RECENT ADVANCES IN CARDIAC SURGERY*

III: SURGERY OF ACQUIRED HEART DISEASE

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MITRAL VALVE DISEASE

(a) Mitral Stenosis

There has been a continuing re-examination of surgical concepts in the treatment of mitral stenosis since the re-introduction of mitral valvotomy in 1948 by Bailey (1949), Harken (Harken et al, 1948) and Brock (Baker et al, 1950). Digital fracture of the fused commissures with the index finger, introduced through the left auricular appendage has always been a less than perfect technique. A blind manoeuvre guided entirely by touch, inherent errors of interpretation and technique are inevitable, minimised only by increasing experience. Furthermore, the pathological anatomy of the rheumatic stenotic mitral valve is subject to variations, some of which remain obstinately resistant to simple finger fracture. This has led to the use of a variety of ingenious instruments for incising the tough fibrous tissue of the commissures. These valvulotomes were designed to be introduced into the left atrium alongside the finger. Positioning of these instruments was dependent on digital palpation. They increased the success rate of valvotomy but were all too liable to cause accidents.

The most successful innovation in the history of blind valvotomy has been the introduction of the use of the Brock aortic valve dilator (Logan and Turner, 1959). This is a two-bladed instrument which is introduced through a small stab-ventriculotomy in the apex of the left ventricle, and guided into position within the stenotic valve orifice with the aid of the examining finger in the left atrium. Separation of the blades by approximation of the handles of the dilator produces a strong distraction force which is maximally exerted on the commissures. The line of fission invariably occurs in the commissures and very satisfactory valvotomies can be achieved. Since its introduction, this technique has gained wide acceptance and considerable and widespread clinical experience with it has confirmed its great value (Cooley and Stoneburner, 1959; Gerbode, 1960; Morrow and Braunwald, 1961; Bjork et al, 1961). Surgical mortality is little increased and the only disadvantage lies in a slightly higher incidence of traumatic mitral insufficiency (Austen and Wooler, 1960).

The problem of restenosis needs to be discussed. It is widely held that true restenosis after a complete valvotomy occurs infrequently (Belcher, 1960; Cooley and Ellis, 1960; Ellis et al, 1962). Most cases of recurrence of mitral stenosis following valvotomy were found to be due to initial incomplete valvotomy. In a series of 51 patients requiring re-operation for mitral stenosis, Ellis and his associates (1962) found that true restenosis had occurred in only 12, the others having been the result of previous incomplete valvotomies. It is difficult to ascertain the actual incidence of true restenosis. When the number of re-operations is considered as a whole, irrespective of whether due to true restenosis or recurrence following incomplete valvotomy, the incidence has been variously reported as 9% over a 9-year follow-up (Morse et al, 1962), 28% over a 5-year follow-up (Fraser and Kerr, 1962), and as high as 70% in patients followed for nine years (Lowther and Turner, 1962).

With the introduction of open-heart techniques, it was initially envisaged that direct-vision valvotomy carried out in a relatively bloodless field would totally supplant blind methods. It was soon appreciated that the open method was not without serious disadvantages. Incision into the left atrium introduces air into the left heart thereby seriously incurring the risk of air embolism. The risk of systemic embolism is further increased by dislodgement of thrombus or calcium during operative manipulation of the valve. Identification of the line of commissural fusion by direct inspection is by no means a

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simple matter. Finally, the total expenditure in terms of time, personnel, equipment, and blood entailed in an open-heart procedure makes it quite impracticable to submit all patients with mitral stenosis to open-heart operations.

The technique of blind valvotomy, reinforced when necessary by the use of the transventricular dilator, remains part of the armamentarium of the cardiac surgeon. It is still the method of choice for most cases of mitral stenosis. Open reconstruction of the mitral valve is reserved for patients with:—

1. restenosis following previous blind valvotomy;
2. past history of systemic embolisation;
3. calcified valves;
4. associated insufficiency.

