Aortic root reconstruction with a bioprosthetic valved conduit: A consecutive series of 275 procedures

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Objective: The study objective was to assess the results of aortic root reconstruction using composite conduits with stented bioprosthetic valves.

Methods: A review was conducted of 275 patients (202 were male, mean age 69 ± 11 years, range 17–88 years) who underwent aortic root replacement using conduits constructed intraoperatively from pericardial valves and impregnated Dacron grafts between September 1993 and February 2005. There were 151 patients with degenerative aneurysms and 63 patients with atherosclerotic aneurysms; 43 patients had dissections (9 acute type A), 13 patients had endocarditis, and 5 patients had other pathologic conditions. The ascending aorta alone was replaced in 154 patients, a hemiarch reconstruction was performed in 105 patients, and extensive arch reconstruction was performed in 16 patients. Hypothermic circulatory arrest and an open distal anastomosis were used in 95% of patients.

Results: Hospital mortality was 17 of 275 patients (6.2%). Four additional patients (1.5%) sustained permanent strokes. Among surviving patients, the rate of stroke was estimated as 0.85 per 100 patient-years and the rate of significant hemorrhage was estimated as 0.3 per 100 patient-years. Reoperation for valve failure occurred in only 1 patient 12 years postoperatively. Long-term survival in men was similar to that of a normal matched control population, but was significantly lower in women ($P = .002$).

Conclusions: Men who recover satisfactorily after reconstruction of the aortic root with a stented bioprosthetic valved conduit (6-month survivors) enjoy long-term outcomes equivalent to that of a normal matched population; the postoperative mortality rate in women is twice that of a normal population.

Surgery of the ascending aorta has been remarkably successful for the last approximately 40 years. Aortic diseases that threaten catastrophic complications of rupture or dissection can now be treated with durable operations that have a low operative mortality.^{1,2}

Aortic root reconstruction is warranted when a diseased aortic valve is associated with a dilated or dissected aortic root or ascending aorta. Elective surgery is also indicated in the presence of significant dilatation of the sinuses of Valsalva, the sinotubular junction, or the ascending aorta. In addition, elective root replacement may be advisable in a minimally dilated aortic root and ascending aorta if aortic

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Abbreviations and Acronyms

COPD = chronic obstructive pulmonary disease

HCA = hypothermic circulatory arrest

SCP = selective cerebral perfusion

valve disease is associated with a genetic predisposition to aneurysm formation or dissection.

Since Bentall and De Bono introduced the surgical technique involving composite mechanical valved conduits in 1968, various adaptations of the original concept have been the standard therapy for patients with an aortic root aneurysm.^{3,4} Because a mechanical valved conduit mandates lifelong anticoagulation, alternative strategies have been sought. Valve-sparing operations have become an increasingly appealing alternative in younger patients requiring aortic root surgery whose life expectancy exceeds the anticipated durability of an implanted biological valve. For elderly patients, in whom biological valves generally last longer, the use of a conduit constructed in the operating room by sewing a bioprosthetic valve to a vascular graft is the most attractive option.

The objective of this study was to evaluate patients who have undergone what we will refer to as a biological Bentall operation to determine whether the benefit of avoiding anticoagulation by using a biological valve in the aortic conduit is offset by the need for reoperation because of valve deterioration.

Materials and Methods

Since 1988, a composite conduit repair (a modified Bentall procedure) has been undertaken in more than 800 patients at Mount Sinai Hospital. A review disclosed 275 patients who underwent aortic root replacement with a biological valved conduit between September 1993 and February 2005. All patients received bioprosthetic conduits constructed intraoperatively from pericardial valves and impregnated Dacron grafts. The mean age was 69 years (range 17–88 years), and 73% were male ($n = 202$). Table 1 summarizes the clinical characteristics of the patients.

The institutional review board approved this research; additional patient consent was not required.

Indications

The principal indication for aortic root reconstruction (Table 1) was a degenerative aortic aneurysm in 151 patients (55%); of these, 9 had annuloaortic ectasia, 7 had a bicuspid valve, and 3 had Marfan syndrome. An atherosclerotic aortic aneurysm was present in 63 patients (23%); 43 patients (16%) had dissections, one quarter of which (9) were acute type A; 13 patients (5%) had aortic valve endocarditis affecting the root; and 5 patients had other pathologic conditions.

