

Mitral Replacement: *

Clinical Experience with a Ball-Valve Prosthesis

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THE MORBID ANATOMY of rheumatic mitral disease is such that in many instances nothing short of excision and replacement will allow adequate relief of the hemodynamic abnormality. Experience with eight such patients in whom mitral replacement has been performed with a ball-valve prosthesis forms the basis of this report.

Considerable work has been performed by other investigators in the development of a total mitral prosthesis for the dog and experience with human mitral replacement prior to our own attempts have been recorded. In the animal laboratory these studies have included the testing of flap valves of various materials,^{3, 6, 9} ball valves,³ sleeve valves without chordae,¹¹ flexible sleeve or leaflet valve with chordae,^{1, 5, 7, 8} homologous aortic valve,⁷ and autogenous pulmonary valves.¹² Problems of fixation, valve function and thrombotic occlusion of the prosthesis have prevented long-term survival in most instances. Human mitral resection and replacement has been reported by Kay,⁸ Braunwald,² Lillehei,¹⁰ Ellis.⁴ While early satisfactory results were obtained in some patients, survival beyond three months has not been reported to now.

Prosthesis

The experience of this laboratory with mitral replacement in the dog reported elsewhere^{14, 15} led to the development of the ball valve prosthesis shown in Figure 1 from which all subsequent valves in this

series have evolved. Firm and lasting fixation has been achieved by the use of interrupted sutures placed through the mitral annulus and through a knitted Teflon cloth ring to which the prosthesis is attached as shown in Figure 2. Satisfactory hydraulic function in the dog was demonstrated by left atrial pressure tracings immediately following implantation (Fig. 3) and by post-operative cardiac catheterization, angiocardiology, and cine-angiocardiology performed from two to 12 months following implantation. Some of the valves in the long-term survivor group have radio-opaque balls or steel pins inserted into the balls so that valve function and ball spin have been observed with fluoroscopy.

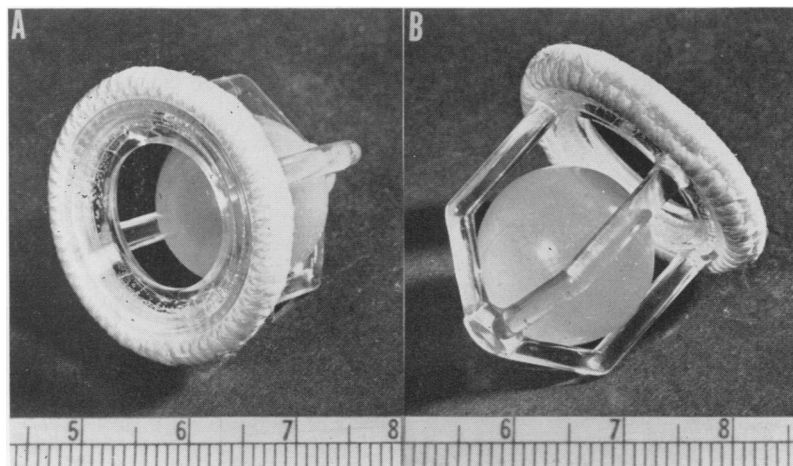
The prosthesis currently employed in the human and the relative dimensions of the two sizes are pictured in Figure 4. A cut-away drawing of the construction is depicted in Figure 5. The case is cast in one piece stainless steel or Stellite 21 and the final dimensions are achieved from the crude castings by machining or grinding. A mirror finish is produced by buffing and electro-polishing. The surface is then silicone coated and carefully inspected. Unless flawless with regard to minor imperfections or irregularities of surface the valve is rejected from further assembly. The knitted Teflon cloth fixation ring is attached by Teflon spreader rings and braided Teflon thread. The ball is of Dow-Corning medical grade heat-cured silastic.

Prior to insertion the valve is cleaned in detergent and autoclaved. Since the initiation of clinical use of the valve minor changes in material and geometry have

* Presented before the American Surgical Association, Boca Raton, Florida, March 21-23, 1961.

This work is supported in part by a grant-in-aid from the Oregon Heart Association.

FIG. 1. The Lucite caged ball valve used in the first long-term dog survivor in this laboratory. A. View of inlet side; B. View of outlet side.



been made. The cages used for Patients 1 and 2 were of Lucite. A change to a metallic cage in subsequent cases allowed a reduction in the external dimensions of the valve with no loss of internal dimension or sacrifice of strength. The fixation device binding the Teflon cloth to the valve in Patients 1-7 consisted of stainless steel spreader rings and stainless steel wire. While all metals used were of the same formulation it was believed prudent to avoid the use of multiple metallic parts for fear of electrolytic corrosion. Subsequent valves have therefore been made with Teflon spreader rings and Teflon thread. The struts of the cage angulated in cases 1-7 was changed to a gentle curve in the current valve. This increases the surface area of contact between the ball and cage in the open position and reduces wear.

While the laboratory demonstration of firm and lasting fixation, satisfactory hydraulic function, and long-term survival is important in the evaluation of a proposed valve substitute there will remain uncertainty regarding the long-term wearing ability of a prosthesis. Extracorporeal accelerated fatigue testing is therefore mandatory prior to clinical use. The mitral ball valve lends itself well to such study since the end point of the test is not the demonstration of total disruption of the valve but easily detectable changes of the size, shape and weight of the silastic ball. Using the

accelerated fatigue test pump developed in this laboratory the valve has been opened and closed at 6,000 cycles per minute at a closing pressure of 150 mm. Hg with the ball so restrained that closure is not a random event in regard to ball surface but is

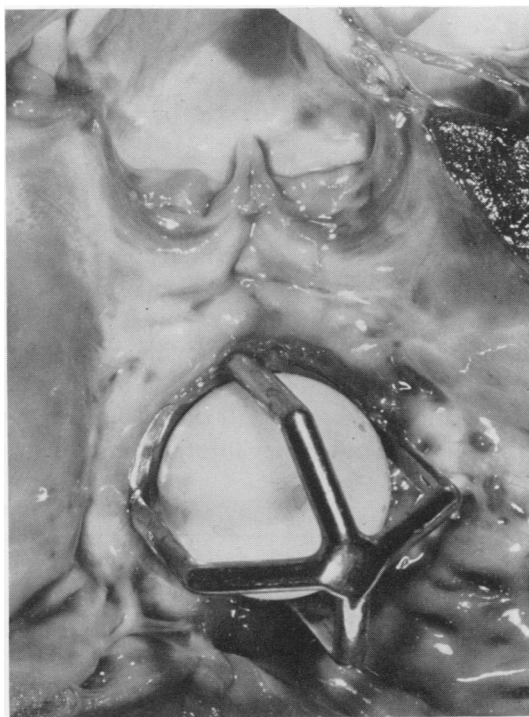


FIG. 2. Left ventricular aspect of dog heart 39 days following mitral replacement with the stainless steel cage barium impregnated silastic ball valve. The Teflon cloth margins are endothelialized and are firmly anchored to the annulus by fibrous ingrowth. The aortic root is demonstrated and the aortic valve remains undistorted.

