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Open Aortic Anastomosis: Improved Results in the Treatment of Aneurysms of the Aortic Arch

JAMES J. LIVESAY, M.D., DENTON A. COOLEY, M.D., J. MICHAEL DUNCAN, M.D., DAVID A. OTT, M.D., WILLIAM E. WALKER, M.D., PH.D., AND GEORGE J. REUL, M.D.

SUMMARY **Over a 7-month period, 15 consecutive patients underwent resection and reconstruction of the transverse aortic arch for a variety of pathologic lesions using moderate systemic hypothermia (24°C) and brief circulatory arrest. Simplified surgical techniques were developed to allow rapid repair. The "open" aortic technique facilitated repair of arch aneurysms, aortic dissections and obstructive lesions of the arch tributaries. The mean cerebral ischemic time was 11.2 ± 1.5 minutes (mean ± SEM). Moderate hypothermia afforded adequate cerebral and myocardial protection during circulatory arrest and shortened the duration of extracorporeal bypass necessary for the cooling and rewarming phases (87 ± 8 minutes). Dacron grafts preclotted by a new method greatly reduced postoperative blood loss. Since these simplified techniques were adopted, 14 patients (93%) have survived aortic arch replacement, with minimal postoperative morbidity. One patient with severe preoperative left ventricular dysfunction died of cardiac failure after operation. These results suggest that aortic arch replacement can be performed safely and with low operative risk.**

SINCE surgical treatment was first proposed for thoracic aortic aneurysms,[1] various operative techniques have been recommended for resection of aneurysms involving the aortic arch. However, resection of aortic arch aneurysms remains a complex procedure that is often associated with high mortality and morbidity rates. The optimal operative technique for management of this difficult group of aneurysms has not been established.

Early attempts at lateral aortorrhaphy were limited to the treatment of localized saccular aneurysms, and carried the risk of emboli from application of partial occlusion clamps during the procedure.[1, 2] Temporary bypass grafts allowed circulatory diversion while the aneurysm was resected, but these long, tedious procedures required multiple arterial anastomoses and were accompanied by technical difficulties from bleeding and emboli.[3–5] With the advent of cardiopulmonary bypass, the aneurysm could be approached more directly.[6] Multiple arterial perfusion lines were used in the extracorporeal circuit for cerebral and visceral perfusion. However, cerebral perfusion techniques may produce cerebral injury by underperfusion, overperfusion or emboli and are often cumbersome due to obstruction of the operative field.[7]

Deep hypothermia with circulatory arrest simplified the approach to aneurysms of the aortic arch and provided a dry, unobstructed operative field in which the surgeon could work.[8–10] Deep hypothermia to 12–16°C has been used to preserve cerebral and cardiac integrity during periods of necessary circulatory arrest. Although the effectiveness of this technique has been demonstrated,[11, 12] further experience during the last 5 years has revealed several problems.[13] Prolonged periods of cardiopulmonary bypass are needed for the cooling and rewarming phases of the procedure. The interference of normal coagulation mechanisms by prolonged bypass and hypothermia has produced troublesome bleeding in some patients. Multiple organ system dysfunction has been observed postoperatively after a technically satisfactory operation and has raised doubts regarding the level of protection with this technique.

We evaluated the technique and results used recently in 15 consecutive patients who underwent resection of the transverse aortic arch.

Methods

The essential features of the operative technique are illustrated in figure 1. Aneurysms of the ascending aorta and the transverse aortic arch are approached through a median sternotomy. Techniques of cannulation and methods of hypothermic perfusion have been described.[12, 13] All patients are cannulated using a single, large, right atrial cannula with arterial return through the femoral artery. Care is taken to ensure arterial cannulation and perfusion of the femoral artery in continuity with the true lumen.