Fourteen patients underwent emergency root reconstructions (including 9 for acute type A dissection and 4 with root endocarditis). Twenty-one patients had urgent procedures because of

TABLE 1. Clinical profile and indication for operation

	n (%)
Demographics	
Mean age y (SD)	69.3 (± 11.3)
Age >60 y	226 (82%)
Male sex	202 (73%)
Previous cardioaortic operations	48 (18%)
Timing of surgery	
Elective	240 (87%)
Urgent/emergency	21 (8%)/14 (5%)
Risk factors	
History of neurologic dysfunction	24 (9%)
History of hypertension	149 (54%)
Coronary artery disease (CAD)	96 (35%)
Smoking/diabetes/COPD	75 (27%)/17 (6%)/8 (3%)
Aortic root pathology	
Degenerative	151 (55%)
Bicuspid valve/annuloaortic ectasia/Marfan syndrome	9 (3%)/9 (3%)/3 (1%)
Atherosclerosis	63 (23%)
Dissection	43 (16%)
Acute type A dissection	14 (5%)
Acute endocarditis	13 (5%)
Other*	5 (<2%)
Aortic valve function/pathology	
Aortic regurgitation	167 (61%)
Prosthetic valve	11 (4%)
Intraoperative findings	
Clot or atheroma	24 (9%)

SD, Standard deviation; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease. *Pseudoaneurysm after ascending replacement ($n = 4$) and giant cell aortitis ($n = 1$).

shortness of breath, anginal pain, or syncope. The remaining 240 patients (87%) underwent elective procedures.

A total of 48 patients (18%) had undergone previous cardioaortic procedures; 27 patients (10%) had received oral anticoagulants before the root reconstruction, and 50 patients (18%) had received platelet inhibitors. At hospital admission, 85 patients (31%) were being treated for hypertension with β -adrenergic blocking agents, and 49 patients (18%) were being treated with angiotensin-converting enzyme inhibitors.

Surgical Technique

Cannulation and myocardial protection. Arterial cannulation was carried out through the femoral artery (19%), the ascending aorta (18%), and, more recently, the right axillary artery (61%; Figure 1) as previously described by our group⁵; the left axillary artery or the aortic arch was cannulated in 6 cases (2%). Venous cannulation was usually through a 2-stage catheter in the right atrium, but in some patients in whom the heart was not fully exposed, the right atrium was accessed through a wire-directed catheter placed through the femoral vein. Myocardial protection was provided with cold antegrade blood cardioplegia, systemic perfusion at 20°C, and, in patients with severe coronary disease, retrograde blood cardioplegia. Cardioplegia was administered every 20 to 30 minutes during periods of myocardial ischemia.

Figure 1. Cannulation sites used: technique changes from 1995 to 2005.

Hypothermic circulatory arrest. HCA was effected by surface (cooling blanket) and perfusion cooling. If HCA was anticipated early in the procedure, the patient was cooled during the initial period of cardiopulmonary bypass. In some patients in whom HCA occurred later in the operative procedure, the patient was maintained at a perfusion temperature of 20°C until approximately 15 minutes before HCA, after which the blood temperature was decreased to 10°C. Adequate cerebral cooling was ensured in all cases by cooling for a minimum of 30 minutes, maintaining a jugular venous saturation greater than 95%, and maintaining an esophageal temperature of 12°C to 15°C. In all patients in whom more than 20 minutes of HCA was anticipated or selective cerebral perfusion (SCP) was used, the head was packed circumferentially in ice.

Perfusion warming was performed at the end of the procedure with the gradient between the esophageal and blood temperature maintained at less than 10°C. Warming was maintained until the esophageal temperature reached 35°C and bladder temperature was greater than 32°C. Downward drift, however, resulted in most patients leaving the operating room with esophageal and bladder temperatures of 32°C. Warming was usually accomplished in 1 hour of perfusion; during the last 15 or 20 minutes, partial bypass was frequently used to take advantage of improved warming with pulsatile perfusion.

Selective cerebral perfusion. Perfusion of all 3 head vessels was achieved with SCP when arch replacement was planned or cerebral protection time was expected to exceed 30 minutes. Once the use of the trifurcation graft was introduced for arch repair, SCP was provided by inflow to the trifurcation graft through the right axillary artery. SCP was performed at a blood temperature of 15°C to 20°C and flow sufficient to maintain a pressure of 50 to 60 mm Hg. This usually required a flow of 800 to 1200 mL/min.