It is interesting to note that in open valvotomy initial splitting of the commissures is often achieved by the dilator applied through the left atriotomy. Further separation of the commissures is accomplished when necessary with a scalpel or scissors. An important advantage of the open method is the possibility of complete evacuation of all calcareous and thrombotic material. It also enables the direct evaluation of valve function following valvotomy and debridement.

Open operations for mitral stenosis fall into two groups: (a) reconstructive procedures, and (b) total valve replacement.

Reconstructive procedures involving direct vision valvotomy and debridement will restore satisfactory valve function in many cases. However for the case with severe scarring, loss of cusp tissue, gross deformity and calcification, satisfactory function can only be achieved by complete valve replacement with a prosthesis. The most successful mitral valve prosthesis developed to date is the Starr-Edwards ball valve introduced in 1961 (Starr et al, 1961). Results with this valve will be discussed later in this review.

(b) Mitral Insufficiency

Competency of the normal mitral valve is dependent on four factors:—(1) the annulus; (2) the valve cusps; (3) the chordae tendinae; and (4) the papillary muscles. Pathological derangement of one or more of these structures may prevent the valve from functioning effectively and lead to incompetence with or without stenosis. It is clear therefore that satisfactory correction of insufficiency can only be achieved under direct vision, and all blind attempts must necessarily be inadequate.

In those instances where dilatation of the valve ring is the main cause, simple plication of the posterior part of the mitral annulus with interrupted sutures often effectively corrects insufficiency (Gott et al, 1957). In the rare instance where insufficiency has been due to rupture of chordae tendinae, competency has been restored by suture of the two ends of the affected chordae (Kay et al, 1961). For the grossly diseased valve with major loss of cusp substance, sclerosis and calcification, total valve replacement is the only effective method.

The introduction of the ball-valve mitral prosthesis (Starr et al, 1961) marked a notable advance in the surgical therapy of mitral valvular disease. Previous attempts at prosthetic replacement had been attended by unacceptably high failure rates. The Starr-Edwards prosthesis consists of a conical four-bar cage of stainless steel enclosing a ball of silastic rubber (a plastic material). The ball seats on the circular base of the cage during ventricular systole and prevents regurgitation. The stainless steel annulus of the base is covered with a layer of teflon fabric to which the fixation sutures are attached. On the cardiac side, the sutures are inserted into the mitral annulus. The results to date have been satisfyingly encouraging. Initially, complications attributable to the prosthesis occurred in the form of embolisation from the thrombus deposited on the sutures and valve base, and in some cases the prosthesis tore loose from the mitral annulus as a result of inadequate fixation. Long-term anti-coagulant therapy has minimised thrombus deposition, and improved suture techniques with heavy dacron sutures have decreased the incidence of the second complication.

Problems in the surgical treatment of mitral valvular disease extend into the post-operative period. Cerebral embolisation of air, calcareous or thrombotic particles continues to be a major complication and cause of the operative mortality. Post-operative increase in pulmonary vascular resistance is especially liable to occur in patients with long-standing disease and pul-

monary hypertension. The clinical picture is characterised by a low cardiac output and hypotension, high pulmonary arterial systolic pressure, decreased oxygen saturation of the central venous blood, and an increasing acidosis due to diminished tissue perfusion and hypoxia. Vigorous therapy including the use of intermittent positive pressure respiration, digitalization, may prove unavailing. The cause of this therapeutically difficult complication remains uncertain. The fact that prolonged periods of cardiopulmonary bypass increase the incidence of this complication would suggest a causal relationship, related to some as yet undetermined form of blood trauma, or to the release of vasoactive substances (Yong et al, 1964).

Results of Mitral Valve Surgery

Trans-atrial digital mitral valvotomy can be accomplished today with a low operative risk, ranging from 3% to 7%. The operative mortality is considerably increased in patients with severe pulmonary hypertension, auricular fibrillation, previous embolic episodes, valvular calcification, and in those patients with Class IV disability. The use of the transventricular dilator has resulted in a much higher percentage of complete valvotomies with very little increase in operative mortality, but it is attended by a greater risk (13-17%) of traumatic mitral insufficiency.