Moderate systemic hypothermia is induced with core cooling to 24°C. Additional myocardial cooling can be accomplished by infusing cold cardioplegic solution into the coronary ostia after opening the aneurysm. Total circulatory arrest is accomplished by first clamping the arch vessels and then ceasing extracorporeal bypass. Clamps are applied to both the arterial and venous perfusion lines to prevent introduction of air into the bypass circuit. After opening the aneurysm, blood is aspirated only as necessary to visualize the transverse arch and proximal descending thoracic aorta. This provides a dry, unobstructed operative field and facilitates a rapid repair.

Attention to the origin of the arch vessels, relief of arch obstruction by endarterectomy or bypass, and repair of aortic dissection are possible during brief circulatory arrest. The distal aortic anastomosis is then completed to the "open" aorta, using an elliptical suture line, and a long tongue of the Dacron graft is sewn in beneath the aortic arch tributaries.[14] In cases of aortic dissection, the two layers of the aortic wall are incorporated in a single suture line, obliterating the false

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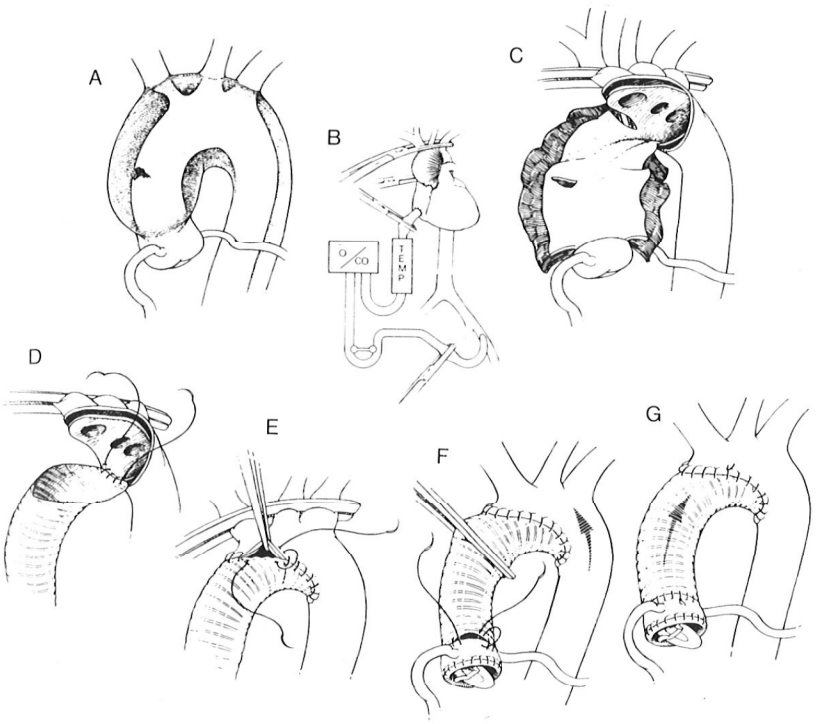

FIGURE 1. *Surgical technique for resection and graft replacement of dissecting aneurysm involving the ascending aorta and transverse aortic arch using moderate hypothermia with circulatory arrest.*

lumen. Invaginating or telescoping the graft inside the true lumen is advisable. A long (120-cm) 2-0 or 3-0 polypropylene suture is placed with care to minimize bleeding from suture holes. Saccular aneurysms are repaired with a Dacron patch sewn from within the aortic lumen.

Air and particulate debris are eliminated by slowly resuming cardiopulmonary bypass. As the blood level rises, filling the aorta, and after all air has been removed from the aortic arch, a clamp is applied to the graft. The clamp on the arch vessels is then released, restoring cerebral perfusion. Intracardiac repair is performed and the proximal aortic anastomosis is completed during systemic rewarming. With associated aortic valve pathology and annuloaortic ectasia, the aortic valve is replaced with a composite conduit that contains a Björk-Shiley valve, and coronary ostial reimplantation is required. In the presence of significant coronary occlusive disease, concomitant coronary bypass is performed. After rewarming to a temperature of 36–37°C, cardiopulmonary bypass is discontinued.

