clarify clinical indication for surgery by correlating these with the hemodynamic abnormalities found by catheterization and have provided an objective evaluation of the effectiveness of the procedure. Serial catheterizations before and after operation disclose whether persistence or recurrence of symptoms is due to restenosis after adequate enlargement of the mitral orifice. Cardiac catheterization may be of assistance in determining whether there is predominant mitral stenosis or predominant mitral regurgitation.

But is it necessary for all or most patients with mitral stenosis to be catheterized before operation? In research institutions this may be desirable because of the advantages listed above. Otherwise catheterization may be indicated only in selected cases. Undoubtedly occasional avoidable errors may be made

if catheterization is omitted. Absence of the typical apical presystolic murmur or the presence or predominance of a systolic murmur has caused oversight of the presence of pure or predominant mitral stenosis until cardiac catheterization was performed. Or a very mild mitral stenosis was indicated by catheterization when the symptoms and signs were interpreted as indicating severe mitral stenosis. Sometimes cardiac catheterization is helpful in determining the mechanical severity of the mitral lesion when the diagnosis of mitral stenosis is definite but the symptomatic disturbance and degree of functional disability are difficult to assess.

Diagnosis of Mitral Regurgitation or Mitral Stenosis

Pure mitral stenosis is usually easily diagnosed on the basis of physical signs and electrocardiographic and roentgenologic findings. But occasionally there is difficulty in determining whether mitral stenosis or regurgitation is predominant. Difficulty arises most often because of the presence of an apical systolic murmur suggesting associated or predominant regurgitation while the electrocardiogram gives no evidence of ventricular hypertrophy and the radiologic findings may be interpreted as suggesting left ventricular hypertrophy. An apical systolic murmur in a patient with probable mitral valvular disease is more probably indicative of regurgitation the greater its intensity and the more prolonged its duration and the less striking the first sound at the apex. But calcification of the mitral valve may be responsible for a weak first sound, absence of the opening snap and the presence of a harsh systolic murmur in cases of mitral stenosis without significant regurgitation. Associated tricuspid regurgitation may be responsible for a loud and prolonged systolic murmur at the mitral area and this possibility should be considered.[35,36] Highest intensity of the murmur near the sternum in the fourth left intercostal space, intensification during inspiration and especially the findings of systolic pulsation of the liver and cervical veins almost always permit a correct diagnosis of tricuspid regurgitation at the bedside. Electrocardiographic signs of right ventricular hypertrophy are frequently absent in cases of mitral stenosis, but when present they strongly support a diagnosis of pure or predominant mitral stenosis despite an apical systolic murmur.[37] Right ventricular enlargement with rotation of the heart often presents a roentgenologic appearance which is misinterpreted as left ventricular hypertrophy. Similar rotation of the heart may lead to misinterpretation of a hypertrophied right ventricular precordial pulsation as representing the thrust of a hypertrophied left ventricle because it can be felt in the region of the cardiac apex.

A variety of methods designed to differentiate mitral stenosis and regurgitation are found to fail in individual cases. Left heart catheterization with study of the left atrial pressure pulse tracing is usually helpful in differentiating predominant mitral regurgitation or stenosis but not in determining the severity of mitral regurgitation accompanying predominant mitral stenosis. Mild degrees of mitral regurgitation may be detected by alterations in the left atrial pressure pulse during norepinephrine infusion according to Braunwald et al.[38] As a rule, operation is indicated in cases of predominant mitral stenosis even when there is a significant amount of regurgitation. In cases of pure or

predominant mitral stenosis the left atrial tracing shows the "V" wave to be of similar amplitude to that of the "A" and "C" waves, the "Y" descent from the "V" wave is slow, and diastasis, i.e. a rise of atrial pressure in late diastole preceding atrial contraction, is absent.[39] In mitral regurgitation the "V" wave is quite prominent and rises far above the height of "A" and "C," or there is a prominent regurgitation "R" wave fusing into the "V" wave with a diminution or absence of the systolic "X" depression; the "Y" descent is rapid and diastasis is present. The mean left atrial pressure is usually elevated in both mitral stenosis and insufficiency. Indicator dilution curves obtained during left heart catheterization are now being used both to determine the presence of mitral regurgitation and, when correlated with cardiac output studies, to quantitate the amount of regurgitation. Radiopaque or radioisotopic material may be injected through a catheter in the left ventricle and the analysis of blood withdrawn from the left atrium indicate the presence and quantity of regurgitation.