TABLE 2. Operative data

Variable	%
Bentall technique	
Buttons ³ /Classic ⁴ /Cabrol ¹⁴	93%/4%/3%
Extent of aortic replacement	
Ascending only/+hemiarch/+arch	55%/37%/8%
/elephant trunk stage I	5%
Cardiopulmonary bypass	
Cannulation	
Right/left axillary artery	61%/<1%
Femoral	19%
Ascending/descending aorta	18%/2%
CPB time*	260 (± 57)
Myocardial ischemia (crossclamp) time*	181 (± 48)
Cerebral ischemia (HCA) time*	26 (± 14)
Open distal anastomosis	262 (95%)
Minimal esophageal temperature*	12.5 (± 2.5)
Concomitant procedures	
Coronary artery bypass grafting	37%
Mitral valve procedure	5%
Replacement/repair (annuloplasty/ring)	1%/4%
Other	4%

CPB, Cardiopulmonary bypass; HCA, hypothermic circulatory arrest. *Results are mean ± standard deviation. Times are in minutes; temperatures are in degrees Celsius.

Aortic root reconstruction. A button Bentall procedure was used in 93% of patients, a Cabrol procedure was used in 4% of patients, and a classic Bentall procedure was used in 3% of patients (Table 2). No valvuloplasty or valve-sparing procedures were included in this series; in all 275 patients, a stented pericardial valve (Carpentier-Edwards Perimount series in most cases; Edwards Lifesciences, Irvine, Calif) was used. The Dacron graft was oversized 5 to 7 mm larger than the valve diameter.

Anastomotic Technique

Proximal anchoring of the Bentall grafts was accomplished with interrupted pledgeted sutures. Coronary button anastomoses were reinforced with small strips of Teflon felt. All graft-to-aorta anastomoses were performed with a sandwich technique, placing the aortic wall between the vascular graft and an external band of Teflon felt, as previously described by Strauch and associates.⁶ All graft material was albumin-impregnated woven Dacron.

Extent of Operation

Only the ascending aorta was replaced in 152 patients (55%); a hemiarch reconstruction was performed in 102 patients (37%); and extensive arch reconstruction was performed in 21 patients (8%), with an elephant trunk stage I in 13 cases. Overall cardiopulmonary bypass time was 260 ± 57 minutes. The distal anastomosis was performed open in more than 95% of the cases (n = 262). Detailed operative data are shown in Table 2.

One third of the patients had coronary artery disease requiring concomitant bypass grafting (n = 101); 15 patients underwent a concomitant mitral valve procedure (Table 2).

TABLE 3. Postoperative complications

Variable	n (%)
Bleeding requiring rethoracotomy*	16 (5.8%)*
Cardiac complications	17 (6.1%)
Ventricular tachycardia/AV-block III (requiring pacemaker)	5 (1.8%)/2 (0.7%)
Myocardial ischemia/infarction (IABP)†	9 (3.3%)†
Infection	5 (1.8%)
Mediastinitis‡/sepsis§	3 (1.1%)‡/2 (0.7%)§
Neurological dysfunction	59 (21.4%)
Temporary (TND, PRIND)/permanent (stroke)	52 (18.9%)/7 (2.5%)
Respiratory insufficiency/tracheotomy	43 (15.6%)/25 (9.1%)
Renal failure/temporary dialysis	6 (2.2%)/4 (1.5%)
Others¶	8 (2.9%)¶
Hospital mortality	17 (6.2%)

AV, Atrioventricular; IABP, intra-aortic balloon pump; TND, temporary neurologic dysfunction; PRIND, prolonged reversible ischemic neurologic deficit. *Requiring revision of distal anastomosis in 1 case and late tamponade in 8 cases. †Requiring revision of button anastomosis in 1 case (<1%). ‡One omentum transplant for infective mediastinitis on day 30, 1 muscle flap closure over the aortic graft, and sternal revision on day 14. §Both died in hospital (1 candida with embolism). ||Three died in hospital (4 stroke survivors). ¶DVT (1)/peripheral embolism (2)/bowel infarction (2)/fasciotomy after femoral cannulation (1)/colectomy for colitis (2).