Graft Preparation

A low-porosity Veri-soft woven Dacron graft (Meadox Medicals, Inc.) is prepared as previously described.[15] Platelet-rich plasma is obtained by centrifuging 50 ml of the patient's heparinized blood and is used to soak the graft. The graft is then placed in a steam autoclave for 5 minutes. This method effectively covers the fabric with a thick proteinaceous coating, eliminates bleeding through the interstices of the graft, and minimizes postoperative bleeding along suture lines.

Results

From October 1980 to May 1981, 15 consecutive patients underwent operations for lesions involving the aortic arch. Twelve were males and three were females, ages 24–77 years (mean 58 years). Fourteen patients had aneurysms that involved the transverse aortic arch; the cause was atherosclerosis in seven patients and cystic medial necrosis in seven (table 1). A large saccular aneurysm arising in the transverse aortic arch was found in two patients. In one patient, the youngest of our series, an unusual hyperplasia of the intimal and medial layers of the aorta produced significant stenosis of the ascending aorta and transverse aortic arch.

Aortic dissection, a prominent feature in 10 patients, was classified (DeBakey) type I in six and type II in four.[16] Three patients had acute aortic dissection. Distal propagation of the dissection produced obstruction of the innominate artery or left carotid artery in six patients and proximal extension of the dissection resulted in aortic valvular insufficiency in six. Three patients had the classic findings of Marfan's syndrome. Associated factors that increased the complexity and risk of the procedure included concomitant coronary artery disease in five patients, severe left ventricular dysfunction in two patients, recurrent an-

TABLE 1. *The Pathologic Process and Operative Findings in 15 Patients with Aortic Arch Lesions*

	Operative findings		
Pathologic process	Aneurysm	Dissection	Aortic obstruction
Atherosclerosis (n = 7)	7	4	—
Cystic medial necrosis (n = 7)	7	6 (3*)	1
Intimal hyperplasia (n = 1)	—	—	1
Total (n = 15)	14	10	2

*Acute dissection.

TABLE 2. *Surgical Management of Aortic Arch Aneurysms in 15 Patients*

	n
Ascending aorta and transverse aortic arch	
Dacron graft replacement	13
Dacron patch angioplasty	2
False lumen (dissection) obliterated	9
Aortic arch tributaries	
Endarterectomy	3
Bypass	1
Aortic valve	
Aortic valve replacement	7
Composite graft	3
Coronary arteries	
Coronary artery bypass	4
Coronary reimplantation	3

eurysm after prior operation in two patients, and obstruction of the superior vena cava in one patient.

The operative procedures used for resection and reconstruction of lesions of the aortic arch in 15 patients are listed in table 2. Despite the complexity of the procedures, cardiac arrest time was only 42 minutes (range 23–73 minutes). Moderate systemic hypothermia with nasopharyngeal temperature of 24.1°C (range 22.9–26°C) provided adequate cerebral protection for brief periods of circulatory interruption. The "open" distal aortic anastomosis facilitated a rapid, precise repair of lesions of the transverse aortic arch. The mean circulatory arrest time was 11.2 minutes (range 6–27 minutes), and the total duration of cardiopulmonary bypass was 87 minutes (range 64–181 minutes), including the period of cooling and rewarming.

Circulatory arrest and the "open" aortic technique enabled direct visualization of obstructive lesions involving the aortic arch and its tributaries. In one patient with intimal and medial hyperplasia, aortic endarterectomy produced a complete "cast" of the aortic arch (fig. 2). When aortic dissection propagates distally to involve arch tributaries, arterial obstruction can be relieved by endarterectomy or bypass (fig. 3).

