CLINICAL PROGRESS

Current Concepts in Surgical Correction of Acquired Mitral Insufficiency

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Since the earliest reports,\(^1\)\(^2\) in 1957, of the successful, surgical correction of mitral insufficiency under direct vision, a vast amount of new knowledge, both experimental and clinical, has accumulated, and considerable progress has been made in the treatment of this cardiac defect. Much of this new knowledge was discussed at a conference on prosthetic valves\(^3\) in Chicago during September 1960, and, in the ensuing period, further experimental and clinical experience has been gained. In order to assess the efficacy of the many procedures now advocated for the treatment of this disease, the reports of recent investigations have been studied and the results are discussed in this paper.

The Rationale of Surgical Technics

The competence of the normal mitral valve depends on occlusion of the atrioventricular orifice by the valve leaflets during ventricular systole. The leaflets, however, are but one component of a complex unit consisting of four parts—the mitral annulus, the valve leaflets, the chordae tendineae, and the papillary muscles—the integrity of all of which is essential for normal mitral function.

Insufficiency of the valve is due to the inability of the leaflets to coapt and occlude the orifice during systole and may be the result of an abnormality of any one or more of the four components of the valve mechanism. Thus, the essential structural abnormality causing the valve to be incompetent may be one of, or a combination of, the following: (1) an absolute loss of leaflet substance, due to a defect, to perforation, or to scarring and shortening of the cusps; (2) an effective loss of leaflet substance, due to calcification and fibrosis of leaflet tissue, to shortening of the musculotendinous control with resultant decreased cusp mobility, or to rupture of the musculotendinous control with resultant "flail" action of the detached portion of the leaflet; or (3) a relative loss of leaflet substance due to dilation of the mitral annulus.

In addition, it appears that once annular dilation has progressed to or beyond a certain critical point, a vicious cycle becomes established. The left atrium and ventricle, working under impaired hydraulic conditions, undergo hypertrophy and dilation, and the common point of their continuity, the left atrioventricular ring, does likewise. Existing insufficiency is thus aggravated and, in turn, causes further compensatory myocardial dilation and hypertrophy, which leads again to further annular dilation and so on. According to White\(^4\) and Edwards,\(^5\) downward displacement of the papillary muscles as the result of left ventricular dilation may also cause functional mitral insufficiency. The chordae are of limited length and when their attachments to the papillary muscles are moved away from the base of the heart, their insertions on the valve cusps likewise are displaced downward.

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This results in an inability of the cusps to close tightly, no matter how tautly the chordae may stretch or how elastic the cusps may be.

The clinical picture of mitral insufficiency thus may be the result of a diversity of pathologic lesions, and it would appear that no single method of correction can be applied to all cases. Definitive surgical treatment must be based on an accurate assessment of the pathologic anatomy of the diseased valve as seen at operation, and this only can be achieved by direct-vision surgery. Blind procedures, as advocated in past years, utilizing various prostheses and tissue grafts, while testifying to the courage and ingenuity of the pioneers in this field, have no place in the present-day treatment of mitral insufficiency.

The following technics, either singly or in combination, may be applicable for the correction of acquired mitral insufficiency.

**Reconstruction of the Abnormal Valve**

Repair of Clefts, Perforations, or Tears of the Leaflet by Direct Suture

Direct suture, either alone or combined with some other procedure, is occasionally applicable for the correction of mitral regurgitation due to acquired defects of the valve leaflets. While experimental evidence suggests that such sutures should be tied over pledgets of plastic material to prevent the suture from cutting through the tissue, this is not essential and no clinical reports of sutures cutting through have been encountered.

In selected cases, therefore, direct suture of defects in the leaflets is a valuable adjunct to other technics and may be all that is necessary to effect complete repair of the incompetent valve.

Increasing the Surface Area of the Leaflet

With a view to increasing the surface area of the cusps, several investigators have studied the effects of implantation of patches of plastic material or of autogenous pericardial grafts in the anterior and posterior mitral leaflets. Five of eight animals in which a knitted Teflon patch had been inserted into the anterior leaflet under sterile conditions, by Johnson and co-workers, survived 2½ to 12 months. At sacrifice, the Teflon was found to have been incorporated into the leaflet tissue, was covered on both surfaces with a film of fibrin, and was free from thrombus; the patches themselves, however, were thickened and stiff and did not appear to take part in the motion of the leaflet when observed in the pulse duplicator. King and co-workers, using Nylon and Teflon, found that their patches were covered with a thin layer of fibrous tissue that had a smooth endothelial-like surface; they too found no clotting. Spencer, however, performed the same experiments using knitted Teflon and found large clots arising from the Teflon and occluding the atrioventricular orifice in dogs, all of which died between 5 and 7 days postoperatively. In order to increase the surface area of the posterior leaflet, Nichols and co-workers inserted an elliptical segment of compressed polyvinyl sponge between the annulus and the leaflet in four patients. The patients survived the operation but long-term follow-up was not reported.

