SURGERY FOR ACQUIRED CARDIOVASCULAR DISEASE

LONG-TERM EFFECTIVENESS OF OPERATIONS FOR ASCENDING AORTIC DISSECTIONS

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Objective: To evaluate long-term effectiveness of a strategy for managing the aortic root and distal aorta according to the pathology in ascending aortic dissection.

Methods: From 1978 to 1995, 208 patients underwent operations for acute ($n = 135$) and chronic ($n = 73$) ascending aortic dissection. Surgical strategies included valve resuspension with supracoronary aortic root repair and ascending aortic graft for normal sinuses and valve ($n = 135$), composite valve and ascending aortic graft for abnormal sinuses and valve ($n = 47$), and valve replacement and supracoronary ascending aortic graft for normal sinuses and abnormal valve ($n = 26$). Resection extended into the arch only if the intimal tear originated in or extended to the aortic arch ($n = 31$).

Results: Hospital mortality was 14%. Cardiogenic shock ($P = .002$) and concomitant coronary artery bypass grafting ($P = .001$) were associated with increased risk; use of circulatory arrest ($P = .0003$) decreased risk. Survival was 87%, 68%, and 52% at 30 days, 5 years, and 10 years, respectively. Advanced age, earlier date of operation, composite graft, and arch resection were associated with decreased survival; residual distal dissected aorta was not. Reoperation was required for 5 proximal and 8 distal problems.

Conclusions: In both acute and chronic ascending aortic dissections, (1) circulatory arrest is associated with low early mortality; (2) with normal sinuses and valve, supracoronary repair of the dissected aortic root and valve resuspension is effective long term; and (3) residual distal dissected aorta does not decrease late survival and has a low risk of aneurysmal change and reoperation for at least 10 years. (*J Thorac Cardiovasc Surg* 2000;119:946-62)

We view the goals of the operation for ascending aortic dissection as establishing a competent aortic valve, replacing the aortic segments in which the primary intimal tear has occurred, preventing antegrade flow into the false lumen when the dissection is acute, and having the patient survive the operation. Increased

control over intraoperative events and appreciation of late aortic complications led some to suggest that extended operative procedures, such as routine aortic arch replacement and total aortic root replacement, should be undertaken to decrease late aortic or aortic valve complications.¹⁻³ In contrast, we and others have followed a more conservative operative approach.

We attempted to tailor the management of the aortic root to the pathology. If the aortic valve and sinuses were structurally normal, aortic valve reconstruction at the level of the sinotubular junction and supracoronary ascending aortic graft replacement were used. If the aortic valve was structurally abnormal, but the sinuses normal, aortic valve replacement and supracoronary aortic grafting were employed. If both aortic valve and sinuses were abnormal, from pre-existing dilatation or extension of the intimal tear proximally to the level of

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Fig 1. Cumulative distribution of the interval between onset of symptoms and operation in patients with acute ascending aortic dissection. The *vertical axis* is the percent of patients with intervals smaller than the values stated on the *horizontal axis*. The *inset* shows various percentiles; for clarity, some of these are presented in terms of hours (*h*) rather than days (*d*).

the valve, total aortic root and valve replacement (Bentall operation) was used.

Likewise, management of the distal aorta was tailored to the pathology. If the intimal lesion was limited to the ascending aorta, the aorta was replaced only to the level of the innominate artery. Complete or hemi-aortic arch replacement was used only when the intimal lesion extended into or originated in the arch.⁴⁻¹¹

The objective of this study was to evaluate the effectiveness of these surgical strategies, applied without regard to acuity of presentation, on survival and late proximal and distal treatment failures.

Patients and methods

Patients. Records were reviewed of 208 patients undergoing repair of a spontaneously occurring, acute ($n = 135$) or chronic ($n = 73$) ascending aortic dissection at The Cleveland Clinic Foundation from 1978 to 1995. Diagnosis was made by aortography, transesophageal echocardiography, computed tomography, or magnetic resonance imaging. Dissections occurring intraoperatively or during cardiac catheterization were excluded. Coronary angiography was obtained in 149 sufficiently stable patients (72%) who had a history suggestive of coronary artery disease, had previous coronary artery bypass grafting (CABG), or were older than 55 years. Its use was less in acute than chronic dissection and did not change significantly over time ($P = .3$).

