Intermediate-term results of ascending–descending posterior pericardial bypass of complex aortic coarctation

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Objective: Extra-anatomic bypass of complex thoracic aortic disease through a median sternotomy has been reported as a safe alternative to thoracotomy. Our objective was to examine intermediate-term outcomes.

Methods: We retrospectively reviewed 50 consecutive patients with congenital aortic coarctation or recurrent coarctation who underwent ascending–descending posterior pericardial aortic bypass between January 1985 and November 2005. Demographic data, in-hospital and postoperative morbidity and mortality, and resolution of hypertension were determined by examination of the medical record.

Results: The mean age at operation was 42 years; 27 (54%) were men. There were no perioperative deaths. Upper-extremity blood pressure after coarctation repair with ascending–descending aortic bypass was significantly improved. Mean systolic blood pressure decreased from 158 ± 25 mm Hg preoperatively to 123 ± 14 mm Hg postoperatively ($P < .001$). There were no graft-related deaths or complications in follow-up extending up to 20 years.

Conclusions: The ascending–descending aortic bypass through a posterior pericardial approach is a safe operation and is effective in relieving obstruction and improving hypertension.

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Coarctation of the aorta leads to hypertensive cardiovascular sequelae such as coronary artery disease, heart failure, stroke, aortic dissection or rupture, and premature death.¹ Aortic coarctation is most often congenital but can also be acquired, as may occur with traumatic aortic transection or obstructive atheromatous disease. Native aortic coarctation is usually repaired surgically through a left thoracotomy, but the best surgical option for patients with concomitant heart disease is uncertain. Also, patients with recurrent aortic coarctation after previous repair or a more complex aortic abnormality may require alternate operative approaches.

We previously reported our initial experience with an ascending–descending posterior pericardial aortic bypass for treating complex aortic coarctation and aneurysmal disease.^{2,3} We concluded that the operation was safe but that the intermediate- and long-term safety and durability of this operation were unknown. The purpose of the current study was to document intermediate-term experience with extra-anatomic

Figure 1. Ascending–descending aortic bypass graft for aortic coarctation. *ASC*, Ascending; *Coarct*, aortic coarctation; *DESC*, descending; *IVC*, inferior vena cava. (Used with permission of Mayo Foundation for Medical Education and Research.)

bypass of aortic coarctation, with particular attention to the patient survival, incidence of graft-related complications, and impact on hypertension.

Materials and Methods

We reviewed the cases of 50 consecutive patients with congenital aortic coarctation or recurrent coarctation who underwent ascending–descending posterior pericardial aortic bypass between January 1985 and November 2005. The Institutional Review Board of Mayo Foundation approved the study. All patients had previously given consent to participate in research.

The main indication for operation in this series was uncontrollable hypertension in the setting of three clinical scenarios: complex native coarctation, recurrent/persistent coarctation, or the need for concomitant cardiac surgery. Hypertension was measured through invasive hemodynamic gradients and computed tomographic angiography in the setting of recurrent/persistent coarctation.

Operative Technique

Our technique of ascending–descending posterior pericardial aortic bypass is performed through a median sternotomy with normothermic cardiopulmonary bypass.^{2,3} The heart is retracted cephalad and to the patient's right. The right pleural space can be opened, if necessary, to assist with exposure. The posterior

Figure 2. Computed tomographic angiogram after posterior pericardial bypass in a 51-year-old woman who had previously undergone 2 coarctation repairs through a left thoracotomy, the most recent of which was an interposition graft. *A*, Posterior pericardial position of the graft (arrow). *B*, The heart has been subtracted from the image to show graft patency (arrow).

pericardium is incised, and the descending thoracic aorta is isolated. The distal anastomosis is created on the descending thoracic aorta, and the proximal anastomosis is created on the ascending aorta. Both anastomoses are created using partial occluding vascular clamps. To reduce the risk of spinal and lower-extremity ischemia during partial aortic occlusion, we routinely measure upper- and lower-extremity blood pressure intraoperatively. The completed graft courses from the ascending aorta, anterior to the right pulmonary veins, and either anterior or posterior to the inferior vena cava into the descending thoracic aorta (Figures 1 and 2). The average size of the bypass graft was 21 ± 2 mm (range, 16–24 mm).

Data Collection

Medical records were retrospectively reviewed for demographic, medical history, radiographic, and operative data. This included in-hospital and outpatient postoperative morbidity and mortality. Postoperative blood pressure was reported as reduction in mean upper-extremity blood pressure after coarctation bypass. This was used as a surrogate for invasive arterial gradient measurements. Postoperative blood pressure values were compared with those from the same extremity used preoperatively, when possible.