Using autogenous pericardium, Sauvage and co-workers replaced the major portion of the aortic leaflet of the mitral valve in dogs. At sacrifice 2 to 6 months postoperatively, grafts were found to have healed well with some thickening at the suture lines; some central pliability remained, and no contraction, calcification, or thrombus formation was noted. The operation was then applied clinically in four patients, with two survivors both well at 6 and 8 months postoperatively, respectively.

Results of experiments with plastic implants in the mitral leaflets are conflicting. While, in selected clinical cases, the use of pericardial grafts may be successful, as demonstrated by Sauvage and co-workers, a consideration of the pathologic anatomy of the diseased valve suggests that the technic rarely will be applicable. Gross scarring and contraction of the anterior mitral leaflet frequently are accompanied by similar changes in the chordopapillary mechanism.
a pliable central portion to such a leaflet, while allowing the leaflet to billow toward the atrium during systole, will not necessarily restore competence by allowing advancement of the free edge of the leaflet.

Mobilization of Leaflets

Closure of the mitral valve orifice is effected mainly by the freely mobile anterior leaflet, and mobilization of this leaflet is of the utmost importance in the correction of mitral insufficiency. This may be achieved by several methods.

Separation of Fused Commissures

Although commissural separation by blunt or sharp dissection\(^{10, 19, 20}\) may increase the mobility of the anterior cusp, it may increase regurgitation if performed in the presence of a dilated annulus. In these circumstances, fusion of the cusps at the commissures acts as an annuloplasty, and removal of this restraint increases the distance through which the anterior leaflet must move to effect closure. It appears, therefore, that commissurotomy alone can be of value only when the annulus is of normal or smaller than normal size.\(^{11}\)

Removal of Calcium from the Leaflet

Plaques of calcium, which cause immobility and rigidity of the anterior leaflet, may be removed by crushing and excision.\(^{6, 7, 10, 20}\) Although, in the occasional case, leaflet mobility may be restored, gross calcification usually is accompanied by pronounced fibrosis and contraction of cusp tissues, and this maneuver is of limited value.

Freening of Chordopapillary Adhesions

Abnormal chordopapillary adhesions may be freed by finger pressure or by sharp dissection, and it may be necessary to split the fibrous subvalvular mass right down into the papillary muscles.\(^{6-8, 21, 22}\) Adhesions between chordae to both anterior and posterior cusps often may be relieved by dividing those chordae connected to the posterior cusp;\(^{20}\) and since, in this type of case, the posterior leaflet is almost invariably grossly fibrosoed, eversion during systole will not occur.

Mobilization of leaflets by these technics may be combined with annuloplasty or some other procedure,\(^{10, 19, 20}\) but in a single case described by Barnard and co-workers,\(^{20}\) mobilization was all that was required to restore competence. Unfortunately, however, many valves that show gross commissural fusion, calcification, and chordopapillary adhesions have an annulus of normal or decreased circumference and, hemodynamically, both incompetence and stenosis are present. Should regurgitation persist after mobilization in these cases, annuloplasty is not applicable, since existing stenosis may be aggravated and total replacement of the diseased valve may be the only method of correction.

Repair of Ruptured Chordae Tendineae

Numerous technics for the correction of mitral insufficiency due to rupture of chordae have been reported. January and co-workers\(^{24}\) constructed artificial chordae of black silk between the papillary muscle and the free edge of the posterior leaflet; at catheterization 6 months postoperatively, the valve was shown to be competent. Kay and co-workers\(^{12}\) described two cases of rupture of chordae to the aortic leaflet of the mitral valve that were treated successfully by suturing the leaflet edge to the papillary muscle with interrupted figure-of-eight silk sutures; in both cases this repair was supplemented by annuloplasty. Nichols and co-workers\(^{6}\) have reported three cases in which they sutured ruptured chordae to their normal point of attachment. The repair was reinforced with Teflon or Dacron fabric, and a good immediate result was obtained in each case.

An alternative approach suggested by Ellis and his associates,\(^{25, 26}\) but applicable only to rupture of the chordae to the posterior cusp, is to fix the flailing leaflet to the ventricular wall and mitral ring by multiple through-and-through sutures, thus forming a baffle against which the anterior leaflet may close during ventricular systole. This technic combined with annuloplasty was used in three cases with good results.