Follow-up

All patients were followed by the referring cardiologist and contacted periodically by our research personnel. The follow-up questionnaire included cardiac reoperations (paravalvular leakage, prosthetic valve endocarditis), myocardial infarction, cerebral, visceral or peripheral thromboembolic events, hemorrhage, endocarditis, and anticoagulant intake, and was completed in all cases by the patients themselves, their cardiologists, or close family members.

Annual computed tomography scans were scheduled in all patients and attained in 61% of patients. Postoperative events were compiled and analyzed according to the Guidelines for Reporting Morbidity and Mortality after Cardiac Valvular Operations⁷ and our institutional checklist. For this study, follow-up was closed on December 31, 2005, and extended to 11 years.

Statistical Methods

Data were entered in an Excel spreadsheet (Microsoft Corp, Redmond, Wash) and transferred to an SAS file (SAS Institute Inc, Cary, NC) for data description and analysis. Patient characteristics are described as percentages, and groups were compared using chi-square tests. Early death is defined as death within 30 days after the procedure or death before discharge, if beyond 30 days. Logistic regression analysis was used to study independent factors associated with adverse outcome, early death, or permanent stroke. For patients who did not experience early death, long-term follow-up commences 30 days after the procedure and continues until the date of death, or December 31, 2005, for patients with no death information. Kaplan-Meier life tables were calculated to describe early and long-term survival. The Cox proportional hazards model was used to identify independent risk factors for

Figure 2. Oral anticoagulation (Coumadin) at hospital admission and discharge after aortic root reconstruction with a bioprosthetic valved conduit.

long-term survival, controlling for age and gender. Long-term survival of male and female patients was compared with New York State death rates from 2001 for corresponding ages and person-years of exposure, and the differences were tested by methods for Poisson regression.

The risk factors considered for analysis were age, gender, history of hypertension, chronic obstructive pulmonary disease (COPD), coronary artery disease, history of neurologic dysfunction, aortic regurgitation, urgency of the procedure, pathologic condition for which the procedure was indicated, cannulation site, extent of procedure, presence of clot or atheroma, open distal anastomosis, and concomitant procedures (mitral valve replacement/repair, concomitant coronary artery bypass grafting, and other concomitant procedures such as tricuspid valve replacement). For long-term analysis, anticoagulant and β -adrenergic blocking agent intakes were also considered.

Results

Hospital Mortality and Adverse Outcome

The overall hospital mortality, defined as death in the hospital or within 30 days postoperatively, was 6.2% ($n = 17$). Four additional patients (1.5%) sustained permanent strokes. Adverse outcome, defined as stroke or hospital death, occurred in 21 patients (8%): 17 deaths (including 3 patients with strokes) and 4 stroke survivors. On analysis of preoperative risk factors one at a time, there was a statistically significant association with adverse outcome of coronary artery disease ($P = .02$), clot or atheroma ($P < .0001$), and concomitant procedure ($P = .02$, without regard to the type of operation performed concomitantly). Among the variables tested, gender, age more than 60 years, COPD, history of hypertension, history of neurologic symptoms, and severity of aortic re-

Figure 3. Kaplan–Meier survival curve. Survival after aortic root reconstruction with bioprosthetic valved conduits: male (N = 190) and female patients (N = 68) versus age-matched New York State populations. *P* values obtained by Poisson regression with follow-up to 10.7 years.

gurgitation did not show evidence of association with adverse outcome in these data.

All known preoperative risk factors were entered in a stepwise logistic regression analysis to identify those that were independent predictors of adverse outcome. Three factors were identified: clot or atheroma ($P = .0004$), coronary artery disease ($P = .01$), and nonelective procedure ($P = .03$).

Postoperative Complications

Severe postoperative complications after bioprosthetic root reconstruction occurred in 68 patients (24.7%) (Table 3). The most common serious complications were respiratory and cardiac. Twenty-one percent of patients had transient neurologic dysfunction, but only 7 patients had strokes, 3 of whom died. Six patients required dialysis, which was permanent in 2 patients; 4 patients had only transient postoperative renal failure.

Medication at Hospital Admission and Discharge and During Follow-up

At hospital admission, 10% of the patients ($n = 27$) were taking low-dose oral anticoagulants (Coumadin/warfarin).