TABLE 1. Demographic characteristics of the study population

Characteristic	Patients	
	No.	%
Age, y, mean (range)	42 (15-67)	
Gender (male)	27	54
Native aortic coarctation	22	44
Recoarctation	28	56
Hypertension	48	96
Coronary artery disease	4	8
Previous operation	35	70
Coarctation of aorta repair	28	56
Aortic valve replacement	3	6
Ventricular septal defect repair	2	4
Patent ductus arteriosus ligation	2	4
Coronary artery bypass graft	1	2
Subaortic stenosis repair	1	2
Aortic valvotomy	1	2

Imaging

Postoperative radiographic images (available for 37/50 patients) were reviewed to assess graft patency and graft-related complications. Imaging modalities consisted of echocardiography, arteriography, computed tomographic angiography, and magnetic resonance angiography performed at varying intervals throughout the postoperative period.

Statistical Analysis

Continuous data are presented as mean $\pm$ standard deviation. They were analyzed using a 2-sided paired *t* test. Data analysis was performed on JMP version 5.1 (SAS Institute, Inc, Cary, NC).

Results

Fifty consecutive patients underwent ascending–descending posterior pericardial bypass of aortic coarctation between January 1985 and November 2005. Demographic data for this study sample are presented in Table 1. The mean age at operation was 42 years (range, 15-67 years), and 27 (54%) were men. Twenty-two patients had native aortic coarctation (44%), and 28 patients had recurrent or residual coarctation after earlier surgical repair. Forty-eight patients (96%) had marked hypertension, and 35 patients (70%) had at least 1 previous cardiovascular operation. Of the previous operations, repair of aortic coarctation through a thoracotomy was the most common (56%), followed by aortic valve replacement, repair of ventricular septal defect, and ligation of a patent ductus arteriosus.

Operative characteristics, including data on cardiopulmonary bypass, are presented in Table 2. Twenty-nine patients (58%) required aortic crossclamping and cardioplegic arrest of the heart, and 5 patients (10%) underwent deep hypothermic circulatory arrest to facilitate concomitant car-

TABLE 2. Operative characteristics*

Characteristic	Value
Bypass time, min, mean $\pm$ SD (range)	107 $\pm$ 53 (18-224)
Crossclamp time, min, mean $\pm$ SD (range)	58 $\pm$ 42 (17-183)
Concomitant operations, %	62
Aortic valve replacement	30
Aneurysm repair	12
Myectomy	10
Coronary artery bypass	8
Mitral valve repair	6
Mitral valve replacement	3
Aortic valve repair	2
Ventricular septal defect repair	2

SD, Standard deviation. *Includes cardiopulmonary bypass and aortic crossclamp times (*n* = 29) and the type of concomitant cardiovascular operations performed at the time of posterior pericardial bypass.

diovascular repairs. The mean cardiopulmonary bypass time was 77 $\pm$ 40 minutes for isolated aortic bypass (no aortic crossclamp) and 126 $\pm$ 53 minutes for patients undergoing concomitant repairs (with aortic crossclamp and cardioplegic arrest of the heart) (*P* < .001). Concomitant operations were performed in 62% of patients; procedures included aortic valve replacement (*n* = 15), ascending aortic aneurysm repair (*n* = 6), myectomy for left ventricular outflow tract obstruction (*n* = 5), and coronary artery bypass grafting (*n* = 4).

There were no intraoperative or perioperative deaths in this series (Table 3). Arrhythmias other than atrial fibrillation or flutter were uncommon. Respiratory complications developed in 4 patients, and reexploration for bleeding was required in 5 patients (10%) (4/5 patients with postoperative hemorrhage were undergoing reoperations). Of note, right lower-extremity weakness developed in 1 patient. This

TABLE 3. Operative results

Result	No.
Mortality	
Operative	0
Study period	1
Morbidity	
Cardiac	
Arrhythmia	11
Respiratory	
Pneumonia	4
Effusions	4
Hemorrhagic	
Reexploration for bleeding	5
Other	
Right lower-extremity weakness	1
Seizures	1
Sternal dehiscence	1

TABLE 4. Effect of bypass on hypertension in the study group

Variable	Value			P value
	Preoperative	Postoperative	Intermediate follow-up*	
Systolic blood pressure, mm Hg, mean $\pm$ SD	158 $\pm$ 25	123 $\pm$ 14	132 $\pm$ 19	<.001
Hypertensive medications, No., mean $\pm$ SD	1.7 $\pm$ 1.4	1.1 $\pm$ 0.8	N/A†	.01

SD, Standard deviation; N/A, not available. *Mean, 32 months. †The number of antihypertensive medications at intermediate follow-up was not available.

weakness resolved, and at latest follow-up the patient reported only right lower-extremity fatigability with strenuous exercise.