More recently, McGoon\(^{27}\) has advocated pli-
cation of the affected leaflet in a plane parallel to the free edge of the valve, thus effectively shortening the flailing segment of the leaflet, which is then restrained by adjacent intact chordae. The technic is applicable to rupture of chordae to both cusps, and, in both cases reported by McGoon, the valve was competent at follow-up examination 8 months postoperatively. Additional successful cases have been reported by Ellis and co-workers and by Steinmetz and co-workers, the latter authors combined the repair with annuloplasty.

Early results with all of the above methods have been satisfactory, but in no case has follow-up been long enough to assess the durability of the repair. Since the operations described by McGoon and by Ellis and co-workers are technically easy to perform, and since recurrence, due to sutures cutting through or breaking, appears to be less likely than if artificial chordae are constructed, one of these techniques would seem applicable for the correction of mitral insufficiency caused by ruptured chordae tendineae.

**Narrowing the Mitral Annulus**

The technics already described have the common goal of increasing the effective area of the cusps in the closed position. The same effect may be achieved by decreasing the size of the valve orifice. Stenosis will not be produced if such narrowing is not excessive. Direct-vision annuloplasty, first described in 1957 by Lillehei and co-workers, has been the most widely adopted technic for the correction of mitral regurgitation. As usually practiced, heavy through-and-through silk sutures are placed in the annulus in the region of one or both commissures and tied over pledges of plastic material in an attempt to prevent the sutures from cutting through.

All investigators agree that the initial results of the operation are excellent. Operative mortality, in cases of pure mitral insufficiency, has been low, and several series with an immediate mortality of less than 15 per cent have been reported. When used in cases of mixed stenosis and incompetence, results have been a little less satisfactory and the reported mortality rates vary between 6 and 42 per cent. In most of these series, annuloplasty was combined with one or another of the maneuvers already described, but narrowing of the annulus was the major factor in restoring competence.

There is less uniformity of opinion regarding the long-term results of annuloplasty. Kay and co-workers followed 50 survivors of annuloplasty (for pure insufficiency in 21 and for predominant insufficiency in 29) for from 4 to 42 months. There was one late death at 16 months in the group operated on for pure insufficiency, and the results were stated to be good in 80 per cent of the remaining patients. In a series of 27 patients seen from 4 to 51 months postoperatively, 20 good, five fair, and two poor results were reported by Clowes and co-workers. Fourteen survivors followed by Steinmetz and co-workers showed very good results, but the length of follow-up in this series was not stated. No recurrences were encountered by Morris and co-workers in six patients with pure insufficiency and 13 with mixed insufficiency and stenosis who were followed for up to 2 years postoperatively.

In a carefully conducted study by Anderson and co-workers, 11 surviving patients were hospitalized for re-evaluation between 4 and 41 months after annuloplasty, and 10 of them showed subjective improvement. In the remaining patient, recurrence of regurgitation was found. Each of the 10 patients classified as improved showed improvement in at least two or more parameters of cardiovascular function studied; two patients, however, showed evidence of some degree of mitral stenosis. On the basis of these results, Merendino has stated that he considers annuloplasty to be a satisfactory operation, especially in those cases in which the annulus is dilated, but often even if the annulus is of normal size. In a similar study, Bigelow and co-workers reassessed 11 survivors of annuloplasty, performed for pure or predominant mitral insufficiency, 1 to 2½ years post-
operatively. Clinical, radiologic, and physiologic (dye-dilution curve) examinations were carried out and left atrial pressures measured. Nine excellent, one good, and one fair result were reported. Wooler and co-workers\textsuperscript{26} reported 21 patients with a good result after follow-up for as long as 4 1/2 years. In all Wooler's cases, which had been selected carefully as described by Nixon and co-workers,\textsuperscript{36} the anterior mitral leaflet was pliable and mobile, and a modified technic, in which the posterior leaflet is elevated, was used.