Overall, 46% of the patients ($n = 126$) were discharged with oral anticoagulants, usually for 3 months, as suggested by the valve manufacturers. In recent years, both the number of patients for whom anticoagulants were prescribed even transiently and the level of anticoagulation have been diminishing (Figure 2). During follow-up, anticoagulation was newly initiated in 4% ($n = 11$); long-term anticoagulation was generally maintained only for indications such as atrial fibrillation, unrelated to the presence of the valved conduit.

The number of patients treated with β -adrenergic blocking agents increased from 26% (72 patients) at admission to 46% (125 patients) at discharge, whereas the number of angiotensin-converting enzyme inhibitor-treated patients did not change.

Late Mortality

Long-term survival among patients who did not die before discharge or within 30 days of the procedure was compared with New York State 2001 death rates (Figure 3). The median duration of follow-up was 3.6 years (range 0–10.7 years).

There were 190 men with a median follow-up of 3.5 years (0.01–10.6 years), totaling 703 patient-years; among

TABLE 4. Long-term survival after aortic root reconstruction: A literature review

First author/year	Bentall technique and conduit	n	Age (y)	Hospital mortality	Survival
Zehr/2004 ⁸	"Modified" Bentall Composite conduits Mechanical (90%) Biological (10%) Valve-preserving	149 54	53 ($\pm$ 16)	4%	93% (5 y) 79% (10 y) Predictors of late death: age, ^m female, MV regurgitation; ^u concomitant procedure, ^u no β -blocker, [‡] inotropes ^u
Hagl/2003 ¹⁵	Button Bentall Composite conduits Mechanical (88%) Biological (12%)	142	46 (13-64) <65 only, Ø concomitant procedure	<1%	95% at (5 y) 93% (8 y)
Pacini/2003 ¹⁶	Classic Bentall (34%) Button Bentall (63%) Cabrol (3%) Composite conduits Mechanical only	274	53.5 ($\pm$ 14.5)	7%	78% (5 y) 63% (10 y) Predictors of late death: CAD, ^m chronic renal failure, ^m postoperative dialysis ^m
Dellgren/2002 ¹⁷	Stentless porcine bioprosthesis	112	78.5 $\pm$ 5.0 >70 only, or symptomatic	7%	74% (5 y) 38% (9 y)
Ehrlich/2001 ¹⁸	Mechanical (N = 47) and biological (N = 37) Bentall	84	74 (66-89) >65 y	8.3%	74% (5 y)
Mount Sinai/2006	Biological Bentall	275	69.3 ($\pm$ 11.3)	6.2%	74% (5 y) Predictors of late death: female, ^m concomitant procedure ^m

m, Multivariate analysis; *u*, univariate analysis; *MV*, mitral valve; *AV*, atrioventricular; *CAD*, coronary artery disease. *No difference in late survival between patients with composite valve conduit reconstruction versus valve-sparing operation. †Freedom from reoperation because of a failure of the Bentall procedure or + pseudoaneurysm. ‡Conduit versus valve preservation at 5 y: 96% vs 63%, $P < .001$. †At admission. §Overall freedom from late adverse event (endocarditis, aortic reoperation, stroke, significant bleeding or thromboembolic complications).

these, there were 34 deaths (4.8/100 patient-years). The death rate was 1.2 times what would have been expected for the control population ($P = .34$). Among the 68 women, however, in whom median follow-up was 2.8 years (0.05-10.7), amounting to 247 patient-years, 21 deaths occurred (8.5/100 patient-years). The death rate in women was twice what would have been expected on the basis of the control group ($P = .002$). A woman is therefore 1.7 times as likely to die after a biological Bentall operation, relative to the corresponding New York State control rates, than a man ($P = .07$).

For the group as a whole, multivariate analysis indicated that the long-term outcome after a biological valved conduit reconstruction of the aortic root among female patients was significantly worse than that for male patients, and that their risk factors differed. For female patients, multiregression analysis revealed the presence of clot or atheroma as an independent predictor of late death. Open distal anastomosis

and prescription of β -blocking drugs at hospital discharge were protective factors for long-term survival in women. In male patients, the presence of COPD and performance of any concomitant procedure were independent predictors of late death.

Aortic Reoperation

Two patients required early revision for mediastinitis after primary aortic root reconstruction with a bioprosthetic valved conduit. No reoperation for early failure of the biological Bentall procedure or for anastomotic pseudoaneurysm occurred.