Open correction of mitral valvular disease, stenosis and/or insufficiency, has been employed since 1957 with steadily improving results. At the Mayo Clinic, a mortality rate around 19% was the experience up to 1961 but in 1962 it had dropped to 7% (Ellis et al, 1963). Morris and associates (1962) reported a surgical mortality of 12% in a series of 42 patients with stenosis or insufficiency alone, or combined. Kay and his colleagues (1961) experienced a mortality rate of 15% in a series of 34 patients with pure mitral insufficiency. The presence of multivalvular disease however considerably increases the operative risk. In the series reported by Ellis and associates (1963) the mortality up to 1961 was 33%, but had decreased to 15% in 1962.

Mitral valve replacement is accompanied by a much higher operative mortality. This has largely been due to the fact that valve replacement has been reserved in the main for patients with grossly diseased valves, and the majority of these patients have had long-standing disease and very severe disability. Referring again to Ellis's series of 46 patients, (Ellis et al, 1963), the operative mortality was 25%. Groves (1963) reported 8 deaths (20%) in a series of 40 Starr valve replacements. Starr himself (1963) reported 13 deaths in 38 patients. Function of this rather non-anatomic type of artificial valve has been found very satisfactory except for the minor disadvantage of an insignificant degree of regurgitation (Morrow et al, 1964).

AORTIC VALVULAR DISEASE

(a) Aortic Stenosis

The pathological anatomy of the stenotic aortic valve, especially when associated with calcification, accounts for the poor results obtained with closed attempts at valvotomy. The transventricular method, introduced by Bailey and associates (1952) and developed further by Brock (1957), and the trans-aortic technique developed by Harken (1958) were both characterised by a high incidence of early and late failures in addition to rather forbidding mortality rates. Reduction in the pressure gradient across the valve was variable, and residual gradients as high as 75 mm.Hg. were reported by Glover and Gadboys (1958).

Open valvotomy with the aid of general body hypothermia and venous inflow occlusion did not gain wide acceptance. The short time permitted for operative manipulation of the aortic valve under direct vision and the severe anatomic disease encountered combined to preclude little improvement in surgical results.

Open-heart aortic surgery employing cardiopulmonary bypass was employed as far back as 1956 by Lillehei and his associates (1956) and has rapidly supplanted blind valvotomy. This contrasts with the position in mitral stenosis where closed techniques continue to retain an important place in surgical therapy.

Criteria for the selection of patients for surgery remain to be completely defined. Operation is generally advised in patients with significant symptomatology. In the absence of significant disability, a gradient across the valve of more than 50 mm. Hg. is generally regarded as sufficient indication. When there is associated mitral stenosis this criterion needs to be modified as the interpretation of the pressure gradient

must be tempered by the presence of a lowered cardiac output. As the simultaneous repair of both aortic and mitral valves carries with it a considerably greater risk, the decision is not one to be lightly undertaken.

Initial techniques in the open correction of aortic stenosis consisted of incision of the fused commissures and debridement of the cusps. By painstaking dissection, separation of the calcareous masses from the cusps was found possible and mobility restored in a large number of cases. This technique, introduced by Mulder and Winfield (1960), was widely adopted. The early haemodynamic and clinical results of such valve "sculpturing" or debridement were encouraging. In Mulder's series of 9 patients, pressure gradients were reduced in all patients to less than 10 mm. Hg. with the loss of only one patient. McGoon and associates (1963) in a series of 149 patients reported that 54% of the gradients had been reduced to less than 20 mm. Hg. and 83% were under 50 mm. Hg. The late results have however been disappointing. In a recent review of their results in 61 patients in 27 of whom debridement had been carried out, Mulder and his associates (1963) found that despite early satisfactory results, most patients had a slow but progressive deterioration after 2 years. The haemodynamic studies revealed a return of pressure gradients of 75%-100% of the preoperative gradients in 5 out of 7 patients in whom these studies were performed.