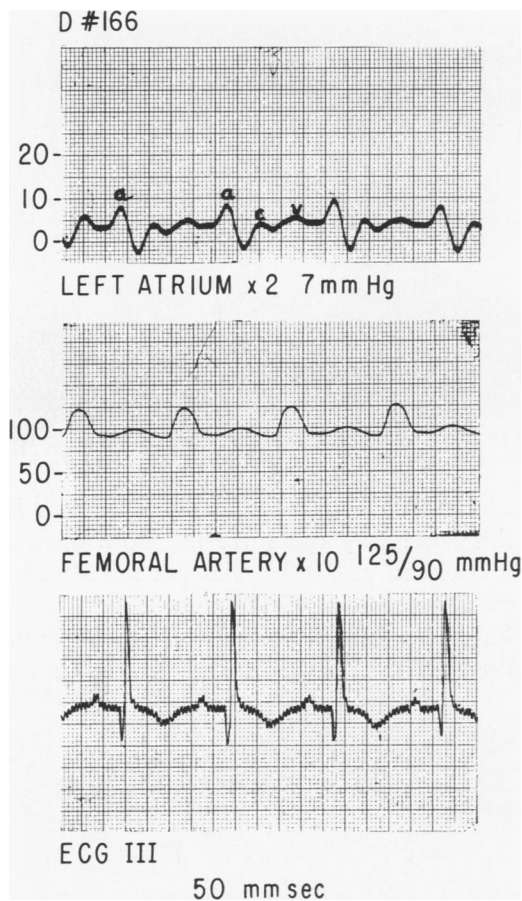


FIG. 3. Operating room pressures following mitral replacement in the dog with the Lucite valve shown in Figure 1. Left atrial pressure tracing is normal both in magnitude and configuration as shown above.

confined to the same area with each cycle. Three weeks of testing in this manner revealed no change in ball dimension, shape, or weight. The proper interpretation of the

extracorporeal test must be tentative and cautious. However, assuming a normal pulse of 80 per minute and similar closing pressures *in vivo* the acceleration is 75-fold. Since the area taking part in the closure is one-tenth of the ball surface area the prevention of ball spin and random closure accelerates the test an additional 10-fold. The total minimal acceleration is therefore 750-fold and at this rate the ball has received the mechanical equivalent of approximately 43 years *in vivo*.

Clinical Material

The mitral ball valve prosthesis was considered available for initial trial in July 1960, and by February 1961, eight patients had undergone resection and replacement therapy for rheumatic mitral disease. Pertinent data concerning this group are presented in Table 1. All patients were seriously incapacitated and were taking digitalis and diuretics. Five patients were in chronic congestive failure despite strict medical therapy in the hospital and were functional Class IV. Most of the patients had severe cachexia with marked weight loss and muscle wasting. Patients 1 and 2 had a history of previously closed commissurotomy and in Patient 1 this was followed by an unsuccessful open procedure for mixed stenosis and insufficiency. Atrial fibrillation was present in all cases.

The usual murmurs of mitral disease were present at the apex and five patients had early diastolic murmurs at the base

TABLE I. Human Mitral Replacement

Pt. No.	Age	Sex	Classification		Date Surgery	Perfusion Time (min.)	Assoc. AI	Results	Comment
			Anat.	Funct.					
1	33	F	Pure MI	IV	8/25/60	108	None	Died	Air embolism 10 hrs. postop.
2	52	M	MS, MI	IV	9/21/60	112	None	Alive	At work as truck dispatcher
3	28	F	Pure MI	IV	10/27/60	89	None	Alive	At work—graduate student
4	45	M	Pure MS	IV	11/ 2/60	151	None	Died	Renal shutdown—11th day
5	32	F	Pure MI	III	1/12/61	58	Slight	Alive	Discharged 4th wk.
6	42	F	Pure MI	III	1/19/61	60	None	Alive	Discharged 3rd wk.
7	41	F	MS, MI	IV	1/26/61	61	None	Alive	Staph. endocarditis—under treatment
8	44	M	MS, MI	III	2/22/61	71	Slight	Alive	No complications

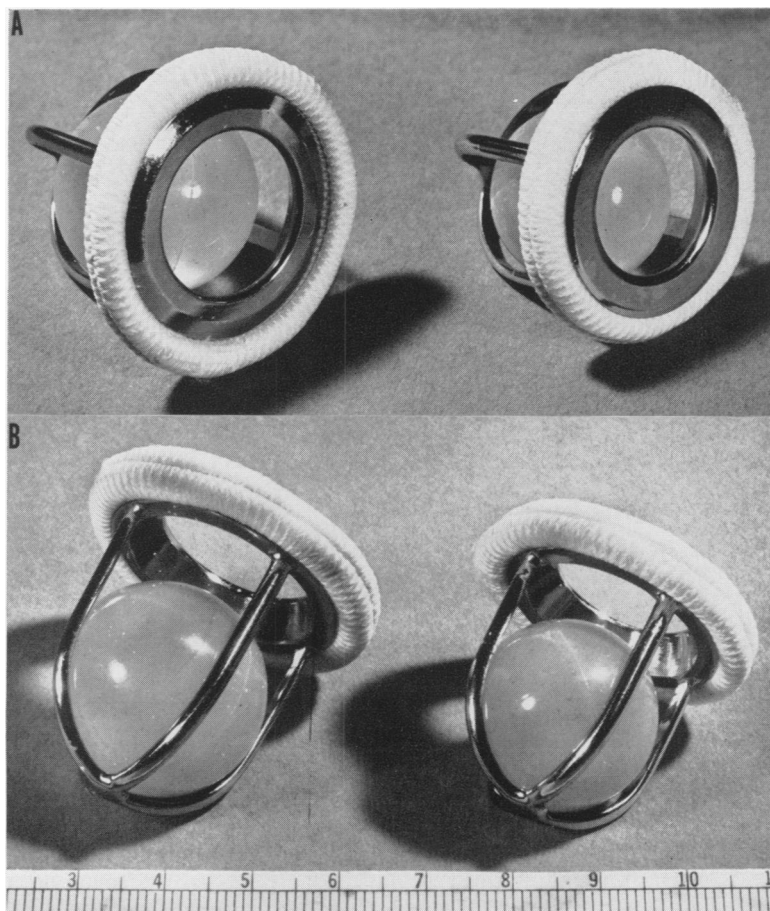


FIG. 4. The mitral ball valve prosthesis for human implantation. A. View of inlet side; B. View of outlet side.

suggesting aortic or pulmonic insufficiency. Left heart visualization by percutaneous retrograde femoral artery catheterization with injection of contrast agent above and below the aortic valve was performed on all potential candidates for open mitral surgery. Slight regurgitation of contrast agent into the left ventricle following supra-auricular injection was demonstrated in one patient and this was correctly considered preoperatively to be injection artifact. Two patients with no evidence of aortic insufficiency on x-ray had slight regurgitation at operation. However, angiocardiology of this type was effective in screening patients preoperatively for subclinical aortic insufficiency of sufficient severity to require aortic cross clamping to maintain operative exposure.