Mitral Regurgitation

Closed technics for the repair of mitral regurgitation have been employed in isolated or small series of cases, but none of the methods have received general acceptance. The use of a nylon-covered spring valve made of the watch spring metal alloy Elgiloy has been promising but has not been widely adopted. In some cases of mitral regurgitation due to a mitral cleft associated with an ostium primum defect, simple suture may be effective. In cases in which regurgitation was due to an annulus which was too large to be occluded by the cusps, encircling sutures have been used to reduce the circumference of the dilated annulus.[40] Davila et al.[41] reported excellent mechanical correction in 43 of 49 cases of advanced or terminal cases of mitral regurgitation but there was a very high mortality within the first few weeks or months after operation. Nichols[42] introduced the method of polar cross plication of the mitral annulus to reduce the circumference of the annulus by suturing and apposing its two poles. The mortality rate, originally in the range of 20 to 40 per cent has been reported to be reduced to 14 per cent.

The trend is now toward surgical treatment of mitral regurgitation by open heart surgery. Annuloplasty, a technic for reconstruction of the defective valve in mitral regurgitation by direct vision with the aid of a pump-oxygenator,[43] was reported in five cases by Lillehei[44] and in three by Herron.[45] An adequate number of mattress sutures were used by Lillehei[46] to plicate the annulus and eliminate the regurgitant jet and were tied down over pillows of compressed plastic sponge. The heart was allowed to beat in order that blood ejected by the left ventricle might disclose the presence and exact site of any persistent regurgitation. In four cases the regurgitation was due to a dilated annulus, in the fifth to a cicatricial contraction and virtual elimination of the mural leaflet. Repair in the latter case was accomplished by placement of a prosthesis, consisting of a cylinder of compressed polyvinyl sponge, horizontally under the mural cusp and suturing it in place by four mattress sutures of heavy silk. Further experience is necessary before a statement as to surgical risk, results and operative indications is warranted but the experience of

Kay[46a] is promising. Direct vision surgical correction of mitral regurgitation was performed in 28 patients, with 2 operative deaths. Various types of annular plication have been utilized.

Aortic Stenosis

Aortic stenosis in children and young adults in whom the valve cusps are not severely calcified and deformed is now generally remediable with relatively small risk by open heart surgery. This is discussed by Morrow et al. in this issue.[47] In infants suffering from syncopal attacks due to aortic stenosis, surgical therapy should be instituted as soon as possible because of the danger of sudden death. In most older adults the surgical treatment of aortic stenosis has not reached a very satisfactory state and operation should be recommended only when the valvular lesion is responsible for progressive or intolerable symptoms and disability due to angina pectoris, syncope or heart failure.

In older adults aortic stenosis denotes calcific aortic stenosis and surgical treatment not only offers substantial risk but offers limited possibility of satisfactory repair in many or most cases because of the calcification, rigidity and deformity of the cusps. Because of the frequency of coronary heart disease in older individuals it is important to determine, if possible, whether the angina pectoris or heart failure is due to the coronary or aortic valvular disease. Most patients with aortic stenosis are asymptomatic for a great many years and sometimes throughout a normal life span. Thus in adults with aortic stenosis early operation, which would minimize surgical risk and permit a more satisfactory valvular repair before gross deformity develops, is difficult to justify in view of the absence of symptoms and the usually favorable outlook.