There was 1 late death from congestive heart failure at 53 months postoperatively. This patient was a 47-year-old man at the time of aortic bypass for recurrent aortic coarctation and concomitant aortic valve replacement. He did not have any postoperative complications, and the graft was patent when imaged with cardiac catheterization 51 months postoperatively.

There was a significant reduction in mean upper-extremity blood pressure after coarctation repair with ascending–descending aortic bypass (Table 4). Mean systolic blood pressure decreased from 158 $\pm$ 25 mm Hg preoperatively to 123 $\pm$ 14 mm Hg postoperatively ($P < .001$). This improvement persisted at intermediate follow-up, with a mean systolic blood pressure of 132 $\pm$ 19 mm Hg at a mean of 32 months postoperatively ($P < .001$). There was also a significant reduction in the number of antihypertensive medications taken postoperatively (Table 4). The mean number of medications decreased from 1.7 $\pm$ 1.4 preoperatively to 1.1 $\pm$ 0.8 postoperatively ($P = .01$).

No graft-related complications were observed in clinical follow-up (mean, 33 $\pm$ 38 months) or radiographic follow-up (mean, 21 $\pm$ 33 months; range, 4 days to 11.9 years). Specifically, 37 of the 50 patients (74%) were imaged, and all grafts were patent without obstruction or pseudoaneurysm formation.

Discussion

Ascending–descending posterior pericardial aortic bypass is a safe procedure for repair of coarctation of the aorta; in this expanded series, there has not been any early mortality and only minimal morbidity. Also, the procedure significantly improved hypertension and decreased the number of antihypertensive medications required to achieve adequate blood pressure control.

Aortic coarctation is a common congenital cardiovascular malformation that if untreated results in serious cardiovascular sequelae and premature death.¹ Although coarctation may present as an isolated malformation, other major concomitant cardiac anomalies, such as bicuspid aortic valve disease, are present in more than 50% of patients.⁴ Many of these concomitant abnormalities ultimately require surgical correction, and thus patients with native or recur-

rent coarctation may present with the need for sternotomy for intracardiac repair. The ascending–descending aortic bypass is easily performed through a midline incision at the time of other cardiac operations.

The most common incision for repair of native coarctation is left thoracotomy, but for reoperations, this approach may be hazardous. In more complex situations, extra-anatomic bypass grafting has been used. Bypass of the aorta through a median sternotomy was first described by Edie and colleagues⁵ and Wukasch and colleagues.⁶ Edie and colleagues described ascending–descending thoracic aortic bypass, and Wukasch and colleagues described ascending-to-abdominal aortic bypass. Aortic bypass posterior to the heart was described by Vijayanagar and colleagues⁷ and was soon modified by Sweeney and colleagues,⁸ Powell and colleagues,⁹ and Robicsek and colleagues.¹⁰ Our technique differs somewhat from that of other studies, which reported performing aortic bypass without cardiopulmonary bypass. We prefer to use cardiopulmonary bypass because it allows maintenance of adequate perfusion pressure during manipulation of the heart.

Izhar and colleagues² and Connolly and colleagues,³ from Mayo Clinic, described ascending–descending aortic bypass grafting for 2 indications: patients with thoracic aortic disease who required repair of concomitant cardiac problems through a median sternotomy and patients with complex thoracic aortic disease in whom extra-anatomic repair appeared safer than anatomic repair. The current study included only patients with native and recurrent coarctation and extends follow-up. Durability is important in younger patients, especially those with isolated coarctation who may have normal life expectancy. In contrast, the longevity of patients with concomitant procedures will likely be limited by associated cardiac problems such as valvular or coronary artery disease. Indeed, the 1 late death in our series was due to congestive heart failure and occurred 4.4 years postoperatively in a patient who had repair of recurrent coarctation of the aorta and associated aortic valve regurgitation.

The posterior pericardial approach for ascending–descending aortic bypass is safe. In our series, the operation was performed in 50 consecutive patients without operative death. There were few complications aside from transient atrial arrhythmias and reoperation for hemorrhage (in patients undergoing reoperation) during the postoperative pe-

riod (Table 3). Paraplegia, the most serious complication associated with descending thoracic aortic surgery, rarely occurs in patients undergoing repair of native coarctation. However, paraplegia has been reported in patients undergoing reoperation for coarctation.¹¹ Several methods have been proposed to minimize the risk of paraplegia in the reoperative setting, including support of the distal circulation with partial cardiopulmonary bypass or temporary shunts¹² and spinal cord protection with hypothermic circulatory arrest.¹³ Each of these techniques seems more complicated than the method described. Also, the risk of spinal cord injury might be expected to be decreased with the posterior pericardial approach because the distal graft anastomosis is made to the distal thoracic aorta just above the diaphragm.