A useful modification of mitral annuloplasty has been described by Kay and co-workers.\textsuperscript{19} The insufficiency is corrected by decreasing the size of the annulus of the mural cusp and preserving all of the annulus of the aortic cusp. When reviewed between 1 and 2 1/2 years postoperatively, 31 of the 36 survivors of this modified operation were found to be greatly improved, and only three patients showed no improvement.\textsuperscript{19}

Other investigators have been less satisfied with their results. In Effler's\textsuperscript{37} experience, the over-all long-term results were disappointing and the beneficial initial physiologic improvement was only of short duration. Ellis and co-workers\textsuperscript{26} have reported that two of three patients, studied in the hospital between 7 and 8 months postoperatively, showed hemodynamic recurrence, even though they remained clinically well. This observation suggests that some patients reported to be clinically well at follow-up examination may be in a similar plight if a more critical evaluation were carried out. Barnard and Schrire\textsuperscript{41} have reported recurrences at 3 months due to sutures cutting out and at 5 months due to progressive dilation of the annulus. Recurrences also have been recorded at 41 months by Steinmetz and co-workers,\textsuperscript{9} and at 4 months by Kay and co-workers\textsuperscript{8} in two cases; and Bigelow and co-workers\textsuperscript{34} reported two deaths at 5 months and 18 months, respectively.

Kay and co-workers\textsuperscript{8} have described a modification of annuloplasty in which they use a horseshoe-shaped Teflon felt prosthesis in an attempt to prevent recurrence due to sutures cutting through the annulus. This prosthesis is anchored at its central point to the central point of the annulus at the incompetent commissure, and at each extremity to a point on the anterior and posterior portion of the annulus. Each limb of the horseshoe is shorter than the segment of the annulus to which it is to be sutured. Fixation of each limb to the annulus by means of a continuous silk suture effectively plicates the annulus, and the multiple point fixation achieved places less strain on each stitch until such time as tissue grows into the Teflon. This technic has been used with success by Ellis,\textsuperscript{38} but Hufnagel\textsuperscript{39} has warned that Teflon felt may stretch and he has had recurrence in two cases within 6 months of operation in which this method was used.

The variable results reported may be due to the different technics employed by various groups. The concept of narrowing the dilated valve ring under direct vision in the presence of a pliable anterior mitral leaflet is, however, a logical one. Despite the reported incidence of recurrence, almost always the result of sutures cutting through the annulus, the overall long-term results of the operation should be good if this complication can be avoided.

Comment

After careful assessment of the pathologic anatomy of the diseased valve under direct vision at operation, a properly selected reconstructive operation may be found to control mitral regurgitation satisfactorily. In some cases, however, either because of gross leaflet destruction or immobility of existing leaflet tissue, the technics described may fail to restore competence, and replacement of part or all of the diseased valve is then indicated.

Replacement of the Abnormal Valve

Partial Replacement with an Immobile Prosthesis

Regurgitation due to destruction or immobility of the posterior leaflet may be controlled by a roll of compressed polyvinyl (Ivalon) sponge, sculptured to suit the anatomic needs
of the incompetent valve, and sutured under the leading edge of the diseased posterior cusp. The anterior leaflet may then coapt against this newly constructed buttress during systole, and, provided that stenosis is not produced, a satisfactory hemodynamic correction may be achieved. The successful use of such a prosthesis was first described by Gott and co-workers40 in 1957 and was discussed more recently by Mitchel and co-workers22 and Gerbode and co-workers.10 Barnard and Schrire11 have described seven clinical cases with a good result in all of them. Long and co-workers41 reported the use of a spindle-shaped baffle in seven patients and had three excellent and three good results and one hospital death from unrelated causes, while Ellis26, 88 has treated 14 patients and has two hospital and three late deaths.

The use of a baffle is limited to those cases in which the anterior leaflet retains some pliability and mobility, and the insufficiency is due primarily to a deformed, deficient, and immobile posterior leaflet. In many such cases, however, it will be found that a prosthesis large enough to limit regurgitation leads to narrowing of the valve orifice, and the technique will not be applicable. Late complications that have been reported include the occurrence of subacute bacterial endocarditis and dislocation of the baffle due to sutures cutting through the annulus before tissue ingrowth had taken place.11

Partial Replacement with a Mobile Prosthetic Leaflet

Recognizing that the rheumatic process frequently has a selectively destructive action on the mural leaflet,42 McKenzie43 devised a self-restraining Silastic monocusp valve without chordae to replace this leaflet in dogs. While pulse-duplicator studies and animal experiments showed that the valve functioned satisfactorily, thrombus formation and resultant embolization was a constant finding in dogs, and 16 days was the longest survival time. Schimert and co-workers44 replaced the posterior cusp in dogs with a Silastic-covered Teflon-felt leaflet and chordae. Eight of 10 animals survived from 2 to 21 days, and at necropsy the prosthesis was found to be free from clot except at the suture line, where normal organizing thrombus, which appeared unlikely to embolize, was present. Seven of 10 dogs in which the anterior leaflet was replaced with a similar prosthesis survived from 3 to 14 days with identical necropsy findings. King and co-workers16 replaced the anterior leaflet, in three dogs, with knitted Teflon leaflets with two tails which were sutured to the papillary muscles. One animal survived for 7 weeks; at necropsy, the graft was found to have separated from the papillary muscle and the Teflon was stiffened, but there was no evidence of clotting. No clinical trial of these prostheses has been reported.