Structural Valve Deterioration

Reoperation for structural valve dysfunction was required in only 1 patient, 12 years after root replacement with a biological valved composite graft.

TABLE 4. (Continued)

	Freedom from/rate of			
	Aortic reoperations	Thromboembolism	Hemorrhage	Endocarditis
Predictors: Marfan, concomitant procedure, AV spare	88% (5 y) 86% (10 y)†	97% (5 y) 96% (10 y)	3% (15 y)	99% (15 y)
	100%§	98% 0.3/100 pt-y	Overall: 85% (5 y)/78% (8y)‡ 93% 1.6/100 pt-y	99% 0.3/100 pt-y
	99% (5 y) 99% (10 y) 94% (20 y);0.28/100pt-y‡	98% (5 y) 91% (10 y) 90% (20 y);0.63/100pt-y	100% (5 y) 87% (10 y) 74% (20 y);0.91/100pt-y	98% (5 y) 96% (20 y);0.35/100 pt-y
	96% (5 y) 87% (9 y)	89% (5 y) 71% (9 y)	>99%	96% (5 y) 90% (9 y)
	-	2.1/100 pt-y	—	—
	0.0/100 pt-y	0.85/100 pt-y	0.3/100 pt-y	0.0/100 pt-y

Thromboembolic Events

Seven of the 125 patients who were alive at study time reported having a permanent stroke during follow-up. One was undergoing long-term anticoagulation for an indication unrelated to the Bentall procedure. One additional patient who died in follow-up is known to have had a stroke, making a total of 8 documented strokes among hospital survivors, a rate of 0.85 per 100 patient-years of follow-up. However, we could not update information about strokes for 39 of the 55 patients who died in follow-up. If they had experienced strokes at the same rate as the 16 deceased patients with known stroke information, the linearized stroke rate would be estimated as 1.2 per 100 patient-years.

Hemorrhage

After hospital discharge, 3 patients had a significant hemorrhage as defined by the Society of Thoracic Surgeons

guidelines. All 3 were alive at study time. Two of them were being treated with anticoagulants for indications unrelated to the biological Bentall procedure. The linearized incidence of significant hemorrhage during follow-up was estimated as 0.3 per 100 patient-years. The median time to hemorrhage was 503 days (498–2016 days).

Discussion

This review of our experience with reconstruction of the aortic root using a stented bioprosthetic valve in the conduit yielded a number of interesting insights. Overall, the study revealed favorable short and long-term outcomes in these elderly patients. The absence of valve failure within the first 10 years and the low incidence of complications make a biological Bentall operation seem not only an attractive alternative to aortic root replacement using a mechanical valved conduit but also raises the question whether biological valved conduit replace-

ment may be preferable in some situations to a valve-sparing operation.

Because the main advantage of implanting a biological valved conduit compared with a mechanical valve is to avoid anticoagulation, we were startled to see that so many of our patients, especially in the earlier years of this experience, were discharged with anticoagulants. Postoperative patient care in our referral practice is largely the province of cardiologists, who generally think that a 3-month interval of anticoagulation postoperatively is a good idea to guard against thromboembolism until the conduit endothelializes fully. Only a small minority of patients remained on anticoagulation long term for reasons unrelated to the conduit (chiefly atrial fibrillation), but the levels of anticoagulation needed for this indication are lower than those considered mandatory to prevent thrombosis of a mechanical valve. Only 18% of the population received platelet inhibitors, perhaps because only 23% of the patients had atherosclerotic aneurysms and were therefore deemed likely to benefit from antiplatelet therapy. We were gratified to see a low rate of embolic, thrombotic, and hemorrhagic complications and an absence of early biological valve failure during long-term follow-up.

Long experience has indicated that tissue valves undergo accelerated degeneration in young individuals, but it may be that newer techniques of valve preservation make a biological prosthesis a reasonable option beginning in early middle age. The greater ease of operation compared with valve-sparing procedures, the absence of early valve failure even when preoperative aortic insufficiency has been moderate or severe, and the lack of worry about early degeneration when a connective tissue disorder is present make biological valved graft replacement appealing.