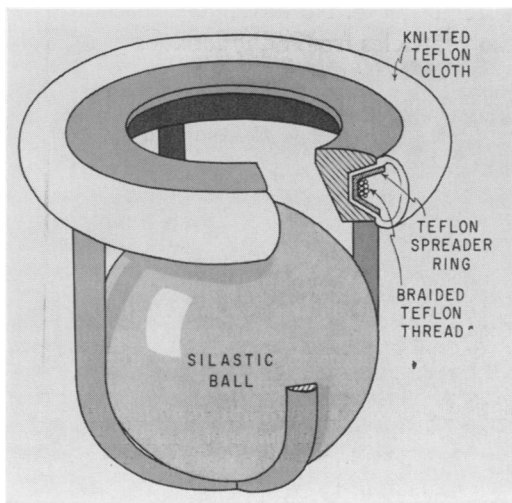


FIG. 5. Cut-away drawing showing method of fixation of Teflon cloth to the metallic cage by spreader ring and Teflon thread.

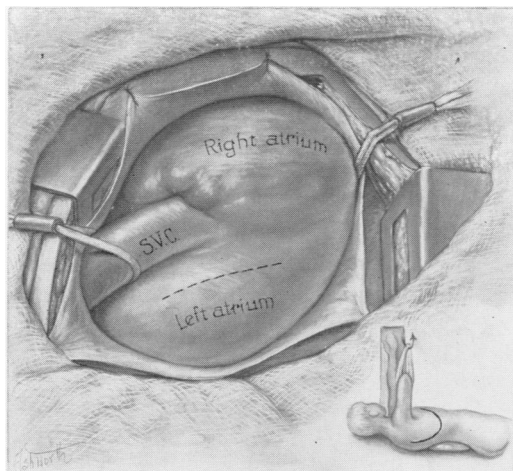


FIG. 6. Operative exposure employed in mitral valve replacement.

All patients had preoperative right heart catheterization demonstrating low cardiac output, pulmonary hypertension, and left atrial hypertension. The data obtained from studies in Patients 2 and 3 whose postoperative catheterization results are available for comparison are presented in Table 2.

Operative Technics

With the patient in the full lateral position exposure is obtained through the entire right fifth intercostal space (Fig. 6). The pericardium is opened anterior to the phrenic nerve. No attempt is made to free the ventricles from adhesions resulting from

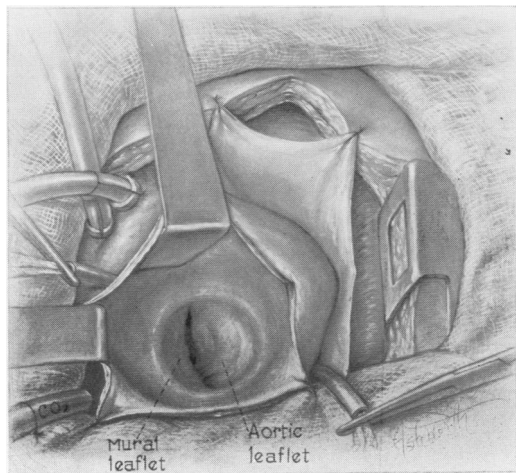


FIG. 7. After total cardiopulmonary bypass has been established the valve is exposed as shown.

previous surgery or pericarditis. The margins of the pericardial incisions are sutured to the drapes to produce a stable operative field and pressures are recorded by needle puncture of the left atrium and pulmonary artery. The cavae are surrounded by tapes. Cannulation is performed in the usual manner using the right common femoral artery or external iliac artery for inflow.

Cardiopulmonary bypass is performed as previously described at a flow of 2.5 l./meter²/body surface/min. which in most instances is reduced to 1.8 l./meter²/body surface/min. as mild hypothermia to 32° C. is produced.¹³ A direct approach via the left atrial wall is preferred and was performed in all instances except Patients 2 and 4, in whom the left atrium was considerably smaller and less accessible than the right atrium. Under these circumstances the transeptal approach provides satisfactory exposure. The left atrium is opened as shown in Figure 7 and the mitral valve exposed. Once the atrium is emptied of blood care is taken to keep the mitral valve incompetent so that foam is not expelled into the aorta. Further protection against air embolus is achieved by flooding the operative field with carbon dioxide. The valvular pathology may be so extensive that resection consists of piecemeal debridement of the mitral annulus.

If the pathology permits, removal of the valve *in toto* saves considerable time. The shorter perfusion time shown in Table 1 in the later cases resulted from adherence to this principle when possible. The attached margin of the aortic leaflet is usually sufficiently flexible so that its junction with the aortic root is clearly discernible. Under these circumstances resection is started by incising this leaflet near the attached margin with no fear of aortic injury, and this incision is continued around the annulus leaving a margin of 3.0 to 4.0 mm. of valve tissue in place (Fig. 8A). On the aortic side this allows the placement of sutures without aortic valve injury and around the remainder of the annulus the residual margin of valve leaflet serves as a marker for

the placement of sutures and provides tough fibrous material that will facilitate firm anchoring of the prosthesis without too deep a bite into the myocardium. With traction upward on the divided valve the papillary muscles are cut and the valve removed. Removal of papillary muscle is not necessary to provide room for the prosthesis so that if adhesions of the papillary muscles to the ventricular wall are present the chordae are divided individually.

In the extensively calcified valve the junction of leaflet with annulus is not clear and it is therefore safer to achieve mobility of the valve prior to resection by dividing the chordae tendineae first (Fig. 8B). The motion of the leaflet thereby achieved allows clear definition of the junction of the valve with annulus and division of the attached margins can follow with safety.

Following resection and inspection of the left ventricle for loose debris one of the two sizes of prostheses is selected and placed in the annulus for a direct fitting. The margins of the Teflon cloth ring must fit easily into the valve orifice and it is best to err on the side of the smaller prosthesis when in doubt. The selected valve is then removed from the heart and 0-silk sutures are placed through the mitral annulus and the cloth margin of the prosthesis. To avoid confusion these are placed through the anterior and posterior commissure first and the remaining sutures inserted one quadrant at a time, using three to four sutures within each quadrant (Fig. 9). The sutures are kept from entangling by placement on a flexible spring. Sixteen to 20 sutures are required for firm fixation and when all are in place the prosthesis is slid down into the annulus and these are tied and cut. The valve is kept incompetent to avoid air embolism by passing a blunt forceps through the prosthesis. The left atrium is then allowed to fill with blood and the atriotomy partially closed. The rewarmed patient is removed from cardiopulmonary bypass, the forceps producing valvular incompetence removed and the remaining atriotomy closed with a partially occluding clamp. This clamp is

