APICAL LEFT VENTRICULAR-ABDOMINAL AORTIC COMPOSITE CONDUITS FOR LEFT VENTRICULAR OUTFLOW OBSTRUCTIONS

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Certain problems related to the left ventricular outflow tract are not amenable to conventional surgical methods, but may be solved with the creation of a double outlet left ventricle by using a composite rigid pyrolite left ventricular apex outlet prosthesis and a fabric valve-containing conduit. Low porosity woven Dacron tube grafts are used for the conduit. Twenty-three patients who have undergone apico-aortic bypass with this conduit are reported here, with gratifying results in eighteen.

The basic defect in left ventricular outflow tract obstructions, which include supravalvular, valvular, subvalvular and cavitary stenoses, is mechanical. These lesions present a spectrum of decreased cross-sectional areas and increased impedances to left ventricular outflow. They result in higher intra or supraventricular pressures proximally, and lower systolic and pulse pressures distally. The major physiologic derangements are limited cardiac output, increased left ventricular work and oxygen consumption, and lowered coronary artery perfusion pressures. Without surgery, the pathologic results are left ventricular hypertrophy, angina pectoris and, on occasion, sudden death.

Conventional surgical management for most such lesions is satisfactory, e.g., ascending aortoplasty for surpravalvular stenosis, aortic valvotomy for congenital valvular stenosis, resection for discrete subvalvular membrane, and a number of procedures directed at relieving obstructive myopathies. In certain instances, however, less than optimal results are achieved by standard methods. The surgeon may be limited by anatomic features, the presence of adhesions from previous procedures, or the possibility of producing heart block, aortic regurgitation or perforation of the interventricular septum.

RATIONALE

Over the last six years, we have accumulated in approximately 200 calves more than 20,000 hours of evaluating and testing of pumping prostheses interposed between the left ventricular apex and the abdominal aorta. More re-

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cently, clinical trials with this left ventricular assist device have been applied in 18 preterminal patients.[1] Early during these investigations, the possibility was evident for using a composite valve-containing conduit to relieve left ventricular hypertension.

The concept is not new (vide infra), but clinical applications required the evolution and refinement of certain techniques of total cardiopulmonary bypass. These included 1) the use of cardioplegic solutions; 2) diagnostic radiography and echocardiography; 3) the fabrication of low porosity synthetic grafts; 4) the availability of stabilized glutaraldehyde-processed porcine aortic valved (Hancock) prostheses, or more reliable synthetic valve prostheses such as the Cooley-Cutter prosthetic valves; and 5) the development of a reliable, durable, thromboresistant, biocompatible material (L.T.I. Pyrolyte® Carbon) for the fabrication of a special rigid apex outlet prosthesis.*

EVOLVING CONCEPTS

In 1910, Alexis Carrel described experiments in which bypasses were established from the left ventricle to the thoracic aorta with the use of vein grafts.[2] Similar studies were undertaken by Jeger prior to 1923. In 1955, Sarnoff, Donovan and Case used a Lucite tube containing a modified Hufnagel ball-and-seat valve to direct the entire cardiac output from the left ventricle to the descending thoracic aorta. In dogs so treated, the ascending aorta could be totally and permanently occluded with apparent impairment of the circulation. Postoperatively, these animals ran, jumped and swam. In 1962-63, Templeton implanted prostheses similar to those originally described by Sarnoff in five patients with severe aortic valvular stenoses; one patient survived more than 10 years. Al-Naaman reported similar experimental approaches in 1962, as did Detmer, Johnson and Braunwald in 1971. Some of our relevant work was reported in 1972, and further experimental studies were reported by Brown, Meyerowitz, Cann, McIntosh and Morrow. In 1975, Bernhard and co-workers reported an operation in which a stainless steel conduit was connected from a patient's left ventricle to the descending thoracic aorta, and in the same year, we reported our clinical trials of a different technique based upon the same concept. Other more complex techniques have been evolved.[3-6]

STATE-OF-THE-ART

Thus far, we have implanted our composite prosthesis in 23 pediatric and adult patients with various forms of primary or recurrent left ventricular outflow tract obstructions.[7,8] In addition, we have fabricated rigid Pyrolite® left ventricular apex outlet prostheses for approximately 50 other institutions, where good results have been reported.