Work on the development of artificial heart valves had begun in the late 1940's. Mention should be made of Hufnagel's ball valve (1951) which was interposed in the descending thoracic aorta. Although physiologically unsatisfactory, it demonstrated that a ball-valve could function satisfactorily for several years and that thrombus formation in the valve was not a formidable problem. The successful use of synthetic fabrics in the development of arterial prostheses led to their application in prosthetic aortic valves. Bahnson (1960) and Hufnagel (1960) both reported successful experiences with aortic valve replacement using single cusps shaped like individual aortic cusps and fashioned from Teflon and Dacron respectively. In a selected group of 32 cases in whom single cusp replacement had been carried out, McGoon (1963) reported a reduction in the pressure gradient to less than 20 mm. Hg. in 75% of the patients. Despite such encouraging early results, studies in patients two years after cusp replacement indicated a gradual but progressive recurrence of stenosis due to fibrin deposition and stiffening of the cusps (Mulder et al, 1963). Similar conclusions have been reached by Larson and Kirklin (1964) and Bjork and associates (1963).

Complete three-leaflet prostheses made of Teflon have been developed and used by Kay and Suzuki (1963), Muller and associates (1960), McGoon (1961) and Roe and co-workers (1960). The early results reported by these groups of workers have again been satisfactory, although the operative mortality has on the whole been higher. Late follow-up data are scanty. Muller (1963) reported that in a few patients followed for more than 2 years, the late results showed no significant regression of their early post-operative improvement. Catheter studies showed minimal or no gradient increase during this period. Kay and Suzuki (1963) noted continued clinical improvement in 20 patients followed for periods from 4 months to 2 years.

More recently much enthusiasm has been shown for the ball-valve type of prosthesis developed by Harken and associates (1960) and Starr and his co-workers (1963). These were designed for implantation in the subcoronary position, like the fabric single cusps and three-leaflet prostheses, and in contrast to the descending aortic position used for the earlier Hufnagel ball-valve. The early experiences with the Harken valve and the Starr-Edwards valve have indicated their superiority over the fabric prostheses in terms of technique of insertion, efficiency and certainty of competency. They are currently the prostheses of choice.

The technical problems associated with aortic valvular surgery are considerable. A constant danger of embolism in the cerebral or coronary circulation exists due to the presence of air, calcific and fibrothrombotic particles in the left ventricle and aorta. The necessity for cross-clamping the ascending aorta during insertion of the valve requires that adequate supportive measures for the myocardium should be instituted to counteract the anoxia. Myocardial ischaemia is poorly tolerated by the severely hypertrophied left ventricular myocardium. Various techniques in use include general body hypothermia and local deep hypothermia, singly or in combination. The most effective

and most physiological technique consists in the individual perfusion of the coronaries through separate cannulae inserted into the coronary ostia. Perfusion of the coronary circulation with cold blood combines the advantages of hypothermia and provides the additional advantage of hypothermic cardiac arrest.

(b) Aortic Insufficiency

The only definitive operation for aortic insufficiency is total valve replacement. Where the insufficiency is the result of widening of the annulus, simple plication may suffce. When necessary, plication of the aortic root is combined with bicuspidisation of the valve. In most cases however, insufficiency is due to rheumatic involvement of the valve with subsequent scarring and loss of cusp substance. As all three cusps are involved, total replacement is necessary.

The operative risk associated with aortic valvular disease is not low. This is not unexpected and is attributable to several factors—the severe technical problems attendant on such surgery, the necessarily long periods of cardiopulmonary bypass and the difficulties encountered in ensuring satisfactory valve function. Furthermore many of the patients have been operated on when in a very advanced stage of the disease. It would thus be more appropriate to examine the salvage rate rather than the operative mortality.