When there is doubt as to the severity of the mechanical obstruction at the aortic valve left heart catheterization may be helpful.[26] Aortic commissurotomy is rarely indicated unless the left ventricular-aortic systolic gradient exceeds 40 or 50 mm. Hg when the cardiac output is not extremely reduced. In the series of cases operated by Brock[48] the usual gradient was 100 mm. Hg. When severe mitral stenosis coexists a systolic gradient greater than 20 mm. Hg across the aortic valve may be an indication of severe aortic stenosis. Severe aortic stenosis has been correlated with deep inversion of the T wave in left precordial leads of the electrocardiogram.[49] It is important to recognize and relieve apparently mild or moderate coexisting aortic stenosis in patients undergoing mitral commissurotomy. With repair of the mitral stenosis an increased blood flow may substantially elevate left ventricular pressure and disclose a more severe aortic stenosis than was previously apparent. Hence a systolic gradient across the aortic valve of less than 20 mm. Hg prior to mitral commissurotomy may be increased strikingly after relief of the mitral obstruction. Occasionally no significant gradient is found in cases diagnosed as definite aortic stenosis on the basis of conventional examinations.[50] Mild aortic regurgitation is not a contraindication to aortic commissurotomy and may be improved when mobilization of the aortic leaflets reduces both the stenosis and the aortic reflux.

In a series of 287 cases of aortic stenosis operated by the closed technic,

mortality has been 18 to 28 per cent by the transventricular and 7 to 15 per cent by the transaortic route.[51,52] The lower mortality rates apply to a small series of cases of combined mitral aortic stenosis in which, presumably, the mitral stenosis was the predominant lesion and the aortic stenosis less severe than in the operated cases of isolated aortic stenosis. Brock[48] reported a surgical mortality of 18 per cent among 78 patients with pure aortic stenosis but only 3 deaths occurred in the last 48 cases. The mortality varied with the clinical severity, preoperatively, and probably was no more than 5 per cent in patients of average risk and 25–50 per cent in those who were seriously ill. Among 34 patients with combined mitral and aortic stenosis the surgical mortality was 9 per cent. Surgical deaths from aortic commissurotomy are usually due to ventricular fibrillation, hemorrhage, production of aortic regurgitation or cerebral embolism caused by dislodgement of calcium particles from the valve. Excellent or good clinical improvement has been reported in 60 to 75 per cent of cases, with particular benefit to patients with angina pectoris or syncope. Left heart catheterization has disclosed a reduction or virtual obliteration of the systolic gradient across the aortic valve but often there is a residual of 30–50 mm. in cases in which the preoperative gradient was about 100 mm. Hg.[48,53,54] An incomplete or unsatisfactory reduction in the gradient has been attributed to intrinsic deformity of the valve which prevented good dilatation, or in congenital cases to a coexisting subvalvular stenosis or to a subvalvular muscular obstruction caused by gross hypertrophy of the outflow tract of the left ventricle[55] which may subside spontaneously after the valvular stenosis is relieved.

At present open heart valvulotomy has virtually replaced or is rapidly replacing closed technics. Hypothermia has been employed[56] but this is likewise being replaced by the use of the pump-oxygenator with retrograde perfusion through the coronary sinus[8] or with cardiac arrest.[7] The mortality rate appears comparable to that with closed methods but the reported series are quite small. The best results, both from the point of view of surgical mortality and valvular repair, are in the congenital cases which are more frequent than was formerly recognized. In cases of calcific aortic stenosis, a satisfactory repair may have to await perfection of a valvular prosthesis to replace the deformed valve. Cooley and associates[56a] performed aortic valvulotomy with the aid of the pump-oxygenator in 17 patients with calcific aortic stenosis and 15 with congenital valvular or subaortic stenosis. Six deaths occurred among the cases of calcific aortic stenosis and none in the congenital cases.

Aortic Regurgitation

No satisfactory operative procedure has been available although that of Hufnagel[57] has afforded moderate amelioration in a relatively small number of fairly advanced cases, usually with free aortic regurgitation. Taylor et al.[58] described the surgical correction of pure aortic insufficiency in 11 patients by the technic of circumclusion. Five were alive and clinically improved. There were four operative deaths and two late deaths, but congestive heart failure was present in all except one of the fatal cases. There is now promise that virtually complete correction of the valvular deformity may be accom-

plished by insertion of a prosthetic valve under direct vision with the use of the pump-oxygenator. Unlike the older Hufnagel valve, this one is inserted at the level of the aortic ring.