The absolute and relative indications and contraindications remain evolutionary. The specific instances in which we have used this approach are included

*Texas Technology Transfer Laboratories, Inc., P.O. Box 4057, Pasadena, Texas 77502 in Table I. In general, primary or recurrent left ventricular outflow tract obstructions of any etiology, in any age group, seem amenable to these approaches.[9,10]

TABLE I. Twenty-three Pediatric and Adult Patients in Whom Composite Prostheses Have Been Implanted

	PRE-OP				POST-OP			
Dx.	Age	Sex	LVP (mmHg)	LV-Ao Gradient (mmHg)	LVP (mmHg)	LVP-Ao Gradient (mmHg)	AoQ (%Co)	Conduit Q (%Co)
1)	11	F	250	130	130	15	71	29
2)	7	M	200	105	135	20	59	41
3)	15	F	220	140	120	10	67	33
4)	36	M	250	130	130	20	76	24
5)	72	M	140	60	130	20	60	40
6)	39	F	220	80	100	0	—	—
7)	15	M	260	100	170	0	59	41
8)	18	F	230	110	180	60	59	41
9)	4	M	205	100	100	20	59	41
10)	5	F	180	70	—	—	—	—
11)*	9	M	240	150	—	—	—	—
12)**	8	F	185	65	—	—	—	—
13)	27	F	150	125	120	5	67	33
14)	16	F	285	120	120	20	55	45
15)	18	M	240	100	180	50	82	18
16)	28	M	150	60	100	40	57	43
17)	20	M	—	100	—	30	50	50
18)	8	M	180	80	100	10	—	—
19)	15	M	230	110	—	—	—	—
20)**	12	M	200	120	120	10	—	—
21)*	49	M	220	100	—	—	—	—
22)*	9	M	220	115	—	—	—	—
23)	66	F	240	40	—	—	—	—
Mean:			213+37	100+28	129+27	21+17	63+9	37+9

1) Congenital A.S.-A.I., previous valvotomy; 2) Supravalvular A.S., previous aortoplasty; 3) Supra and subvalvular A.S., previous aortoplasty; 4) Subvalvular A.S., previous resections; 5) Calcific A.S., calcific annulus and ascending aorta; 6) Calcific A.S., previous A.V.R.† with small annulus; 7) Supravalvular A.S., previous aortoplasty; 8) I.H.S.S.; 9) Congenital A.S.; 10) Subvalvular A.S.; 11) Congenital supravalvular A.S., pulmonary branch stenosis; 12) Subaortic stenosis, M.I., previous coarctation, previous resections, previous ventriculotomy; 13) A.S., previous A.V.R.,† small annulus and hemolytic anemia; 14) Congenital supravalvular A.S.; 15) Congenital A.S. with small annulus, previous A.V.R.,† 16) Congenital A.S. with small annulus, previous valvotomy and commissurotomy; 17) Congenital subvalvular A.S.-A.I., previous resections, PDA ligation and valvotomy; 18) Supra and valvular A.S., branched pulmonic stenosis, previous resection and valvotomy; 19) A.S.-A.I. with

small annulus, previous coarctation, valvotomy and A.V.R.;† 20) Congenital Supra and valvular A.S. with small annulus, previous valvotomy; 21) Chronic hemolysis with small aortic annulus, previous calcific A.S., non-calcific M.S., A.V.R.† and M.V.R.;§ 22) Congenital A.S.-M.I., previous resections, A.V.R.;† 23) Calcific A.S.-A.I. and hemolytic anemia, previous A.V.R.

* Early death
** Late death
† A.V.R. = aortic valve replacement
§ M.V.R. = mitral valve replacement

PREOPERATIVE PREPARATION, ANESTHESIA AND INTRAOPERATIVE MONITORING

Adults and children are prepared in the usual manner for surgery requiring cardiopulmonary bypass. The preoperative medications may include digitalis and antiarrhythmic agents. Because all of these patients have primary or recurrent obstructions to left ventricular outflow, the major objectives of anesthetic management are to assure and maintain a relatively constant heart rate and blood pressure. For these reasons, atropine and scopolamine are not used. Premedication includes light sedation with diazepam or morphine, and light general anesthesia is induced and maintained with halothane or narcotics (morphine/Demerol/fentanyl) in conjunction with N_2O and thiopental, based on heart rate and blood pressure.

OPERATIVE TECHNIQUE

A median sternotomy is made and cannulations of the venae cavae and ascending aorta are performed in the usual manner (Fig. 1). Total cardiopulmonary bypass with hemodilution techniques is used. Propranolol (0.5-1.0 mg) may be injected with the institution of bypass, depending upon the degree of left ventricular hypertrophy. The left atrium is vented by way of the right superior pulmonary vein. The ascending aorta is crossclamped just proximal to the origin of the innominate artery and 500 ml of cardioplegic solution,* to which 1.0 mg of propranolol (light sensitive) is added, is infused in the aortic root. Topical hypothermia is induced with iced saline (4.0° C) and, after the heart stops, the proximal ascending aorta, the aortic valve, and the left ventricular outflow tract are examined to determine the necessity or advantages of fashioning a double-outlet left ventricle.