The importance of clot or atheroma observed intraoperatively underlines the importance of embolization in determining both short- and long-term adverse outcomes after aortic root replacement regardless of method. One of the results we anticipated was that axillary cannulation would emerge as a factor reducing the risk of embolization (and therefore of adverse outcome) in these patients, many of whom have a high risk of stroke because of underlying atherosclerosis. During the last 5 years of the study, axillary cannulation was used predominantly because the axillary artery is rarely—in contrast with the ascending aorta or femoral artery—affected by severe atherosclerosis. Although the low rate of adverse outcome in the relatively small number of patients with different cannulation techniques did not permit the identification of axillary artery cannulation as a significant factor contributing to long-term survival, we did observe that the rate of adverse outcome during the last 5 years of the series, when axillary artery cannulation was the technique of choice, decreased to 5.1%.

In addition to its perceived advantage in preventing embolization, the axillary artery also provides an excellent route for SCP, which may be required in high-risk cases for cerebral protection. Axillary artery cannulation also diminishes the risk of reentry into a previously operated chest by allowing rapid initiation of cardiopulmonary bypass.

Another potentially important but somewhat unexpected finding of this study is that the long-term outcome of female patients who survive root replacement with a biological valved conduit is different—and worse—than the outlook for male patients, if compared with an age-matched population. As noted in Table 4, Zehr and colleagues⁸ found female gender to be a univariate predictor of late death in a significantly younger population with the same male:female (25%) ratio. Male patients who recover satisfactorily after reconstruction of the aortic root with a biological valved conduit enjoy long-term outcome equivalent to that of a normal age-matched population, but women who survive the biological Bentall procedure are twice as likely to die during follow-up than their age-matched normal peers. This finding is in accord with similar observations after combined valve and coronary artery bypass surgery, after which morbidity and mortality are less favorable for women than for men.^{9–11} The difference in the prognosis for men and women after aortic root operation may represent a difference in the pathophysiology leading to surgery in men and women: Only 31% of the male patients had an atherosclerotic aneurysm ($n = 35$; 17%) or dissection ($n = 27$; 13%), in contrast with 60% of female patients with atherosclerotic aneurysm ($n = 28$; 38%) or dissection ($n = 16$; 22%).

An increased propensity to develop degenerative aneurysm disease in men was found in several series.^{12,13} Although degenerative disease can affect the entire vascular system (as in Marfan syndrome), localized degenerative aortic aneurysm disease (eg, bicuspid valve disease) may be considered cured once the aortic root has been resected and is therefore unlikely to affect long-term survival. The relatively high mean age and the low percentage of Marfan disease may reflect an unusually high proportion of localized degenerative disease in the men in this series. In contrast, an atherosclerotic root aneurysm, or a dissection—which accounted for a much higher proportion of the cases in women—may reflect more severe and widespread disease. In the majority of the female patients, although resection of the root aneurysm eliminated the risk of localized rupture or dissection, a propensity for dissection or widespread atherosclerotic disease likely continued to be a threat in other segments of the vascular system.

This theory to explain our results is supported by the finding that the presence of clot and atheroma in the aortic root was the most significant predictor of late death in female patients. The fact that an open distal anastomosis

enhanced long-term outcome is consistent with the known risks of crossclamping the aorta in the presence of atherosclerosis or dissection. Similarly, that the use of β -adrenergic blocking agents improved long-term survival in women makes sense if many of them had ongoing serious cardiovascular pathologic conditions. It is also likely that women are referred later for aneurysm surgery, because the major indication for elective operation is the extent of aortic dilatation, which is usually measured in absolute terms rather than being indexed to the size of the patient. It seems plausible that a 6-cm aorta reflects more advanced disease in a petite woman than in an average (much larger) man.

In men, COPD and any concomitant procedures independently predicted late death after the biological Bentall procedure. Nevertheless, longevity for male survivors did not differ from the expected mortality rate in an elderly age-matched control population.^{14,15}

Conclusions

The excellent results after implantation of bioprosthetic valved conduits for patients requiring aortic root reconstruction may lead to an expansion of the indications for this procedure. In patients for whom anticoagulation is contraindicated or undesirable, reconstruction of the aortic root with a stented bioprosthetic valved conduit offers an excellent alternative to the use of a mechanical valved prosthesis and may be preferable to a valve-sparing operation in middle-aged and older individuals, those with connective tissue disorders, and those with more than mild aortic insufficiency preoperatively.

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