Partial Replacement with a Mobile Pericardial Leaflet

Frater and co-workers45 recently have performed a series of experiments in dogs in which the mural leaflet and adjoining commissural cusp tissue of the mitral valve were excised and replaced by an autogenous pericardial graft. The graft was sutured above to the annulus and anchored below to the papillary muscles by two tails. Twenty-eight experiments were performed with eight long-term survivors, four of which were sacrificed at 2, 4, 8, and 14 months, and four animals were alive at 5, 7, 12, and 15 months, respectively. Examination of the pericardial leaflets in animals succumbing within 3 weeks of operation showed them to be pliable but thickened, with fibrin deposition on one or both surfaces. Microscopically, a fibrin layer was prominent in all cases, and the pericardium was edematous and showed cellular degenerative changes; in nearly half of the cases, bacterial colonies were identified in the fibrin layer. Valves examined 2 months or more after insertion showed considerable contraction, and little pliability remained. Microscopically, the pericardium had become hyalinized, and, in some instances, cartilage formation could be detected.

Leaflet replacement by autogenous pericardium was then applied clinically in nine patients, five of whom required correction of
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more than one diseased valve. In three cases, a tricuspid leaflet was inserted; in two of these, there was improvement at 9 months and 1 year postoperatively and, in the third, operation was performed too recently for evaluation. In six cases, a posterior mitral leaflet was constructed. There was one early postoperative death, at 4 days, due to persistent mitral insufficiency, and one death at 1 year, probably due to myocardial infarction. The remaining four patients were all improved between 6 months and 1 year postoperatively.

Judging from these clinical results, autogenous pericardium can at least partly correct atrioventricular valve regurgitation, and there is as yet no evidence to suggest gross contraction and loss of pliability as seen in the dog. Before the effectiveness of this procedure can be assessed adequately, however, longer follow-up of clinical cases is essential.

Experimental Results with Total Replacement by a Prosthetic Valve

Monocusp Flap Valves

A number of investigators have made attempts to replace the mitral valve with a variety of flap valves. Any such flap valve must either be fixed above to some form of rigid ring or anchored below by means of artificial chordae in order to prevent its eversion into the atrium during ventricular systole. Using the former approach, Berg and co-workers46 devised a monocusp flap valve fabricated from various types of plastic material or stainless steel and found that the plastic prostheses were not durable and that both types of valve favored clot formation. During ensuing years, several workers have repeated these experiments using modifications of design, material, and technic of insertion, with and without the use of anticoagulants, but all, sooner or later, have encountered the problem of clot formation and resultant embolization. 47–51 Fatigue fracture of plastic flaps also has been encountered,47 and, in an attempt to relieve the strain on the hinge of a flap valve, Frater and Ellis47 devised a flexible monocusp Mylar valve with multiple hinges. The unsupported Mylar cusp continued to fracture, and, therefore, the cusp was covered with knitted Teflon cloth before being used clinically.52 Hemodynamically, these monocusp valves all functioned adequately, and long-term survival in an occasional animal has been recorded.49

Multicusps Flap Valves

Starr53 tested bicuspid Silastic flap valves whose flaps were fixed to the circumference of a Teflon or stainless-steel ring or to a central bar, and Long and co-workers41 used a molded one-piece Silastic bicuspid prosthesis. Clotting was encountered in all of these experiments, and similar findings were reported by Frater and Ellis47 and by Magovern54 for a quadricusps Silastic valve. In an attempt to duplicate the anatomy of the normal valve, Akutsu and co-workers55,56 designed a tricuspid semilunar valve held in a ring which was inserted into the left atrioventricular orifice of dogs. Valves of polyurethane VC and knitted and woven Teflon, with and without siliconization, were employed, and the longest survival attained was 9 days. Results with knitted Teflon were reported as being the most satisfactory.

Valves Incorporating Artificial Chordae Tendineae

Braunwald and co-workers57,58 designed a flexible prosthesis that simulated the anatomy of the normal mitral valve; this was constructed of open-cell polyurethane reinforced with a thin layer of Dacron fabric and was fixed above to the circumference of the mitral annulus and anchored below by artificial chordae of woven Teflon. Four of 25 animals in which this valve was placed, survived between 8 and 40 hours, and, although the valve showed some fibrin deposition at necropsy, there was no evidence of clot formation. Seidel and co-workers59 used a smooth polyurethane valve with chordae of Dacron covered with polyurethane, and reported one dog surviving for 6 months before the valve ruptured. Three animals died between 2 and 3 weeks postoperatively, and at necropsy thrombus was present on the suture lines.