*THI Cardioplegic Solution: 500 ml 5% Dextrose and 0.45% NaCl containing:
Potassium Chloride 20 mM (20 mEq) [1492.0 mg];
Magnesium Chloride 7.5 mM (15 mEq) [713.9 mg];
Sodium Bicarbonate 2.5 mM (2.5 mEq) [210.0 mg];
Calcium Chloride 1.0 mM (2.0 mEq) [147.14 mg].

Once a decision is made, the median sternotomy is extended into the upper abdomen (Fig. 2). The transverse colon and stomach are retracted downward and to the right. After division of the triangular ligament, the left lobe of the liver is mobilized and retracted to the right (Fig. 3). The right crus of the diaphragm is then incised to expose a generous portion of the supraceliac abdominal aorta (Fig. 4). This segment of the abdominal aorta, just beneath the diaphragm, is encircled with umbilical tapes and a portion is isolated with a partial occluding vascular clamp. The distal end of an appropriately sized Dacron graft containing a valve is anastomosed end-to-side to the abdominal aorta with a continuous 4-0 or 3-0 braided polyester suture (Fig. 5). An aperture is made in the left ventricular apex with a circular knife, just to the left of the terminal radicles of the left anterior descending coronary artery (Fig. 6).

The special polished Pyrolite® carbon rigid inlet prosthesis is then inserted into the left ventricular cavity with its longer extent positioned against the ventricular septum (Fig. 7). The Teflon sewing ring is secured to the apex with a continuous suture of braided polyester and reinforced with interrupted mattress sutures, buttressed with felt pledgets. The graft extension of the prosthesis is then passed through an opening made in the diaphragm and tailored [in length] to result in a gentle curve for anastomosis to the abdominal valve-bearing segment of graft (Figs. 8 and 9). Prior to releasing the ascending aortic cross-clamp, precautions are taken to evacuate any residual air from the composite conduit, proximal and distal to the valve, the left ventricle and the ascending aorta. Depending upon the time required for performing the procedure, the entire operation may be accomplished during cold cardioplegic ischemic arrest. Intermittent coronary perfusion with release of the aortic clamp may also be used. In the presence of adequate cardiac hypothermia with pharmacologically induced cardioplegia, a period of circulatory arrest of more than 60 minutes is well tolerated.

After the cannulae have been removed, pressures are measured in the left ventricle, in the conduit proximal and distal to the valve, and in the ascending aorta. In most patients, we have temporarily occluded the ascending aorta to determine the effect upon the systemic circulation. Generally, after a brief fall in blood pressure of approximately 20 percent, the systemic pressure rises to a normal level, indicating that the conduit could, if necessary, conduct the entire left ventricular output.

ALTERNATIVE TECHNIQUES

We currently prefer the aforementioned methods. There are alternative methods that can be employed. For example, situations might be encountered where the composite conduit could be implanted within the mediastinum to course from the left ventricular apex to the ascending aorta or the undersurface of the aortic arch. This would avoid entry into the abdomen, but would require re-entry into the mediastinum for subsequent replacement of the conduit valve. Or, the composite conduit could be implanted between the left ventricular apex and the descending thoracic aorta, requiring left thoracotomy and cardio-

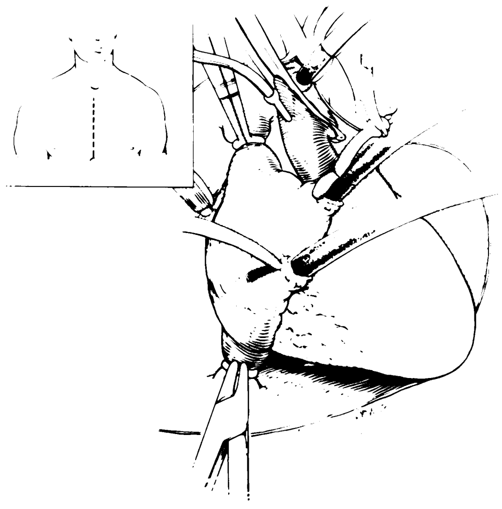

Fig. 1 To determine the necessity or advantages of creating a "double outlet" left ventricle, the patient is placed on total cardiopulmonary bypass via a median sternotomy with cannulation of the superior and inferior vena cavae and the ascending aorta. Special partially occluding caval clamps are used to assure capture of venous return. The ascending aorta is cross-clamped, cardioplegic solution with fresh propranolol infused, and topical hypothermia induced.