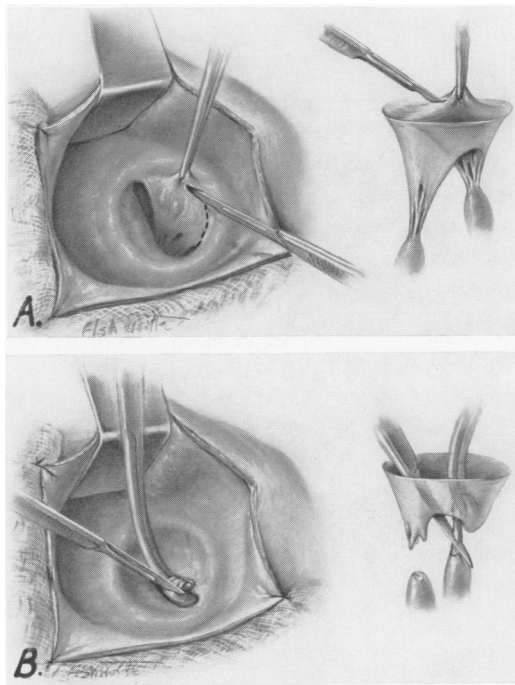


FIG. 8. A. Method of excision initiated by incising aortic leaflet near attached margin. B. Alternate method of excision initiated by dividing chordae tendineae.

opened once or twice to flush the atrium of air after bypass has been completed. The right superior pulmonary vein is checked for air by needle aspiration and decannulation is effected in the usual manner.

Operative Findings

There was considerable variation in the extent of calcification, loss of surface area, subvalvular contractures, and commissural fusion of the mitral valve found in surgery. The specimens shown in Figures 10-12 were amenable to total removal rather than piece-meal debridement and hence represent the least damaged valves resected. The operative findings are described below for each patient.

Patient 1. The pathology at the time of mitral commissurotomy in 1953 is not known. At the time of open mitral surgery in March 1960 the mitral annulus was found to be small and the anterior commissure fused for a distance of 3-4 mm. The mural leaflet was rolled under and functionless. The aortic leaflet was flexible and free of calcification and seemed adequate in surface area. The fused commissure was divided and a single

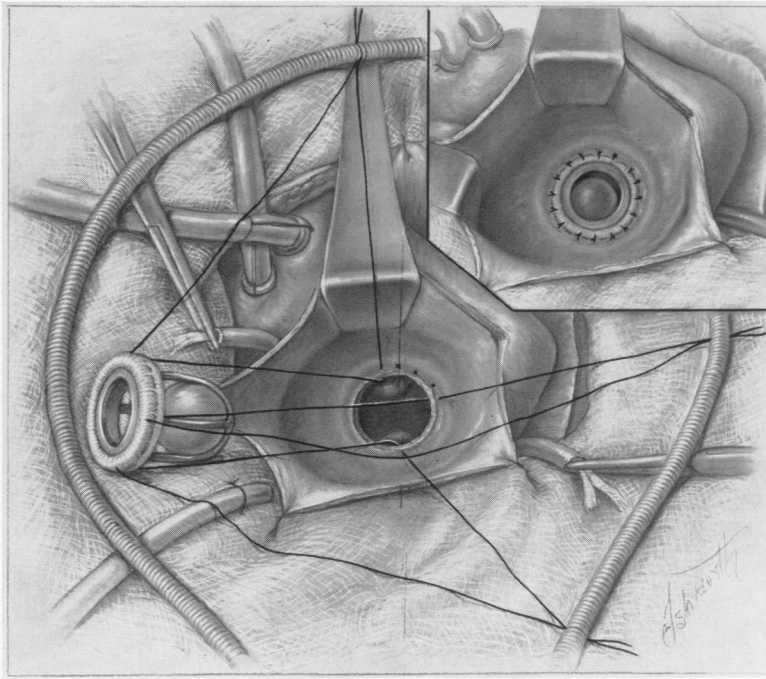


FIG. 9. Method of placement of silk sutures. Insert shows valve in place.

leaflet replacement with a roll of compressed Ivalon sponge was sutured into place. Mitral replacement was performed on August 25, 1960, because of persistent congestive failure with repeated bouts of pulmonary edema due to overwhelming mitral insufficiency. The Ivalon leaflet had not undergone any change in size and was free of thrombus material. The sutures anchoring this leaflet were divided and the leaflet easily removed. During the resection of the mitral valve the extent of subvalvular shortening was greater

than was anticipated at the time of previous surgery. The posterior papillary muscle was adherent to the left ventricular wall and the posterior aspect of the aortic leaflet was pulled down to this by shortened chordae.

Patient 2. At the time of mitral commissurotomy in 1956 complete calcification of the mitral valve was found and fracture of the posterior medial commissure was not possible. Mitral replacement was performed on September 21, 1960 with a preoperative diagnosis of predominant stenosis with insufficiency. The mural leaflet was completely destroyed by fibrosis and calcification. The aortic leaflet was massively calcified, and thickened to 1.0 cm. at its free margin. The posterior papillary muscle was adherent to the ventricular wall and the chordal support of the aortic leaflet was shortened and thickened. A fixed orifice of 3–4 mm. was present.

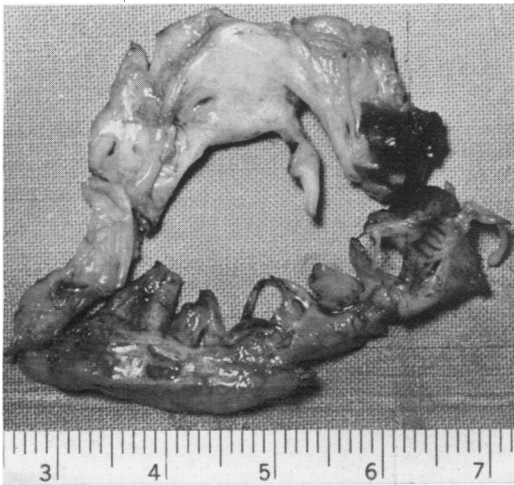


FIG. 10. Operative specimen from Patient 5 with pure mitral insufficiency. There is marked loss of surface area and chordal shortening.

Patient 3. Mitral replacement was performed on October 27, 1960 with a preoperative diagnosis of pure mitral insufficiency. The mitral valve ring was slightly dilated to about three fingers. The mural leaflet was completely rolled under and functionless. The anterior leaflet was free of calcification, flexible, and decreased in surface area posteriorly. The free margin of the aortic leaflet was thickened to 3–4 mm. and pulled downward by chordal shortening especially posteriorly. Annuloplasty was performed narrowing the orifice to two finger breadths but persistent severe regurgitation required that a resection procedure be done.

Patient 4. Mitral resection and replacement was performed on November 2, 1960, with a preoperative diagnosis of calcification of the atrial wall, mural thrombus, and severe mitral stenosis. Soft thrombus material was present over the entire atrium and extended into the orifices of the pulmonary veins. The entire left atrial wall with the exception of the septum was calcified. The valve orifice was 3–4 mm. in diameter and regurgitation was not evident. The mural leaflet was markedly retracted and thickened. The aortic leaflet was flexible along its attached margins but calcified and thickened to 5.0 mm. along the free margin. Leaflets were contracted to about half normal surface area; severe subvalvular contracture was evident.