Ball Valves

As early as 1957, Kernan and co-workers60

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described a valve consisting of a Teflon shield housing a Lucite sphere. The valve was inserted into the mitral ring of 25 dogs, and, although it was found to be hemodynamically satisfactory, there was only one long-term survivor. Necropsy revealed that animals died from thrombus formation, emboli, or displacement of the valve. Similar experiments by Ellis and Bubulian\textsuperscript{63} with a Lucite ball valve also were complicated by clotting, as were those in which they used a Teflon valve with a free-floating disk on a central spindle.

Experiments by Starr,\textsuperscript{53} in which he used various flap valves, demonstrated that thrombus built up around the fixation ring and then extended out onto the cusp to interfere with its action. Reasoning that this could not interfere with the action of a ball valve, Starr and Edwards\textsuperscript{62} designed such a valve consisting of a Lucite cage and Silastic ball, the fixation ring of the cage being covered with Teflon fabric. This valve was tested in experimental animals, and 80 per cent survival for from 10 to 14 days was obtained; one dog survived for 13 months. Postmortem examination demonstrated thrombus on the inlet side of the ring originating from the suture line, and therefore a Silastic shield to cover this area after insertion was incorporated in the design. Twenty-six experiments were then performed, and necropsy on animals dying within 3 weeks of operation showed no clotting. Despite the shield, clot was present in animals necropsied at 2, 4, and 6 months postoperatively.

Recently Cartwright and co-workers\textsuperscript{63} have described an “open end” caged ball valve, which has been inserted in the mitral orifice of 10 dogs; eight animals survived for 5 to 42 days without anticoagulant protection, and necropsy showed that death was due to infection or embolization.

It is apparent therefore that, although a number of valves which are hemodynamically satisfactory have been developed, long-term survival has not been achieved in the dog because of the incidence of thrombus formation and resultant embolization. Recent work by Gott and co-workers\textsuperscript{64, 65} with colloidal graphite-coated prostheses may help to overcome this complication.

**Clinical Results with Total Replacement by a Prosthetic Valve**

**Monocusp Flap Valves**

In 1960 Ellis\textsuperscript{66} reported the clinical use of a Teflon-covered Mylar monocusp valve, and, in the following year, one patient was described\textsuperscript{52} as still well 6 months postoperatively. Necropsy on two patients, who died 4 and 6 weeks postoperatively, showed no thrombus formation; in one, the leaflet was covered with a thin layer of fibrin and, in the other, whose ease was complicated by subacute bacterial endocarditis, a thicker fibrin covering was present.\textsuperscript{66} At the Mayo Clinic, 19 total valve replacements using a modification of this valve were performed during 1962.\textsuperscript{67} In 13 patients, whose valvular disease was confined to the mitral valve, there were three postoperative deaths. Multivalvular disease requiring simultaneous correction was present in six patients and, in this group, there was only one survivor. Long-term results of these operations are still to be assessed.

**Multicusp Flap Valves**

Long and co-workers\textsuperscript{41} have used a Silastic bicuspid valve in one patient who died 9 days after the operation. At necropsy, clots, originating at the junction of the endocardium and the prosthesis, were found on both the atrial and ventricular surfaces of the valve.

**Valves Incorporating Artificial Chordae Tendineae**

Despite limited experimental success, Braunwald and co-workers\textsuperscript{68} inserted a flexible polyurethane valve with Teflon-tape chordae in five patients. There were three operative deaths due to technical reasons, one patient survived for 14 hours, and one for 3 months. At necropsy on the last patient, there was no adherent clot present on the valve, which was covered with a thin layer of fibrin but remained pliable and mobile. Using a Teflon sleeve-valve with chordae, Kay and co-workers\textsuperscript{51} have performed total replacement of
the mitral valve in five patients, with no survivors.