Aneurysms may involve the aorta at multiple sites, especially in patients with aortic dissection. In such cases, we prefer to use a staged approach directed first at the most life-threatening problem. Usually, this is the ascending aorta. The presence of aortic insufficiency, proximal aortic dissection or coronary insufficiency are strong indications for directing operation toward that segment first. In the present series, a 43-year-old female with Marfan's syndrome presented with an enlarging ascending aortic aneurysm, aortic insufficiency and back pain from distal dissection involving the arch, descending thoracic aorta and abdominal aorta (fig. 4). The initial procedure was aortic valve replacement with a composite graft, coronary artery reimplantation and aortic arch reconstruction. Two weeks later, the descending thoracic aneurysm was resected.

The results of surgery for this group of patients are summarized in table 3. The overall survival was 93% (14 patients). One patient, a 70-year-old male, died after repair of a saccular aneurysm of the transverse aortic arch and quadruple coronary bypass. He had coronary artery disease and severe left ventricular dysfunction (preoperative ejection fraction of 25%). The patient could not be weaned from cardiopulmonary bypass and died of low-output cardiac failure.

Postoperative morbidity was minimal in this group of patients. In contrast to the postoperative complications in patients undergoing deep hypothermia, there was a remarkable absence of dysfunction of vital organs. Among the 14 surviving patients, 13 (93%) were neurologically normal immediately after the procedure. One patient had a right cerebral stroke after arch resection of an atherosclerotic aneurysm using hypothermia and temporary circulatory arrest (24.3°C, 7 minutes). The distribution of the infarction, the nature of the aneurysm, and the short duration of arrest suggested an embolic cause. The patient made a nearly complete recovery, with only mild residual weakness of the left arm. A second patient was initially neurologically normal after undergoing aortic arch reconstruction, innominate artery endarterectomy and bypass, and aortic valve replacement for a recurrent type I aortic dissection involving the innominate artery. On the third postoperative day, however, the patient had a left cerebral stroke, suggesting a recurrent dissection or embolus involving the left carotid artery.

Pretreatment of Dacron grafts and rapid correction of coagulation abnormalities have eliminated most

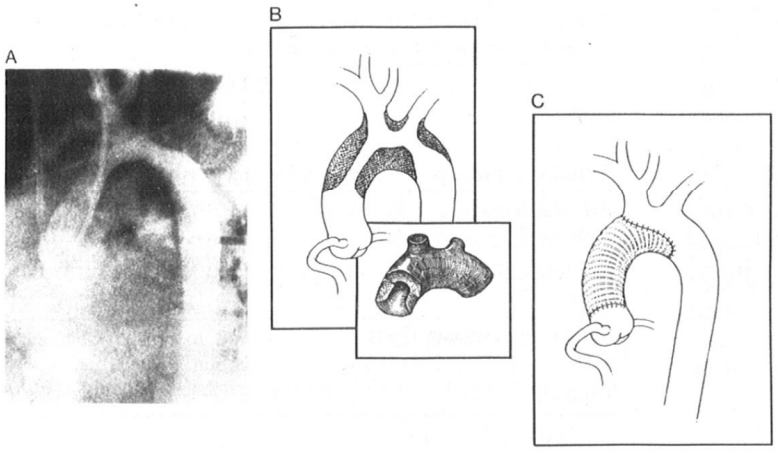

FIGURE 2. *Treatment of patient with diffuse hyperplasia of the transverse aortic arch. (A) Aortogram before operation showing the location and extent of disease. (B) Diagram of hyperplasia of the aortic wall and the operative specimen after aortic endarterectomy. (C) Diagram of reconstruction of the transverse aortic arch.*