In two patients with aortic regurgitation secondary to bacterial endocarditis the deformed aortic valve was excised and replaced by a three-cusp silicone-rubber prosthesis with space between flexible pillars to permit coronary flow.[59] In another case reported by Lillehei,[60] a 45-year-old man with rheumatic aortic regurgitation had mild cardiac symptoms since the age of 30, and for one year had attacks of angina pectoris or pulmonary edema on exertion. His blood pressure was 200/50/0. With the aid of a pump-oxygenator for 48 minutes and retrograde coronary sinus perfusion a compressed polyvinyl sponge leaflet was inserted to compensate for the loss of the original leaflet substance. The blood pressure returned to normal at 130/75 and the diastolic murmur and water-hammer pulse disappeared. Further experience and follow-up results must be awaited before these prostheses can be evaluated.

Congenital Cardiac Lesions

Patent Ductus Arteriosus

Surgical correction is indicated in virtually all cases, whether or not symptoms are present, except in asymptomatic infants. On the other hand, if infants with a patent ductus fail to gain weight and experience repeated pulmonary infections or heart failure, section of the ductus should be effected promptly, after digitalization and other indicated medical therapy.[61] Although operation may be undertaken in early childhood, reasonable delay is permissible in asymptomatic young children if the parents so desire. The optimal age is probably between 3 and 15 years. The surgical over-all mortality is less than 3 per cent, including adults and children in heart failure,[62] but there are large series in which 100 or more cases have been operated without mortality.[63] The immediate mortality was substantially higher in adults and in children below the age of three than in older children, chiefly because of the higher incidence of heart failure in the first two groups.[62] The results were satisfactory in more than 95 per cent of adults and more than 98 per cent of the children.

It is important to recognize associated lesions which exist in about 10 per cent of cases and more frequently among infants and young children. Coarctation of the aorta, ventricular septal defect or pulmonary valvular stenosis are the more common associated lesions. If pulmonic stenosis is present, this must be corrected before the ductus is closed or else closure of the ductus will greatly intensify the strain on the right ventricle and produce right heart failure.

Aortic-pulmonary septal defect[64,65] and very rarely ruptured aneurysm of the sinus of Valsalva[66,67] may simulate patent ductus, but both are usually surgically remediable.

Patent Ductus with Pulmonary Hypertension

These cases may present a diagnostic problem because there is only a systolic murmur or a discontinuous systolic-diastolic murmur. Its late systolic accentuation and audibility in the back may be diagnostically suggestive. The pul-

monary hypertension may be moderate or severe. In the latter circumstance there may be intermittent or continuous reversal of shunt with arterial hypoxemia and visible cyanosis, especially after exercise. Cardiac catheterization may be desirable in cases of patent ductus arteriosus with the typical machinery murmur only to determine whether there are associated lesions. In cases with pulmonary hypertension and atypical murmur, cardiac catheterization is usually essential for diagnosis and to determine whether the pulmonary hypertension is due to some associated lesion or to increased intrinsic pulmonary vascular resistance.

There is general agreement that the patent ductus should be closed in cases with pulmonary hypertension in which the pulmonary pressure is substantially below systemic. Final decision as to closure may be made at operation after observing the effects of temporary occlusion of the ductus. The development of marked tachycardia and systemic hypotension or increased pulmonary hypertension is a contraindication, but the procedure of temporary occlusion should be repeated several times before final decision as the initial unfavorable response may not recur. In patients with pulmonary blood pressure virtually equal to systemic blood pressure, with intermittent right-to-left shunt and cyanosis, there is disagreement as to the indication for ductal closure. In these cases also decision may be based on the effect of temporarily obliterating the ductus at the time of operation; permanent section may be performed if this procedure induces a fall in pulmonary pressure. The surgical mortality in cases of patent ductus with pulmonary hypertension varies with the type of case and the severity of the hypertension. The reported series of cases are still too small to present statistically significant mortality rates. Ellis et al.[68] noted an over-all mortality of 18 per cent among 72 reported cases, but the rate was 56 per cent in the 16 patients with a right-to-left shunt. In a series of 31 cases reported by Shumacker and Lurie[69] the mortality rate was 10 per cent in uncomplicated cases of patent ductus arteriosus with hypertension. Young et al.[69a] reported 95 per cent survival among 23 patients with "atypical" patent ductus arteriosus and pulmonary artery pressure approaching or equal to aortic pressure in whom the pulmonary pressure fell and aortic pressure rose after temporary ligation, whereas only 1 of 4 patients survived when these changes did not occur.