**Ball Valves**

Starr and co-workers\(^6\) have reported the use of their Silastic ball valve in 16 cases. There were three operative deaths and three late deaths due to sepsis. Emboli occurred in two patients, 8 days and 9 months postoperatively, respectively, and two required reoperation for recurrence due to sutures having cut through the annulus. Nine of 10 survivors, all on long-term anticoagulant therapy, remained in excellent condition with no subjective or clinical evidence of cardiac disability. The longest survivor had been followed for 15 months. Effer\(^3\) has inserted the Starr valve in 22 patients. There were two early postoperative deaths, three deaths due to infection 3 to 4 weeks after operation, and one death at 6 weeks due to dislocation of the prosthesis. Survivors were followed for a maximum of 1 year; seven were stated to be in excellent health and eight, improved. Five patients recatheterized postoperatively were stated to be physiologically normal.

At the Mayo Clinic during 1962,\(^6\) 27 operations for total replacement of the mitral valve with the Starr prosthesis were performed. Among 19 patients with disease confined to the mitral valve, there were five deaths; and among eight patients with associated disease of other valves that required correction, there were five deaths. Lillehei\(^7\) has reported seven survivors of 10 operations at which a Starr valve was used for total replacement of the mitral valve. Two patients, neither of whom was receiving anticoagulant therapy, experienced late embolic complications, and, therefore, these drugs are now used routinely after prosthetic valve replacement. Most recently Cartwright and co-workers\(^8\) have used their modification of the Starr prosthesis—the open-end titanium-caged ball valve—in three patients, with excellent results. The longest survivor had been followed for 5 months at the time of their report.

**Lenticular Prosthesis**

Barnard and co-workers\(^1\) have reported the clinical use of a lenticular Silastic prosthesis suspended, by means of a spindle, from a Teflon-coated stainless-steel ring. The fixation ring is covered with compressed polyvinyl sponge, and the valve is anchored to the mitral annulus by interrupted silk sutures that are threaded through a second polyvinyl ring and then tied. This has the effect of sandwiching the annulus and the remains of the excised leaflet tissue between two layers of polyvinyl, thus allowing maximal opportunity for tissue growth. Dr. Barnard has informed us in a personal communication that the prosthesis has been used in eight patients without mortality. All patients were given long-term anticoagulant therapy postoperatively, and survivors have now been followed for up to 8 months. One instance of hemiplegia occurred at 5 months after operation, presumably due to embolization, from which the patient recovered.

**Total Replacement by Valve Grafts**

The concept of replacement of a diseased valve by means of a valve graft has aroused considerable interest, but much controversy exists concerning the fate of such grafts in experimental animals. Much of the work performed concerns valves other than the mitral, but nevertheless the findings are pertinent to the problem of mitral valve replacement.

Several investigators have reported the use of grafts of homologous aortic valve at extracardiac sites in experimental animals. Bill and co-workers\(^2\) described the use of such a graft in an extracardiac shunt between the left atrium and the ventricle in dogs. Survival for up to 4 months was achieved, but the cusps of the valve were shriveled and fibrotic at necropsy. Hufnagel\(^3\) stated that homologous aortic valves failed to function normally when placed in the descending aorta of dogs, but Murray\(^4\) reported that similar grafts survived and functioned well for periods up to 9½ months. Lam and co-workers,\(^5\) using both fresh and preserved homologous aortic valves inserted in the descending aorta of dogs, found that the leaflets became shriveled.
and inactive and ultimately disappeared completely unless persistent aortic incompetence was induced. Similar experiments were repeated by Beall and co-workers and survivors were studied up to 13 months postoperatively. Pressure tracings in 12 of 16 animals demonstrated that the valve was competent, and, at necropsy, the leaflets, while slightly thickened, appeared to have remained pliable and functional.

Equally conflicting results have been reported with intracardiac grafts of homologous valves. Lower and co-workers replaced the pulmonary valve with a homologous pulmonary valve in dogs and concluded that such a graft is unsatisfactory, since the valve leaflets became thickened and retracted, and, microscopically, showed pronounced degenerative changes when examined up to 10 months postoperatively. Heimbecker and co-workers inserted homologous aortic valves into the tricuspid orifice in dogs and found acceptance of the donor valve to be good but variable; survival up to 18 months was obtained. In experiments to replace leaflets of the aortic and pulmonary valves with homologous leaflets, Litwak and co-workers found that, although in an occasional dog the graft survived for 6 to 9 months, the majority of grafts became thickened and retracted and were incapable of normal function. Robiesek and co-workers reported some thickening, contraction, and calcification, but no evidence of graft rejection after experimental replacement of one leaflet of the tricuspid valve in dogs that survived up to 3 years. Pollock and Thomas found that similar grafts became shrunken and fibrosed within 4 months after operation.