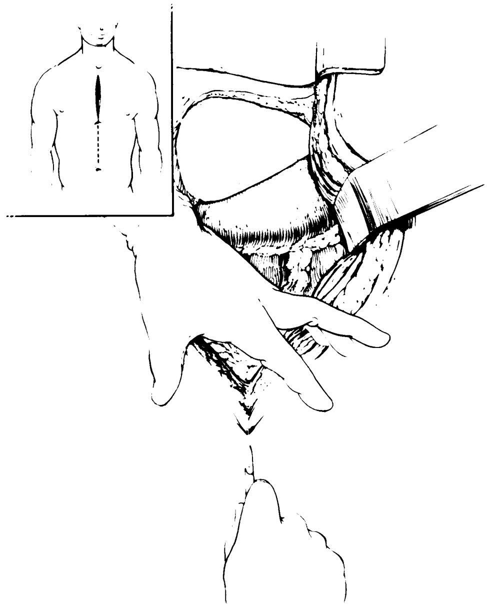

Fig. 2 After examining the ascending aorta, the aortic valve, and the left ventricular outflow tract via an ascending aortotomy, a decision is made and the median sternotomy is extended into the abdomen to the level of the umbilicus.

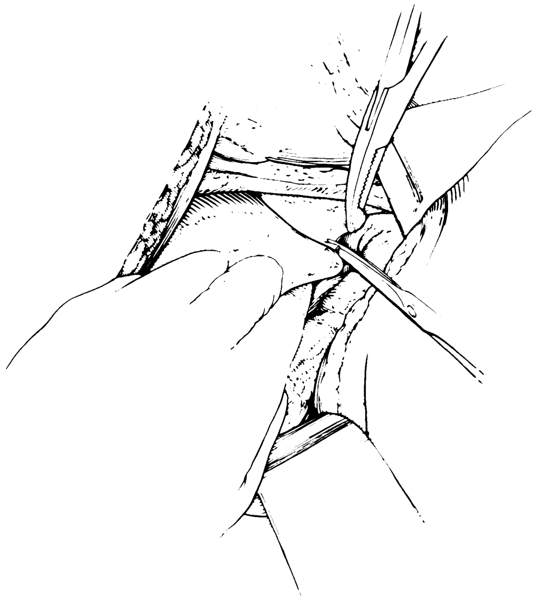

Fig. 3 The stomach is retracted downward and to the left; the left lobe of the liver is retracted toward the right, and the triangular ligament is divided to expose the supraceliac abdominal aorta, beneath the diaphragm.

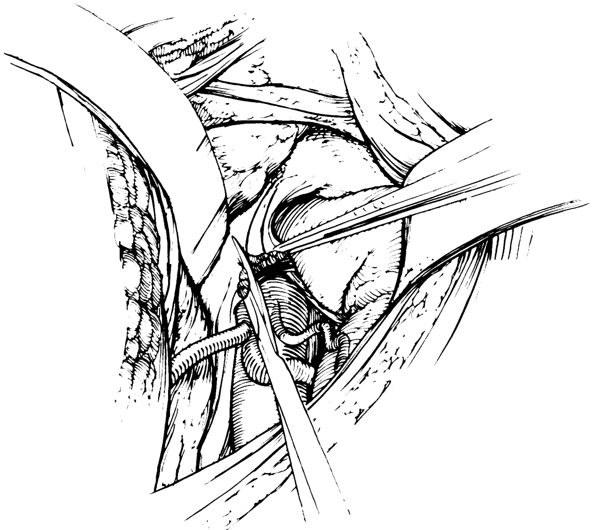

Fig. 4 The right crus of the diaphragmatic hiatus is divided to expose a generous portion of the supraceliac abdominal aorta. With adequate dissection, a 5 to 8 cm segment of the supraceliac abdominal, intradiaphragmatic and distal thoracic aorta can be exposed.

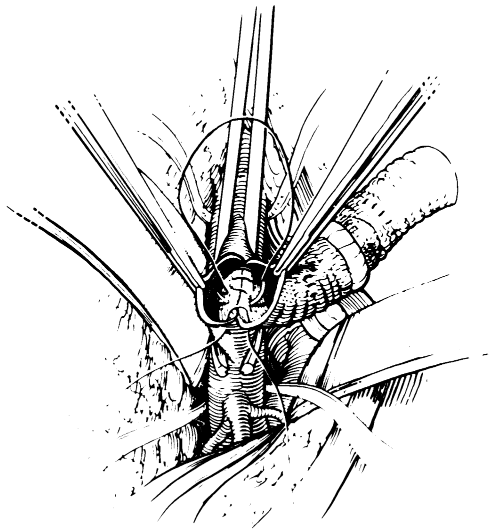

Fig. 5 Umbilical tapes are passed around the exposed segment of the aorta, proximally and distally. A partial occluding vascular clamp is applied and an appropriate linear aortotomy is made. The distal end of the valve-bearing graft is anastomosed end-to-side to the aorta with a running suture of 4-0 or 3-0 braided polyester.