Patient 5. Mitral valve replacement was performed on January 12, 1961 with a preoperative diagnosis of pure mitral insufficiency. The mitral annulus was of normal size and there was no fusion of the commissures. Calcification was not present.

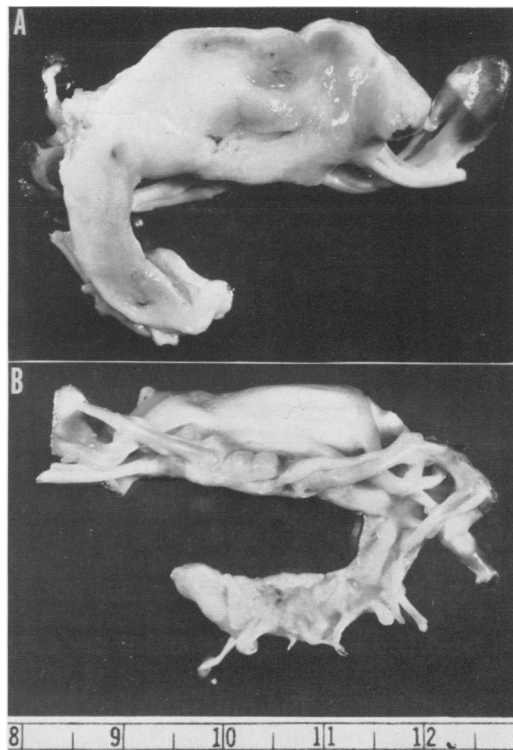


FIG. 12. Operative specimen from Patient 8 with predominant mitral insufficiency. A. View from atrial aspect; B. View from ventricular aspect.

Flexibility was maintained but there was marked loss of substance of both leaflets. The anterior leaflet was rolled under, especially posteriorly and pulled downward into the left ventricle by extreme chordal shortening (Fig. 10).

Patient 6. Mitral replacement was performed on January 19, 1961 with a preoperative diagnosis of pure mitral insufficiency. The mitral annulus was of normal size and the mural cusp was deficient in surface area and held tightly against the ventricular wall. The aortic leaflet was flexible and there was no evidence of fusion of the commissures. Posteriorly the aortic leaflet was markedly deficient in surface area; in addition, chordae attaching to the free margin of this leaflet were shortened resulting in marked limitation of mobility.

Patient 7. Mitral replacement was performed on January 26, 1961 with a preoperative diagnosis of calcific mitral stenosis and insufficiency. There was no dilatation of the mitral annulus. The valve orifice was 10–12 mm. in diameter and there was fusion of both commissures. Severe calcification was present in both leaflets and this was especially heavy posteriorly where blocks of calcium crossed the zone of commissural fusion. There was marked loss of surface area of the leaflet and extreme shortening of the chordae tendineae (Fig. 11).

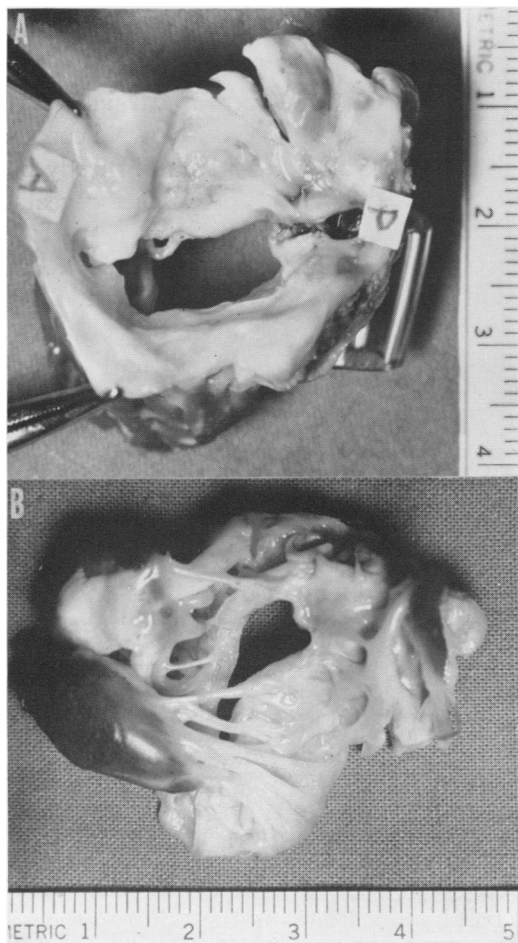


FIG. 11. Operative specimen from Patient 7 with calcific stenosis and insufficiency. A. View from atrial aspect; B. View from ventricular aspect.

TABLE 2. *Right Heart Catheterization Before and After Human Mitral Valve Replacement*

Pt. No.	Time of Study		Average Pressures (mm. Hg)						Index e/Meter ² / min.	O ₂ Cons. cc./min.
			RA	PA			Wedge			
				S	D	M	M	V		
2	Pre-op	Rest*	7	60	36	42	28	3	2.6	300
	Post-op	Rest	5	36	17	22	12	—	1.9	236
	(15 wks)	Exercise	—	54	20	36	14	—	2.1	420
3	Pre-op	Rest	2	50	16	35	20	45	1.9	176
	Post-op	Rest	1	29	10	17	7.5	—	2.5	150
	(14 wks)	Exercise	—	46	13	26	12	—	3.6	342

* Pre-op. study performed by Henry T. Lang, Jr., M.D. and Ralph Berg, Jr., M.D., Spokane, Washington.

Patient 8. Mitral resection and replacement was performed on February 22, 1961 with a pre-operative diagnosis of predominant mitral insufficiency. At operation there was no mitral annulus dilatation. There was slight fusion of both commissures and marked loss of leaflet surface area (Fig. 12).

Results

The two deaths and two serious complications following mitral replacement are noted in Table 1. Patient 1 was returned to the recovery room following an uneventful operation and was awake with normal signs. She was able to sit up for a post-operative chest film which revealed an air fluid level in the right chest that was mistakenly interpreted as partial hemopneumothorax. Ten hours postoperatively as she turned to lie on her right side she expired of massive air embolism. Postmortem x-rays confirmed the air fluid level represented sequestered air in her left atrium.

The prophylactic measures against air embolism described in the previous section were taken in this patient with the exception of flushing out the left atrium after bypass was discontinued. This maneuver performed by momentarily opening the partially occluding clamp on the atriotomy incision would most likely have avoided this death.

The second fatality occurred in Patient 4 and resulted from renal shutdown on the eleventh postoperative day. Bypass was prolonged in this patient because of poor exposure related to the small size of the

calcified left atrium and the need to recover dislodged mural thrombus at frequent intervals during the procedure. The patient was returned to the recovery room with normal vital signs but failed to awaken. Left hemiplegia, coma, and anuria persisted to his death. His cardiac status remained good with no evidence of congestive failure or hypotension until shortly before death. Autopsy examination revealed right cerebral infarction and lower nephron nephrosis. Examination of the heart revealed firm fixation of the prosthesis. There were small adherent clots on the suture line and over the teflon cloth but no thrombus material on the valve itself.