Total replacement of the mitral valve with the homologous aortic valve was first reported by Murray in 1956. The valve was inserted in the mitral orifice in an inverted position and fixed below, by means of two tails of aorta, to the papillary muscles; survival for 9½ months in the dog was implied. More recently Willman and co-workers have reported similar experiments with survival up to 5 months. At necropsy, valves were found to be contracted and distorted, and covered with vegetations. Microscopically, infiltration with mononuclear cells, areas of flaky calcification, and colonies of bacteria were seen; these changes were interpreted as being due to homograft rejection with superimposed subacute bacterial endocarditis. When using a modification of this technic, whereby the valve was anchored to the ventricular myocardium below at three points, Heimbecker and co-workers failed to produce any long-term survivors after total replacement of the mitral valve.

Since earlier experiments had demonstrated that homologous pulmonary valves failed to function adequately, Lower and co-workers devised a technic to replace the mitral valve by means of the autologous pulmonary valve. In 22 experiments in dogs, five long-term survivors with functioning valves 1 year after operation were reported.

Current experiments in our laboratory have demonstrated that it is technically possible to transplant the mitral valve in the dog, and one animal is presently surviving 7½ months after operation. Good healing of such homografts to both the annulus and the papillary muscles has been demonstrated, and, at necropsy up to 5 months after insertion, grafts have been pliable and relatively normal in appearance.

Although it has been shown that replacement of the mitral valve with a homologous valve is technically feasible, it would appear that further experiments are needed to ascertain more exactly the fate of such valves. It is of interest, however, that few of the experiments using homograft valves have been complicated by clot formation; this is an almost constant finding when plastic valves are used.

The results of homologous valve transplants in patients are more encouraging. In 1956 Murray reported that good results had been achieved with aortic valve homografts placed in the descending aorta of patients for the correction of aortic insufficiency. Four years
later, Murray\textsuperscript{84} reported that three patients were alive 4\(\frac{1}{2}\), 2\(\frac{3}{2}\), and 1\(\frac{1}{2}\) years after operation and that continued function of the graft had been confirmed in each case by means of dye-injection studies. More recently Kerwin and co-workers\textsuperscript{85} reported that Murray's first patient was still alive and that the graft continued to function after 6\(\frac{1}{2}\) years. In addition, they recorded five other survivors of nine operations. Three additional patients, all well, were reported by Cooley,\textsuperscript{86} the longest survivor having been followed for 1 year.

Transplantation of a homologous aortic valve to an intracardiac site has been reported only recently, by Ross,\textsuperscript{87} who has inserted such a graft in the subcoronary position in seven patients.\textsuperscript{88} There was one operative death; follow-up of the remaining patients was not recorded.

Apart from an early report by Murray\textsuperscript{74} concerning which no further details have appeared, only one clinical case of homograft mitral valve replacement has been recorded. Heimbecker and co-workers,\textsuperscript{78} using a technic similar to that which they had employed experimentally, replaced the mitral valve with a homologous aortic valve. The patient died 1 month postoperatively from unrelated causes, and, at necropsy, it was noted that the leaflets of the valve graft had remained pliable and functional.

Convincing proof of survival of homologous valves in the descending aorta of humans has been presented, and the recent successes just described will be followed with great interest. Should long-term clinical survival of intracardiac homografts be proved, the use of such grafts may become the method of choice for total replacement of the mitral valve, especially in view of the absence of complicating thrombosis and embolization when this technic is employed.

**Comment**

Many of the technics for replacement of the mitral valve are still in the experimental stage; others have only recently been applied clinically. In most reported series, total mitral valve replacement was accompanied by a significant operative mortality. Serious late complications may occur, and little is known concerning the long-term fate of the survivors. Therefore, until the risks of total valve replacement can be reduced, and until more is known concerning the fate of the survivors these technics should be confined to cases in which competence cannot be restored by reconstructive procedures.

**References**


Surgery for Cardiac Insufficiency


Mitral Incompetence

Though morbid changes in the mitral valve were recognized by Morgagni (1761), the clinical features and diagnosis were first made clear by James Hope in 1832, who also seems to have been the first to realize the factor of regurgitation through the cardinal valves, and to have come to this conclusion in June 1825 in reference to human disease; this was therefore before his experimental observations in 1830 and subsequent years on the murmurs produced by rendering the valve segments incompetent. He also recognized that mitral regurgitation might be due to widening of the orifice, consequent on dilatation of the left ventricle, rendering the valves, though otherwise healthy, incapable of closing it, a view later confirmed by McDowel (1853), Stokes (1854), and Gairdner (1856).—Sir Humphry Davy Rolleston. The Harveian Oration. Great Britain, Cambridge University Press, 1928, p. 40.
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