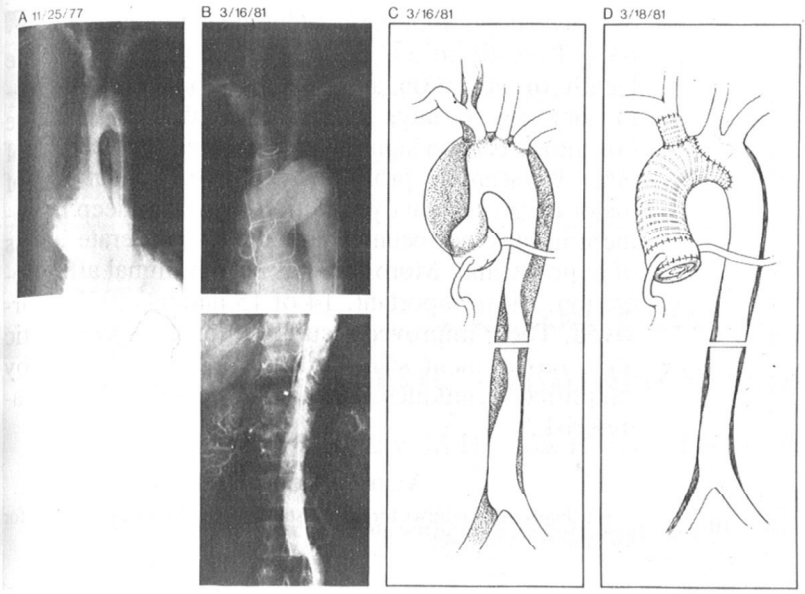

FIGURE 3. *Treatment for recurrent aortic dissection, right carotid occlusion, and aortic insufficiency. (A) Aortogram before first operation showing aortic dissection involving the innominate artery. (B) Aortogram after first operation showing recurrent aortic dissection with right carotid obstruction. (C) Diagram before reoperation showing the extent of aortic dissection. (D) Diagram after reoperation showing aortic arch reconstruction, innominate artery endarterectomy and bypass, aortic valve replacement and obliteration of the false lumen.*

postoperative bleeding problems. The mean postoperative blood loss for the first 24 hours in 13 patients was low — 1152 ± 245 ml (fig. 5). The average postoperative transfusion requirement was 2.6 units of blood. One patient of the Jehovah's Witness faith underwent successful resection of the aortic arch without blood replacement. One patient required reexploration for excessive bleeding and was found to have an occult tear in the left subclavian artery from a cross-clamp injury.

Discussion

Aneurysms of the aortic arch have long posed a formidable surgical challenge, because resection involves interruption of circulation through this channel and requires preservation of cerebral and myocardial integrity. Techniques used in the past often have resulted in long, tedious operations with uncertain protection of vital organs and a high risk of mortality and morbidity.

The application of deep hypothermia with circulatory arrest has greatly simplified the surgical approach to lesions of the aortic arch, and improved surgical results have been reported.[9–12, 12, 17, 18] In 1978, we reported our initial experience with this technique; five of six patients survived aortic arch replacement.[12] In 1980, Ergin and Griepp[17] reported that 10 of 14 patients survived arch resection using deep hypothermic arrest, including nine of 10 patients operated upon electively.[17] We reviewed our continued experience with this technique over a 4-year period in 20 patients.[13] An overall operative mortality of 50% (10 of 20 patients) has led us to reassess our methods of hypothermic arrest. Three specific complications were identified: postoperative bleeding, dysfunction of vital organs and uncertain preservation of cerebral and myocardial integrity.

Hypothermia depresses normal coagulation mechanisms, and prolonged cardiopulmonary bypass depletes factors necessary for coagulation.[19, 20] Continued exposure of the preclotted graft to heparinized blood during necessary periods of rewarming on bypass washes fibrin from the surface of the graft and promotes bleeding from its long suture lines. The technique of Bethea and Reemtsma[21] has been modified to prepare grafts for hypothermic conditions.[15] These plasma-soaked grafts prepared by autoclave have greatly reduced the amount of postoperative bleeding after thoracic aortic replacement.