One patient (No. 5) required reoperation for massive hemorrhage from a laceration of the left ventricle produced by the rod used in this case to maintain mitral incompetence while the left atriotomy was being closed. Upon reopening the right thoracotomy massive bleeding was noted from the left side of the heart. The right chest was closed and the ventricular tear repaired through a left anterior thoracotomy. The patient subsequently made an uneventful recovery and was discharged from the hospital four weeks postoperatively in excellent condition.

Patient 7 developed an acute staphylococcal endocarditis on the third postoperative day which responded to appropriate antibiotic therapy. All subsequent blood cultures were negative and she is at present in the hospital still under treatment.

The remaining patients (No. 2, 3, 5, 6) are at home and doing well. Patient 8 has had an uncomplicated course but has not yet been discharged from the hospital. The first survivor (Patient 2) is back at work as a truck dispatcher and the second survivor (Patient 3) is a graduate student.

Postoperative Cardiac Status

All patients undergoing resection and replacement of the mitral valve in this clinic had a satisfactory hemodynamic result as reported in Table 3. There was no difficulty in discontinuing cardiopulmonary bypass and left atrial pressures fell to normal in the operating room except in Patient 8 in whom the mean left atrial pressure fell from 20 to 18 mm. Hg. There was complete freedom from extra-systoles of ventricular origin that might imply impingement of the valve on the left ventricular endocardium. Transient supraventricular tachycardia or rapid atrial fibrillation with rates up to 160/min. were well tolerated in the immediate postoperative period without hypotension or evidence of pulmonary congestion. While all patients had normal venous pressures during the first few postoperative days congestive failure as manifest by moderate hepatic enlargement and tenderness was not unusual beginning from the fifth day to the second week after surgery and responding to increased doses of digitalis and diuretics. All patients showed a dramatic change in heart size and configuration by the time of discharge (Fig. 13, 14).

Phonocardiography was performed on the surviving patients and confirmed the

absence of murmurs due to mitral disease. A typical phonocardiogram before and after replacement is shown in Figure 15. The mean interval in this series between the onset of the Q-wave in the electrocardiogram and the closing sound of the valve was 0.06 seconds and falls within the normal limits for the intact mitral valve. The mean interval between the semilunar valve closure and the "opening snap" of the prosthesis was 0.10 seconds. The patients were pleased by the diminution in cardiac noise and activity noted early in their recovery period but there was occasional awareness of the valve sound in the very thin patient when at bedrest or disrobed. The closure sound in such patient is audible without a stethoscope if the ear is within a few inches of the naked chest. The wearing of a hospital gown or clothing renders the valve inaudible at this range.

Two patients have thus far had postoperative cardiac catheterization and the results are shown in Table 2. The mean pulmonary artery pressure and wedge pressures were normal at rest and only slightly elevated in Patient 2 with exercise. The cardiac index rose in both instances with exercise with a normal response evident in Patient 3.

Red cell survival studies are planned in all patients and were completed in Patient 2, five months following valve implantation. The results are shown in Figure 16.

Anticoagulant Therapy

All patients were given oral anticoagulant therapy beginning on the seventh post-

TABLE 3. Operating Room Pressures Before and After Human Mitral Replacement

Pt. No.	Left Atrium						Pulmonary Artery						Femoral Artery	
	Before			After			Before			After			Before	After
	V	ED	M	V	ED	M	S	D	M	S	D	M		
1	22	12	17	14	9	11	—	—	—	—	—	—	75/55	90/70
2	40	25	32	15	10	13	50	37	45	35	20	25	100/60	75/45
3	50	17	37	10	7	9	50	25	37	35	20	25	100/65	90/50
4	25	15	20	12	5	9	60	35	45	50	35	40	130/80	100/75
5	27	13	17	12	7	10	35	25	30	35	25	30	150/95	115/75
6	25	15	20	15	8	10	30	25	28	—	—	—	115/80	95/60
7	55	32	42	18	14	15	60	50	52	35	25	30	100/70	75/50
8	35	20	25	22	15	18	40	27	35	—	—	—	130/75	100/60

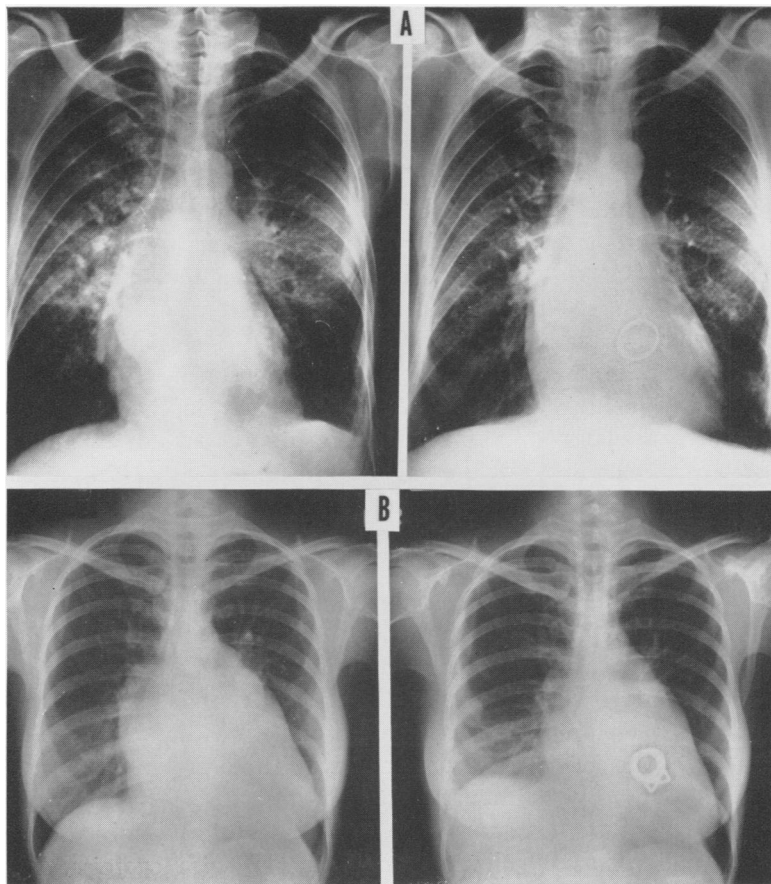


FIG. 13. A. Pre- and postoperative chest x-ray of Patient 2 in whom a Lucite cage valve with steel spreader ring was used. B. Chest X-ray of patient 3 immediately before and one month after mitral replacement.

operative day. There have been no thromboembolic difficulties in the six surviving patients. Patients 2 and 3 were given heparin beginning on the third postoperative day but the subsequent late right hemothorax developing in both patients resulted in reliance upon oral medication alone with a prothrombin depressing drug. It is of interest that because of this complication anticoagulant drugs were discontinued during the second postoperative week in patients 2 and 3 without embolic phenomena. Patient 3 also underwent excision of a left inguinal encapsulated hematoma two months following valve replacement and was again maintained with a normal clotting mechanism for one week without complications. The need for postoperative anticoagulant therapy following human mitral replacement still remains in doubt. However, experience with thromboembolic difficulties in the dog following implantation with a similar prosthesis and the occasional occur-

rence of this complication with the Hufnagel valve in the descending aorta of the human suggests the possible vulnerability of an intracardiac ball valve in this regard. Chronic atrial fibrillation was present in all patients and in itself increases the risk of embolism. Until further experience with human mitral replacement is obtained it seems prudent to maintain a state of diminished blood coagulability in these patients indefinitely.