One patient in our series, a 33-year-old woman, did exhibit right lower-extremity weakness postoperatively that was attributed to spinal cord ischemia. This patient underwent ascending–descending aortic bypass for residual coarctation after 2 previous thoracotomies and unsuccessful balloon angioplasty. At the 3-year follow-up, the patient's weakness had resolved, but she reported right lower-extremity fatigability with strenuous exercise. Of note, this is the only patient in our series who had aortic bypass without extracorporeal circulation and experienced moderate intraoperative hypotension during cephalad retraction of the heart. Wukasch and associates⁶ reported aortic bypass for coarctation without extracorporeal circulation, but their method used distal anastomosis to the supraceliac abdominal aorta. Use of the posterior pericardial approach without cardiopulmonary bypass has been advocated by Kanter and colleagues.¹⁴ Although avoidance of extracorporeal circulation may be possible in smaller patients without cardiomegaly, decompression of the heart during bypass improves exposure of the descending thoracic in most adult patients and ensures adequate perfusion during cephalad retraction of the heart.

In patients requiring reoperation, the altered surgical field makes re-repair through a thoracotomy more hazardous. The risks of dissecting through collateral circulation and extensively mobilizing the aorta are minimized with the ascending–descending aortic bypass approached through a median sternotomy. As a result, the morbidity and mortality profiles in the present series compare favorably with those of previously published series of re-repair of aortic coarctation through a left thoracotomy. Massey and Shore¹⁵ reported a retrospective series of 65 patients, 20 of whom were reoperative cases. Of the 14 operations for recurrent aortic coarctation, there were no early deaths and late mortality was 4.5% at 19 years. Postoperative morbidity was reported at 75% for reoperative cases and included recurrent laryngeal injury in 5 of 14 patients (36%). On the basis of our overall complication rate of 24%, the majority of which

were unrelated to aortic bypass, reoperative repair of aortic coarctation through a median sternotomy seems to be safer.

The intermediate-term durability of this repair is satisfactory. There have been no graft-related complications, and notably absent is the development of any graft infections in follow-up that extends to 20 years. Although postoperative imaging was not available for every patient, all grafts that were imaged ($n = 37$) were patent, with no evidence of pseudoaneurysm, patient–graft mismatch, dissection, or notable graft narrowing. Similarly, there was no clinical or radiographic suggestion of aortic graft–esophageal fistula, a concern raised by others.¹⁴

In our series, aortic bypass had a beneficial effect on systemic arterial hypertension. After coarctation repair, mean upper-extremity systolic blood pressure decreased significantly, with a concomitant decrease in the number of antihypertensive agents required. Most patients continued to receive some form of antihypertensive therapy, but the decrease in number of medications required indicates that persistent hypertension after bypass is much easier to control medically (Table 4). The improvement in blood pressure control and the number of antihypertensive agents required are encouraging, but whether this effect is long-lasting is uncertain.

We consider using the posterior pericardial approach for aortic bypass in adult patients with complex coarctation requiring surgical correction, especially those with hypoplasia of the aortic isthmus or a concomitant cardiovascular lesion (or both), but we have been reluctant to use this method in children and adolescents. Subsequent somatic growth in such patients may lead to tension on the graft and formation of a false aneurysm, and small-caliber prostheses in young children may not provide adequate flow during adulthood.¹⁴ Another group of patients requiring special consideration are those who will likely require reoperation in which the graft position may limit future surgical options.

There are nonsurgical therapies for treating native and recurrent coarctation. In some centers, percutaneous angioplasty and stenting seem to have good results for treating simple (narrow-shelf) recurrent aortic coarctation and may well become the treatment of choice.¹⁵ Percutaneous dilatation and stenting are also used to treat native coarctation in children, but there is less experience in adults who have more fragile tissue and may have calcification or atherosclerosis (or both).¹⁶ However, even in children, balloon angioplasty has a relatively high rate of late pseudoaneurysm formation,¹⁷ and it is uncertain whether stents with or without prosthetic covering will eliminate this complication.

Conclusions

The ascending–descending aortic bypass through a posterior pericardial approach is a safe operation and is effective for relieving obstruction and improving hypertension at

intermediate-term follow-up. On the basis of this experience extending to 20 years, we conclude that the results are durable and that the procedure is of particular value for adult patients who have complex coarctation requiring surgical correction and have concomitant cardiovascular abnormality.

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