Despite a technically satisfactory operation, some patients have major organ system dysfunction after deep hypothermic arrest. Hepatic dysfunction, renal

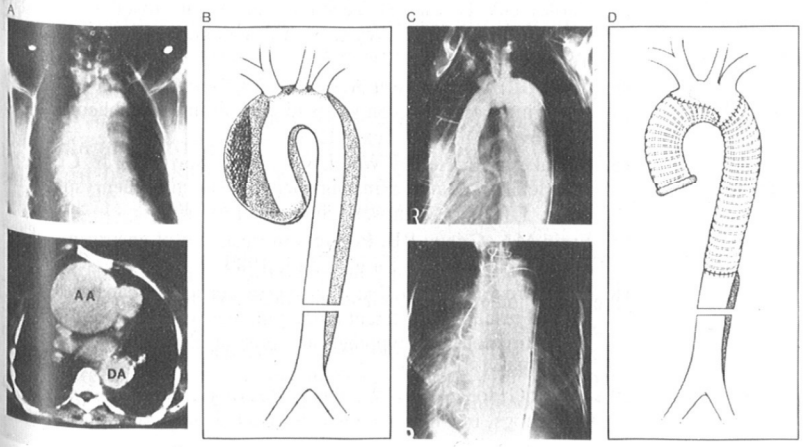

FIGURE 4. *Treatment of patient with Marfan's syndrome, aortic aneurysm, dissection and valvular insufficiency. (A) Aortogram and computerized tomographic scan before operation showing ascending aortic (AA) and descending aortic (DA) aneurysms. (B) Diagram before operation showing the extent of disease. (C) Aortogram after resection of ascending and transverse arch aneurysm showing residual dissection of descending thoracic aorta. (D) Diagram after staged reconstruction.*

TABLE 3. *Surgical Results of Aortic Arch Replacement in 15 Patients*

	n	%
Results		
Survival	14	93
30-day mortality	1	7
Morbidity		
Neurologic deficit	2	13
Myocardial infarction	1	7
Pulmonary insufficiency	1	7
Postoperative bleeding	1	7
Renal or hepatic dysfunction	0	0

failure and pulmonary complications have been reported. Similar complications with deep hypothermia in adults have also been reported.[22–24] Ergin and Griepp[17] noted almost routine postoperative pulmonary edema in their patients.[17] In addition, the degree of cerebral and myocardial protection with deep hypothermia has been unpredictable. These complications may be related to methods of cooling and rewarming with hypothermic perfusion, the rapidity of which may produce temperature gradients, tissue edema, cellular injury and formation of free gaseous emboli in the blood.

We have modified our technique to provide moderate levels of systemic hypothermia (23–24°C) and to expedite a rapid repair using brief circulatory arrest. Moderate levels of hypothermia afford adequate cerebral and myocardial protection and reduce the duration of perfusion for the cooling and rewarming phases of bypass. Circulatory arrest provides an unobstructed, dry operative field. The "open" aortic technique facilitates direct repair of obstructive lesions, dissections, and aneurysms of the aortic arch. A single elliptical anastomosis can be performed to the "open" distal aorta at the level of the arch tributaries, usually in less than 15 minutes.