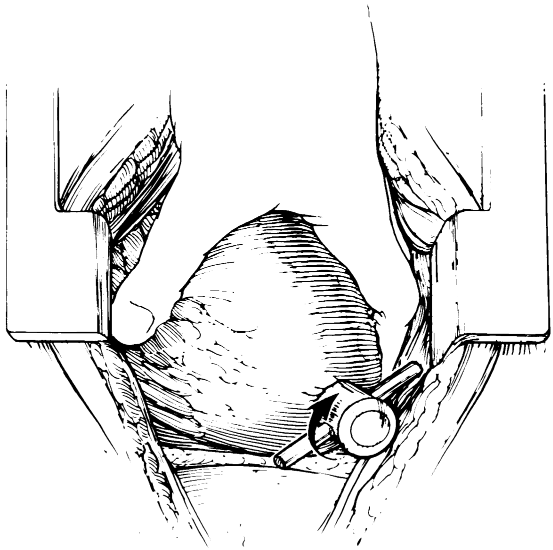

Fig. 6 The left ventricle is elevated and a circular arpeture cut in the apex with a special knife, just to the left of the terminal radicles of the left anterior descending coronary artery. The circular segment of the left ventricular apex is removed and the left ventricular cavity examined and explored digitally to assure an unobstructed apical outflow tract.

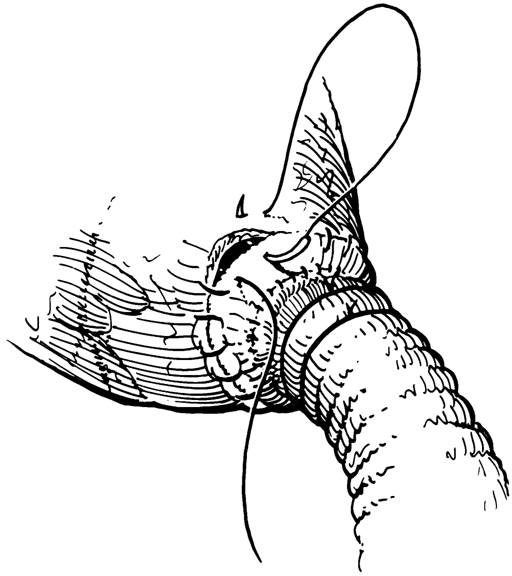

Fig. 7 The proximal end of a special, rigid, polished Pyrolyte® left ventricular apex outlet prosthesis is inserted into the apex with its longer extent positioned against the septum. The sewing ring of the prosthesis is secured to the left ventricular apex with a continuous suture of braided polyester reinforced with interrupted mattress sutures, buttressed with felt pledgets.

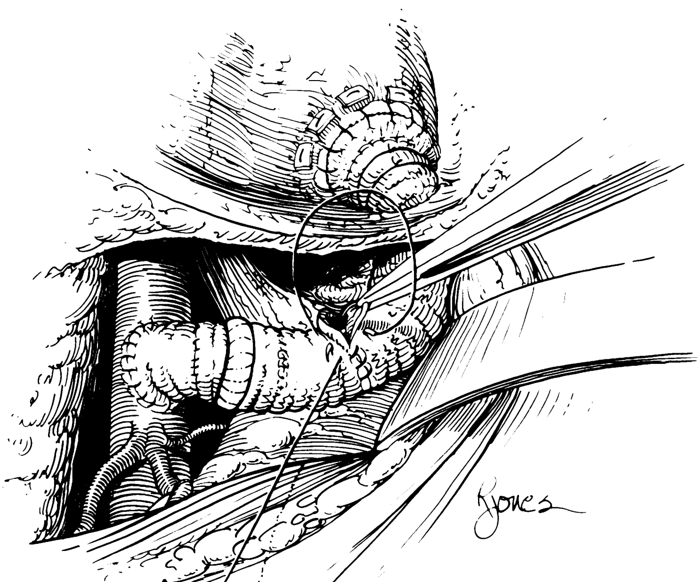

Fig. 8 The distal portion of the graft attached to the left ventricular apex outlet prosthesis is passed through the aperture in the diaphragm and anastomosed to the abdominal valve-bearing segment.