Coarctation of the Aorta

Because of the very poor outlook for patients with coarctation of the aorta surgical treatment is indicated in virtually all patients with this lesion. Although the ages between 10 and 15 have been mentioned as most favorable, operation may be performed at any age, but preferably before the age of 20 after which progressive arteriosclerosis is a significant handicap. In infants and very young children the occurrence of heart failure is an indication for operation if medical treatment is not rapidly effective.[70,71] If a good response is obtained operation may be delayed until the aorta is larger. Some surgeons do not favor surgical treatment of coarctation of the aorta in children below the age of five or six or in adults beyond the age of 30, unless there is very severe hypertension or congestive heart failure, and a few are opposed to

surgery in patients more than 30 years old, regardless of their clinical manifestations.

The constricted area is resected and end-to-end anastomosis established in the great majority of cases but occasionally a plastic graft must be inserted or a subclavian-aortic anastomosis may have to be performed. The over-all mortality including complicated cases and patients of all ages has been between 5 and 10 per cent.[72] But in large series of cases the more recent mortality in uncomplicated cases has been approximately 2 per cent or less.[73] In 1187 cases reported by the section of cardiovascular surgery of the American College of Chest Physicians there was an over-all mortality of 8.6 per cent, chiefly among young children, infants, adults and those with complications.[74] The mortality rate was 7.8 per cent among cases of postductile (adult) coarctation and 28.7 per cent among the smaller number of cases of preductile (infantile) coarctation of the aorta. Normal blood pressure has been restored in 75 per cent, and a satisfactory reduction effected in an additional 15 to 20 per cent of cases. Reactive hypertension occurs as a postoperative complication in many cases.[75] Although this is usually of self-limited duration, it may be fatal, especially if hypotensive drugs are used. No significant benefit occurred in 10 per cent due to severe arteriosclerosis or serious abnormalities which precluded repair.

A patent ductus arteriosus is associated in 5 to 15 per cent of cases, often with concomitant pulmonary hypertension. In preductal coarctation, the patent ductus must not be obliterated before correction of the coarctation because sudden additional strain on the left ventricle may cause acute left ventricular failure. The aorta should be clamped proximal to the coarctation and both the ductus and aorta distal to the coarctation should be clamped simultaneously. Then the coarctation and ductus are repaired. Other coexistent lesions such as aneurysms, aortic regurgitation or stenosis, anomalies of the aortic arch, abnormalities of the aortic or mitral valve, especially hypoplastic mitral valve, are common in preductal coarctation.

Atrial Septal Defect

Correction of atrial septal defects of the high (sinus venosus)[76] or ostium secundum type may be accomplished by atrioseptopexy[77] or the atrial well[78] methods with a surgical mortality of about 5 per cent and satisfactory results in about 95 per cent of cases.[79] However, it is probable that open heart surgery with direct vision will soon replace these methods because the surgical risk need not exceed that of the closed methods, and because correction of the defect is more reliable, associated defects can be discovered and corrected and complicated defects are more likely to be remedied. Lewis et al.[80] reported a series of 63 patients with atrial septal defect, including 3 of persistent ostium primum, between 3 and 61 years of age (median 23) operated on with the aid of cardiac inflow occlusion and hypothermia. There were 6 operative deaths (mortality 9.5 per cent) but no deaths occurred in the last 19 consecutive operations. Pulmonary hypertension disappeared after operation. Swan and associates[80a] reported the results of repair of atrial septal defects of the secundum type in 100 consecutive patients under direct vision,