Discussion

Considerably more information is required before the search for the ideal mitral prosthesis may be discontinued. In the interim, however, the results presented in this report, in terms of extracorporeal accelerated fatigue testing and animal and human implantation, suggest that under certain circumstances the use of the ball-valve mitral prosthesis is justified. The indications for mitral replacement with this prosthesis are

related to the operative findings and the comparative risks and advantages of replacement versus more conservative surgical management. The immediate risks of mitral valve implantation in terms of mortality and morbidity are acceptable when consideration is given to the poor functional status of the patient prior to operation and to the present developmental nature of the procedure. Satisfactory hemodynamic results can be expected with some regularity following the valve replacement procedure since the hydraulics of the valve varies only with the size of the prosthesis. However, the advantages of the prosthesis over plastic procedures on the mitral valve in terms of predictability of hemodynamic result must be balanced by the unknown long-term hazards involved in total dependence upon an intracardiac appliance. For this reason the only indication for mitral replacement in this series has been the opera-

tive findings of a hopelessly diseased valve not amendable to any reasonable plastic procedure in a patient with severe symptomatology (functional Class III or IV) from whom prior permission for the use of the prosthesis has been obtained.

Evaluation of the pathology in terms of the need for replacement is not difficult in those cases of complete bone-like calcification of the valve with marked loss of valve substance and chordal contracture. Pure stenosis or a combined lesion with predominant stenosis is usually present in this group of cases and these findings may be predicted by preoperative cardiac fluoroscopy. Even in the presence of pure stenosis primary replacement is indicated in this group. Considerably more judgement is required in the evaluation of the insufficiency group. In the patient with marked dilatation of the annulus, flexible aortic leaflet with adequate surface area, and rolling un-

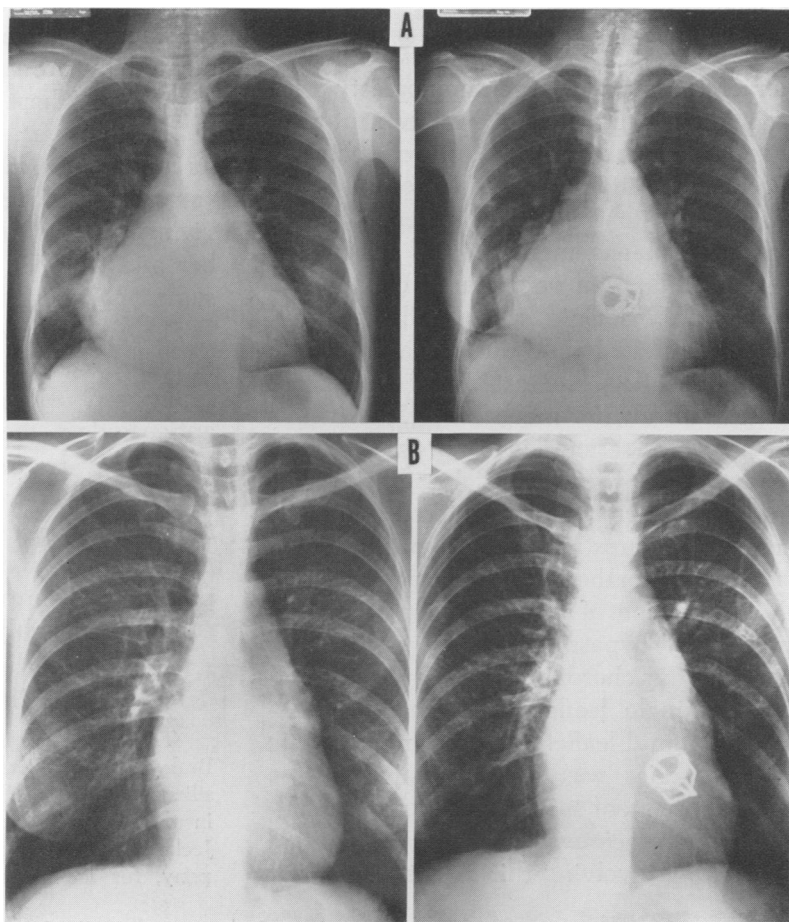


FIG. 14. A. Chest x-ray of Patient 5 immediately before and one month following mitral replacement. B. Chest x-ray of Patient 7 immediately before and one month following mitral replacement.

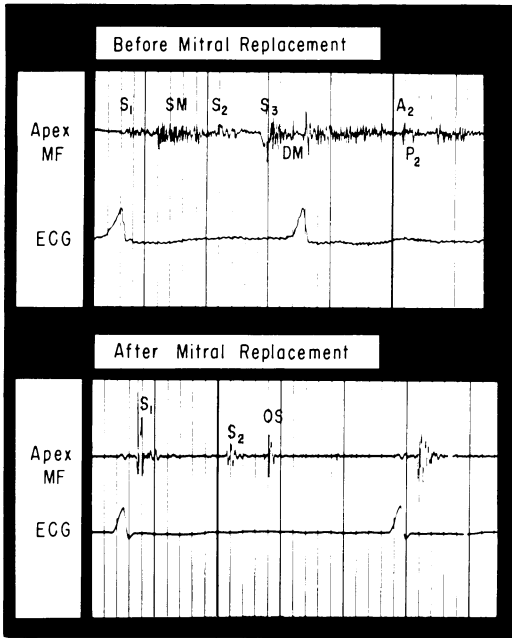


FIG. 15. Phonocardiogram of Patient 3 measured immediately prior and three months following mitral replacement. O.S. represents "opening snap" of prosthesis.

der of the mural leaflet annuloplasty with or without mural leaflet replacement may give excellent results. Ruptured chordae tendineae with annular dilatation also represents a prime indication for conservative operative management. In the absence of annular dilatation or ruptured chordae severe mitral insufficiency is usually the product of marked loss of surface area of one or both leaflets and extensive contracture of the subvalvular mechanism. It is in this group with serious involvement of both leaflets and their chordal support that mitral replacement is considered. It is possible to underestimate the contribution of subvalvular pathology to regurgitation since decompression of the heart during cardiopulmonary bypass takes some of the tension off the chordae. The poor result following single leaflet replacement for destroyed mural leaflet in patient number one in this series was clearly related at the time subsequent mitral resection to a failure to appreciate the degree of chordal shortening involving this leaflet. This error

was not repeated in the subsequent cases of pure mitral insufficiency (Patients 3, 5, 6).