At the Mayo Clinic, in a series of 149 patients with aortic stenosis, the overall mortality was 26% (McGoon et al, 1963). In another series comprising 61 patients, a similar mortality rate of 24% was reported (Mulder et al, 1963). Pure aortic insufficiency is associated with a lower operative risk than aortic stenosis, and certainly much less than multi-valvular disease. In McGoon's report (McGoon et al, 1963), the operative mortality for aortic insufficiency was 13%, for aortic stenosis 21% and for multivalvular disease 50%.

CORONARY HEART DISEASE

This presents a formidable challenge. It must first be realised that very few patients with coronary arterial disease are suitable for surgery. The careful autopsy studies of Edwards at the Mayo Clinic (Swedlund et al, 1962) provide sobering confirmation. Yet there undoubtedly occur a small proportion of patients in whom the arteriosclerotic process remains confined to a small segment of the major coronary arterial trunks leaving the rest of the arterial tree minimally affected. The basis for the selection of these surgically suitable cases lies in accurate, high-quality arteriographic studies. Successful techniques have been developed by Sones and his group (1959) using a specially designed cardiac catheter which may be manipulated into the orifice of the coronary artery, thereby permitting highly selective localization of the dye injection. A different technique (Bjork and Hallen, 1961; Bilgutay and Lillehei, 1962) employs the induction of momentary cardiac arrest by the intra-coronary injection of acetylcholine before injection of the contrast media. It is claimed that resumption of cardiac activity is easily achieved, when necessary using an intra-cardiac pacemaker electrode.

Techniques of direct arterial surgery applied to coronary arterial occlusive disease have so far been confined to endarterectomy and the use of vein-patch grafts in the closure of the arteriotomy in these very small arteries (Senning, 1961; Ellis and Cooley, 1961; Spencer et al, 1963). The number of clinical cases successfully treated remains small. Additional procedures, still in the experimental stage, consist in the anastomosis of the internal mammary artery to a coronary artery, usually the circumflex branch of the left coronary (Spencer et al, 1964a).

The successful performance of direct arterial surgery on the coronary arteries demands a surgical skill of the highest order. Factors which have been found essential include the use of very fine suture material and the induction of hypothermic cardiac arrest so as to provide a quiet operative field (Spencer, et al, 1963, 1964b). The use of micro-surgical instruments and an operating microscope as advocated for micro-arterial surgery (Jacobson and Suarez, 1960) would appear to be of advantage.

Numerous methods of indirect re-vascularization of the ischaemic myocardium have been advocated (Beck, 1951, 1958; Vineberg, 1962). Despite the enthusiasm of their originators, conclusive evidence of their effectiveness is wanting.

CARDIAC PACEMAKERS

Advances in medical electronics have made possible the effective treatment of heart-block. Interest in this problem arose from the occurrence of traumatic heart-block arising from injury to the conduction bundle during open-heart surgery. The use of pacemakers have enabled successful survival of most of such cases.

A pacemaker consists essentially of an electrical circuit which produces a rhythmic electrical stimulus. This is applied to the myocardium through electrodes in contact with or inserted into the muscle. The electrical stimulus overrides the intrinsic idioventricular rhythm to produce a normal rate of contraction. Two types of pacemakers are available. In the external pacemaker, the electrodes are led through the chest wall and connected to the pacemaker by the bedside. This arrangement is satisfactory for the emergency treatment of heart-block, and serves to tide the patient over till the return of normal sinus rhythm. For the patient with permanent heart-block, restoration of normal mobility and activity may be provided by using a more portable battery-operated external pacemaker (Lillehei et al, 1960), or by the use of a completely implantable battery-operated internal pacemaker (Zoll et al, 1961; Chardack et al, 1960). The former method necessitates the passage of the electrode wires through the chest wall and skin, thus exposing the patient to the danger of infection. The implantable pacemaker is a small compact unit, completely enclosed in an inert plastic (Teflon or silastic) envelope, and is small enough to be implanted in the subcutaneous fat of the anterior abdominal wall or axilla. These implantable units are powered by batteries with a five-year life.