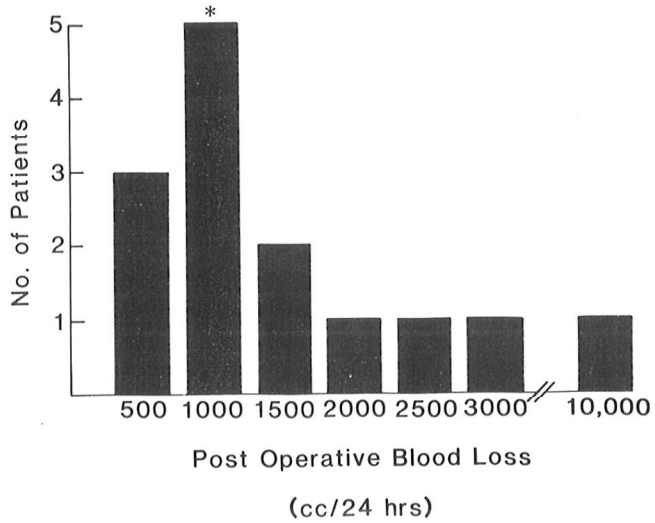

FIGURE 5. *Postoperative blood loss after aortic arch resection.*

Since adoption of these techniques, results have improved greatly in this difficult group of patients. The length of operation and the duration of cardiopulmonary bypass have been shortened. Postoperative bleeding has been significantly reduced to the level of other intracardiac procedures. The complications of major organ system dysfunction seen with deep hypothermia have not been observed with moderate levels of hypothermia. Morbidity has been minimal after operation. Most important, 14 of 15 patients (93%) survived. These improved results demonstrate that aortic arch replacement can be safely accomplished by simplified techniques, with an acceptably low operative risk.

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Dacron Patch Closure of Aortic Annulus Mycotic Aneurysms

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SUMMARY **Six patients with large mycotic aortic annular aneurysms were successfully operated on over a 3-year period. Aortic valve replacement was facilitated in all six patients by closing the orifice of the abscess with a Dacron patch and then seating the prosthetic valve at the level of the aortic annulus. In each case, a portion of the prosthetic valve ring was sutured directly to the patch. No patient has clinical evidence of a perivalvular leak 18–48 months after operation. One patient required reoperation to close a ventricular septal defect caused by partial patch dehiscence. Dacron patch closure has been highly effective in our experience and is simpler than many other options.**

THE PRESENCE of a mycotic aneurysm extending into the aortic annulus in the patient with bacterial endocarditis may require extraordinary techniques to eradicate the infection and correct the hemodynamic abnormalities. Leaving the orifice of the aneurysm open, suture closure of the orifice, patch closure of the aneurysm, and translocation of the inserted prosthetic valve are methods of management.

We summarize the course of six patients operated upon at the University of Washington in Seattle from January 1, 1978, to December 31, 1980, each of whom had a large mycotic aneurysm involving the aortic annulus. Aortic valve replacement was facilitated in all six patients by closing the orifice of the aneurysm with a prosthetic patch and then seating the prosthetic valve at the level of the natural aortic annulus.

Material and Methods

We reviewed the operative report for each patient who underwent aortic valve replacement at the University Hospital between January 1, 1978, and December 31, 1980, either as an isolated or combined procedure. All six patients (five men and one woman) operated upon during that interval in whom an annular abscess was closed with a patch are included in this report. The patients were 25–57 years old. The annular abscess complicated native valve endocarditis in five of the patients and prosthetic valve endocarditis in one. The relevant features of each of the six patients are shown in table 1. Microorganisms that presumably infected the valve were cultured from the blood within 4 weeks of operation in five patients. Cultures of excised valve tissue were positive in two patients. The duration of postoperative antimicrobial therapy varied, and was determined by kind of infection and the patient's course.

Operation in each case included the use of standard cardiopulmonary bypass techniques and cold potassium cardioplegia. The abscess cavity was debrided and its orifice closed with a woven Dacron patch sewn into place with a continuous monofilament suture (figs. 1–3). An aortic xenograft prosthesis was inserted and attached to the remaining noninfected aortic annulus and to the patch at the level of the annulus with interrupted mattress sutures. No attempt was made to tilt or displace the prosthetic valve ring to avoid sewing across the Dacron patch.

Results

All patients survived the operation, and all except patient 6 had an uneventful convalescence. Patient 6 developed a systolic murmur and increasing heart failure 3 weeks after initial operation. Cardiac catheterization demonstrated a subaortic ventricular septal defect, but no perivalvular aortic incompetence. At reoperation (table 1), the lower margin of the patch used to close a large abscess extending from the aortic annulus into the interventricular septum had dehisced from the crest of the septum; inflammatory tissue was not present. The defect was successfully repaired.

All patients were active and free of cardiac symptoms 18–48 months after operation. Persistent or recurrent infection has not occurred, and none of the patients has a murmur of aortic valve incompetence.

Discussion

The surgical management of patients with infective

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