There are marginal instances in which the results of annuloplasty or leaflet extending procedures are difficult to predict unless these procedures are actually performed. It is reasonable under these circumstances to attempt to conserve the patient's valve and then assess the results either visually or by palpation and pressure studies immediately after bypass. Should there be dissatisfaction with the results obtained, the repair can be taken down and the valve replacement performed at the same sitting.

Summary and Conclusion

Mitral replacement with a ball-valve prosthesis has been performed on eight patients. The prosthesis prior to this experience was demonstrated to provide firm and lasting fixation to the mitral annulus, satisfactory hydraulic function and long-term survival in the dog. All patients had a satisfactory hemodynamic result documented by pressure studies in the operating room. There were two postoperative deaths that were unrelated to the prosthesis and the remaining patients are convalescing satisfactorily. The first two surviving patients, operated upon in September and October 1960, are free of cardiac symptoms and back at work.

The results obtained thus far in terms of cardiac catheterization, phonocardiography, red cell survival, and the need for anticoagulant therapy are presented.

Mitral valve replacement at present is indicated only in severely incapacitated patients with operative findings of a hopelessly damaged valve not amenable to any plastic procedure and in whom operation cannot reasonably be postponed.

Acknowledgments

The authors express their appreciation to Silas Braley, of Dow-Corning, for his help in supplying silicone rubber and other silicone products used in the fabrication of the prosthesis, to Norman Jeckel, of U. S. Catheter and Instrument Company, for making available various Teflon cloth

RED CELL SURVIVAL FOLLOWING MITRAL VALVE REPLACEMENT

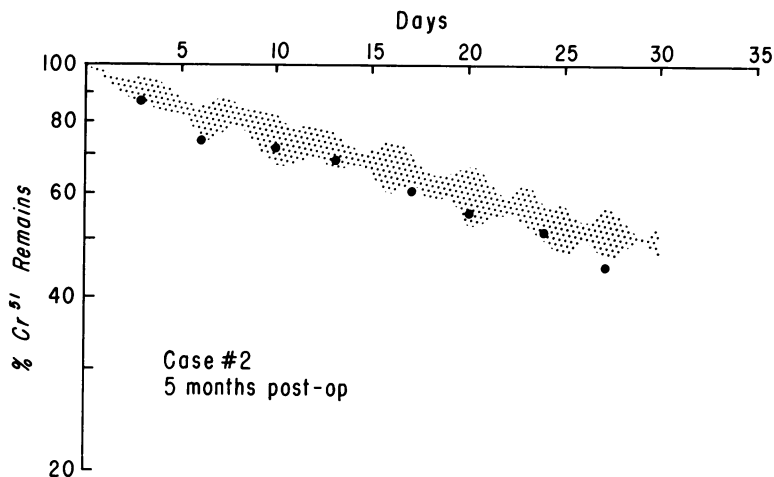


FIG. 16. Radioactive chromium tagged red cell study of Patient 2. Shaded area represents the normal limits in this laboratory.

products used in the fixation ring, and to R. R. Miller, of Precision Metalsmiths Incorporated, Cleveland, Ohio, for his help with metallurgical problems involving casting technics. The prostheses used in this study were obtained from the Edwards Laboratories Inc., 603-H Alton Street, Santa Ana, Calif.

Addendum

Since submission of this paper, four more patients have had mitral replacement with no operative deaths and one late death due to staphylococcal endocarditis. This patient and Patients 7 and 8, who also died of endocarditis two months after replacement, was operated upon during an epidemic of staphylococcal infections involving other cardiac surgical patients and requiring temporary closure of the operating suite. All seven survivors continue to maintain dramatic initial functional response.

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DISCUSSION

DR. MICHAEL E. DEBAKEY: I must say that this paper persuades me to re-evaluate my attitude toward ball valves. I have been somewhat prejudiced against them because of my very early experience with their use in changing the directional flow in blood pumps. Our more recent experience with the use of such ball valves, as in the Hufnagel valve in aortic insufficiency, also tended to make me somewhat prejudiced.

Perhaps today with much better materials, materials that obviously have less effect upon the cellular and other components of the blood, these valves may be less harmful and therefore more useful.

Nonetheless, it seems to me that this is very impressive work on the part of Drs. Starr and Edwards. Everyone who is familiar with this area of pathology and with the problems relating to correction of this type of lesion knows the difficulties involved in attempting to replace the mitral valve. Although these results are yet too early for final evaluation, they are most encouraging.

DR. GEORGE H. A. CLOWES, JR.: As one who has heard the story on this business of artificial valves practically since its beginning in connection with the Artificial Internal Organ Society, I am equally impressed with Dr. DeBakey.

This is a most remarkable piece of work, to have had six out of eight patients survive. I simply want to outline briefly some of the problems that have confronted workers in this field that Dr. Starr was a little too modest to talk about.

Now I know that from his excellent paper on oxygen consumption, and so on, he did a very careful job of work before he did this thing. But lots of competent people like Drs. Koll, Kay, Muller and others have worked on it. They found that the great problem was not that they could not put in valves that would work, but that they always produced thrombi in dogs. This was true particularly at the junction between the myocardium or endocardium and the prosthetic substance. On the left side if these thrombi dropped off, the animal died of a cerebral embolism, and this inevitably took place within three or four weeks.

For that reason, many of us have been very reticent about putting in these artificial prostheses. We have been waiting for the time when we

thought we had to do it; but Dr. Starr has succeeded in doing it, and he has proved the point that was brought out at the NIH meeting in Chicago last fall concerning artificial heart valves, that probably man does not react as violently as the animal does in producing a clot at the interference between myocardium and the artificial prosthesis. It may be that man is a better candidate for this type of thing than the animal.

DR. ALBERT STARR: (Closing) We were prejudiced against the ball valve for use as an intracardiac prosthesis, and it was difficult to state in the short presentation the various steps that led to the choice of this "repugnant" intracardiac appliance.

Numerous other types of valves were tried, and as Dr. Clowes has mentioned, the problem of thrombosis in the dog made evaluation impossible. However, with the ball-valve prosthesis it was possible to obtain long-term dog survivors without anticoagulant treatment. I believe the reason for this is that the valvular mechanism is not attached to the body of the prosthesis itself. The clot in the dog grows by direct extension like an infiltrating tumor rather than by multicentric origin, so that the clot which forms on the margin of the valve at its point of attachment is less likely to interfere with valve function with the ball valve as compared with other types of prosthesis in which leaflets are anchored to the mitral annulus itself. I think this explains our ability to obtain long-term survival with the dog with the ball valve.

Some of the dogs who were not on anticoagulant treatment have had embolic problems requiring on one occasion reoperation for saddle emboli. For this reason, the patients in this series are receiving anticoagulant therapy. All had atrial fibrillation. Many of them have had anticoagulants before operation. The price we pay for adequate hydraulic function in terms of anticoagulant treatment is really not great.

The valve that we currently use in the dog is somewhat different from the ball valve in the human. We have found that if we shield the suture line with some bland material such as silastic so that the zone of injury of the endocardium is separated from the circulation, that the tendency to thrombotic occlusion is completely overcome and embolic complications even without anticoagulant therapy following implantation in the dog are markedly reduced.