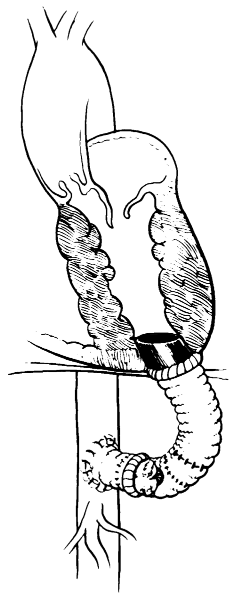

Fig. 9 Schematic illustration of the rigid Pyrolyte® apical left ventricular outlet prosthesis anastomosed to a valve-bearing conduit in a patient with left ventricular outflow tract obstruction and a deformed aortic valve.

pulmonary bypass from that approach. This approach does not allow examination of the ascending aorta, the supravalvular, valvular and subvalvular areas. In other circumstances, the conduit could be implanted between the apex of the left ventricle and the infrarenal abdominal aorta. Its chronic presence within the free peritoneal cavity, however, could result in visceral encroachment, intestinal erosion, or obstruction. In one patient, we used a median sternotomy and accomplished the apico-abdominal bypass during several episodes of electrically-induced ventricular fibrillation and circulatory arrest. Although no complications were encountered, we prefer to use cardiopulmonary bypass during the apical attachment.

VARIATIONS

Figures 10, 11 and 12 depict the utility of variations in these approaches used in three different circumstances. In the first, calcification of the ascending aorta and a calcific stenosed aortic valve in a patient with coronary artery occlusive disease precluded conventional methods. The L.V. apical polished Pyrolyte® prosthesis was used and two saphenous vein grafts from the conduit, distal to the heterograft valve, were brought back through the diaphragm and anastomosed to the left anterior descending and first obtuse marginal branches of the circumflex with good results for both lesions (calcific aortic stenosis and coronary artery occlusive disease). In the second instance, the patient had undergone aortic and mitral valve replacement and had residual aortic (prosthetic)

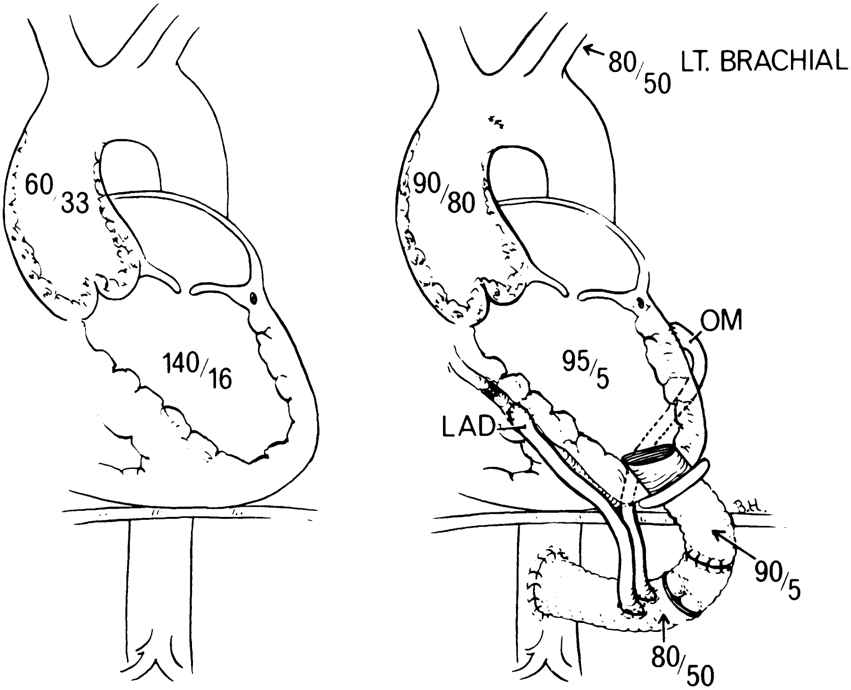

Fig. 10 Diagram of the procedure in Case 5 (Table I).