Inherent defects peculiar to this arrangement are inevitable, of which the most common have been battery failure, fracture of the electrode wires due to interaction between metal and tissue fluids, and occasionally complete breakdown (Parsonnet et al, 1963). Improvements in design and standard of production have minimised the incidence of such failures.

The most commonly employed internal pacemakers are designed to produce a fixed rate of stimuli. More recently, a synchronous pacemaker has been produced which is nodal-triggered, thus possessing the advantage of adjustability of rate in response to the needs of the patient (Center et al, 1963).

CONCLUSIONS

Successful surgical correction of the common forms of congenital and acquired heart disease has become an established part of the physician's therapeutic armamentarium today. In numerous centres throughout the world, cardiac surgery with or without the aid of cardiopulmonary bypass has developed into an almost routine surgical procedure. All this has been achieved within the short space of the last decade. The rate of progress in this field of surgical endeavour during this period has been exciting and almost breathtaking for those engaged in this field. However many problems remain to be solved.

In the area of congenital heart disease, the rarer lesions which continue to take a heavy toll amongst infants await more satisfactory techniques of repair. Transposition of the aorta, total anomalous venous return, tricuspid atresia, Ebstein's anomaly are examples which come easily to mind. Problems imposed in the repair of these are formidable and include those attendant on the use of cardiopulmonary bypass in these very small infants. Congenital heart disease will always be with us, and a significant proportion of these infants will require urgent treatment in the first few months of life. It is clearly in this area that continued vigorous search for effective surgical treatment and safe cardiopulmonary bypass techniques is required, and is being undertaken. Future developments and progress in pediatric and neonatal cardiac surgery will prove to be as exciting as the achievements of the past decade.

In the field of equipment and instrumentation for cardiopulmonary bypass much has already been accomplished. However, further development is to be expected, particularly towards simplification, ease of maintenance and safety of operation. Recent clinical successes with the use of disposable plastic bubble oxygenators and haemodilution techniques have almost eliminated the need for large amounts of donor blood. Clearly the ideal artificial heart-lung machine will be of the membrane oxygenator type, with a low priming volume and

using a non-blood prime consisting of a balanced electrolyte solution, isotonic, iso-osmotic and similar in pH to blood.

The final word in valvular prostheses has yet to be said. The ball valve prosthesis so successfully applied in aortic and mitral valve replacement is likely to be replaced by one which anatomically as well as functionally resembles the valve it replaces. The most important new frontier is undoubtedly coronary heart disease. Ultimately the rational treatment of this highly fatal disease may lie in prevention and treatment of atherosclerosis, but until this is available, vigorous efforts to formulate an effective surgical attack may prove rewarding in suitable cases.

The use of temporary cardiopulmonary bypass for prolonged periods in support of the failing myocardium is being actively explored. The problems associated with prolonged passage of blood through an extra-corporeal circulation are numerous and formidable but not insuperable. It is precisely this aggressive policy which had made possible the impressive achievements and advances to date.

Finally, an aspect of cardiac surgery which has captured the popular imagination remains to be dealt with. Cardiac homotransplantation and even heterotransplantation is being explored in a few centres. The few reports available so far indicate that the technical problems involved in the suture transplantation of the mammalian heart are not insoluble. What remains to be overcome are the immunological problems of graft- rejection inherent in homo- and heterograft transplants. In the case of renal homotransplants, renal failure during rejection crises is not immediately nor suddenly fatal and the crises can be controlled with the aid of drugs. The same happy situation is unlikely to apply in cardiac transplants. Until methods for permanent suppression or abolition of the graft-rejection mechanism are available, cardiac transplantation remains an exercise in technical expertise confined to the laboratory, and useful only for publicity releases in the popular press.

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