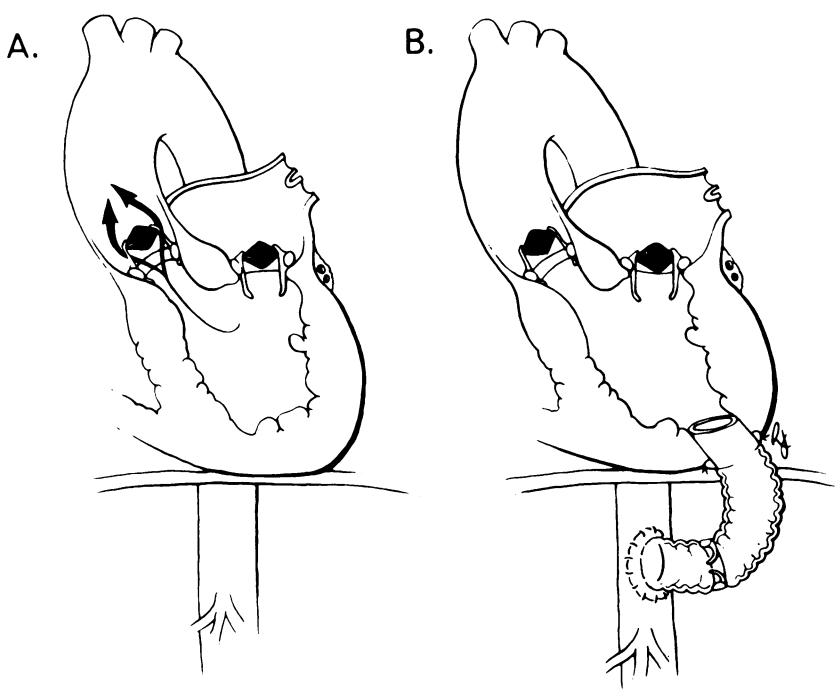

Fig. 11 Diagram of the procedure in Case 21 (Table I).

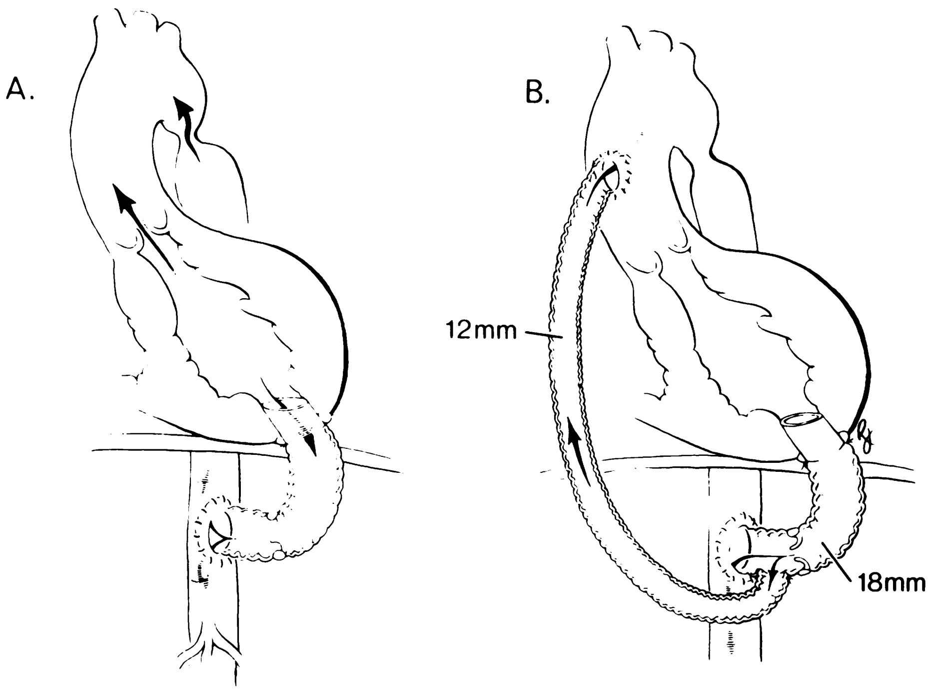

Fig. 12 (A) Diagram of a procedure in which the conduit was inserted (at another institution). (B) Graft from the conduit, distal to the valve, to the ascending aorta inserted (in our institution) to alleviate symptoms of cerebral ischemia.

valvular stenosis with hemolysis.[11] Implantation of the composite valved conduit resolved both problems. In the third instance, the patient had a deformed, stenotic aortic valve in association with coarctation of the aorta and cerebral ischemia. Both problems were resolved by means of staged implantation of the composite conduit and a 12 mm graft from the conduit distal to the valve, beneath the diaphragm to the ascending aorta.

POSTOPERATIVE CARE

For the most part, these patients have not presented any special problems other than those normally encountered after open-heart operations. After 48 hours in the Intensive Care Unit, where vital signs were monitored continuously and appropriate respiratory and circulatory support measures were utilized, they were returned to routine care in the hospital. Dismissal from the hospital occurred on an average of 10 days after operation.

ANTICOAGULANTS

For most patients in whom the conduit contained a heterograft valve, no anticoagulants were used. In some, aspirin and Persantin were started on the third postoperative day. Coumadin was continued in those patients who already had a synthetic prosthetic valve in the aortic or mitral annulus. In only one patient was a synthetic valve prosthesis (Cooley-Cutter) used in the conduit (Table I, Case 23). She already had a similar small diameter valve in the aortic annulus and was re-operated upon because of hemolysis and residual left ventricular hypertension. Antibiotic coverage during the early postoperative period was used in all patients.

COMPLICATIONS

The complications from this operation were few, consisting of postoperative hemorrhage, cardiac arrhythmias and minor respiratory problems. Cerebral embolism occurred in only one patient, but the neurologic effects were temporary and resulted in no residual disability. The source of the embolus in that patient was not determined, and no subsequent complications occurred after anticoagulation. One patient died two months after operation from infection around the conduit (Table I, Case 21). During that operation, an inadvertent opening was made in the abdominal portion of the esophagus.

EXPERIENCE OF OTHERS

Stansel, in New Haven, has employed this technique in five instances.[12] Notably, in one, a 2-year-old boy with aortic insufficiency, the aortic valve was closed and the valved left ventricular apical conduit became the sole egress for left ventricular output. We have not yet done this, but suggested its feasibility a number of years ago (Fig. 13).

Weldon, in St. Louis, using a stainless steel apical prosthesis of his own design, reports good results in two patients.[13] In treating an infant with aortic atresia, he reports an unsuccessful attempt to fashion a new apical outlet with a reversed saphenous vein, the original experimental technique used by Carrel in 1910. We have sent small (10 mm I.D.) L.V. apical polished Pyrolyte® prostheses to others for use in infants.

RESULTS

During an 18-month period, 23 patients underwent apical left ventricular abdominal aortic shunt in our institution (Table I). Three patients died early, and two died more than one month after operation. Two of the three who succumbed early were undergoing operation for supravalvular aortic stenosis and died immediately after surgery, raising the question of whether, in that anomaly, diverting blood away from the coronary ostia comprises coronary circulation (Table II). These were the only patients who did not have an immediately favorable hemodynamic response to operation. One patient with idiopathic hypertrophic subaortic stenosis (IHSS) who had undergone previous unsuccessful conventional ventricular septectomy did not obtain a satisfactory reduction in intracavitary ventricular pressure.

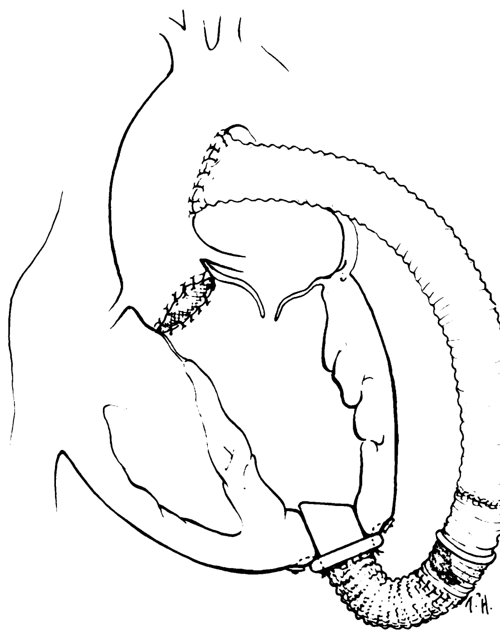

Fig. 13 Diagram of composite conduit extending from the left ventricular apex to the undersurface of the aorta with closure of the aortic annulus.

TABLE II. Apico-Aortic Conduit Grafts

Diagnosis	No. Patients 23	Early Deaths 3 (13%)	Late Deaths 2 (8.7%)
Congenital aortic stenosis			
1st operation	3		1
with previous valvulotomy	3		
with previous AVR	2		
Supravalvular stenosis	3	2	
Valvular and supravalvular			
1st operation	1		
previous valvulotomy	1		
Tunnel stenosis and IHSS			
previous operation	1		
Subaortic stenosis			
with previous operations	4		1
Previous AVR for RHD			
hemolytic anemia	4	1	
Aortic stenosis and			
CAOD	1		

SUMMARY

Creation of a double outlet left ventricle with the use of a fabric valve-containing conduit may solve certain problems related to the left ventricular outflow tract which are not amenable to conventional surgical methods. Among these problems are complex types of supra-valvular stenosis, combined valvular and annular stenosis (tunnel stenosis) and subvalvular stenosis. Calcification of the ascending aorta and aortic sinuses (which occurred in one of our patients with calcific aortic stenosis and coronary insufficiency) may be correctible with this approach, and thus preclude conventional aortic valve replacement. Hemolysis that occurs after the implantation of a prosthetic aortic valve may also be corrected with this technique.

Twenty-three patients are reported who have undergone apico-aortic bypass with a valved conduit. A rigid connector is recommended for the ventricular attachment. Low porosity woven Dacron tube grafts are used for the conduit. In all but one patient in whom a Cooley-Cutter biconical disc prosthesis was in the conduit, a glutaraldehyde preserved porcine heterograft valve was used. Anticoagulants were not necessary after operation, but were used in those patients who had intracardiac synthetic valve prostheses. Three early deaths and two late deaths occurred in this series, but the remaining patients have obtained gratifying results from operation.

ACKNOWLEDGMENT

This report will appear as a chapter in *Modern Technics in Surgery* to be published by Futura Publishing Company of Mount Kisko, New York, and is included here with permission of the editor, Lawrence H. Cohn, M.D.

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