Definitions. Aortic dissections were classified as *acute* (symptoms < 14 days) or *chronic* (symptoms ≥ 14 days). The median interval between onset of symptoms and operation in acute dissections was 1 day, with 25% of the patients

operated on within 12 hours (Fig 1). Patients with acute dissection were more at the extremes of New York Heart Association (NYHA) class (Appendix Table I), the dissection was less likely limited to the ascending aorta (Appendix Table II), and finding blood in the pericardium was more common than in those having chronic dissection (Appendix Table III).

The dissections were classified according to the *known distal extent of the dissection* determined by preoperative testing and intraoperative findings (Appendix Table II): (1) limited to the ascending aorta, (2) involving the ascending aorta and arch, (3) extending from the ascending aorta to the descending thoracic aorta, and (4) extending from the ascending aorta into the abdominal aorta. Because not all patients underwent imaging of the entire aorta, the known distal extent may have underestimated the *actual* distal extent of dissection. Dissection limited to the ascending aorta was more common ($P = .06$) in patients undergoing reoperation (41%) than in those undergoing primary repair (27%).

Patients were further classified according to *completeness of resection* and replacement of the dissected aortic segments. Those with dissected aorta remaining distal to the aortic replacement (63%) were classified as having residual distal dissected aorta (Appendix Table IV). Although the actual distal extent of dissected aorta may have been underestimated by lack of imaging of the entire aorta preoperatively in some patients, we were able to accurately classify all patients as to whether or not they had residual distal dissected aorta by our preoperative and operative findings. Patency of the residual dissected aorta (vs thrombosed false lumen) after surgery was not determined.

Operative methods. Three operative strategies were used to manage the dissected ascending aorta and aortic valve: (1) replacement of the supracoronary ascending aorta, supra-

Fig 2. Mortality after operations for ascending aortic dissection. **A**, Overall survival. Each *symbol* represents a death, positioned according to the Kaplan-Meier estimator. The *vertical bars* are asymmetric confidence limits of the estimates. Superimposed are parametric survival estimates and their confidence limits (*solid line* and *dashed line*, respectively). The *inset* tabulates the number of patients traced beyond the indicated interval after operation (*n*) and the parametric survival estimate. **B**, Hazard function.

coronary root repair, and aortic valve resuspension (65%), (2) composite graft replacement of the aortic valve, sinuses, and ascending aorta (23%), and (3) replacement of the supracoronary ascending aorta and aortic valve (12%) (Appendix Table II). The type of repair performed depended on the aortic valve, aortic root, and type of ascending aortic pathology as detailed in the introduction. Early in the series, some surgeons used the composite graft technique for most ascending aortic dissections; however, as experience was gained, every attempt was made to preserve the aortic valve in patients with normal valves, reducing use of composite grafting ($P = .07$, Appendix Fig 1, A).

Supracoronary aortic root repair and aortic valve resuspension were performed as follows. The proximal false lumen was obliterated with a tailored piece of Teflon felt placed in the false lumen. A second piece of felt was placed inside the aorta and a third piece outside the aorta. The dissected aortic wall layers and three layers of Teflon felt were sandwiched together with monofilament suture. Thus, the aortic valve was resuspended by repair of the entire intima including the commissures. Composite aortic valve and ascending aortic graft replacement were usually performed with direct reimplantation of the coronary ostia into the aortic graft.¹² Patients undergoing aortic valve replacement and supracoronary

Table I. Hospital mortality related to patient characteristics and acuteness of dissection

Variable	Total			Acuity of dissection					
	n	Hospital mortality No. (%)	P	Acute (n = 135)			Chronic (n = 73)		
				n	Hospital mortality No. (%)	P	n	Hospital mortality No. (%)	P
Demography									
Age (y)*			.6			.9			.5
<30	10	1 (10)		7	1 (14)		3	0 (0)	
30-50	43	3 (7)		29	3 (10)		14	0 (0)	
50-60	51	9 (18)		36	6 (17)		15	3 (20)	
60-70	63	10 (16)		37	7 (19)		26	3 (12)	
≥70	41	6 (15)		26	4 (15)		15	2 (13)	
Sex			.1			.09			.5
Male	145	24 (17)		95	18 (19)		50	6 (12)	
Female	63	5 (8)		40	3 (8)		23	2 (9)	
Presentation									
NYHA*			.7			.7			.01
I	52	8 (15)		43	8 (19)		9	0 (0)	
II	70	8 (11)		37	4 (11)		33	4 (12)	
III	46	5 (11)		20	4 (20)		26	1 (4)	
IV	37	7 (19)		32	4 (12)		5	3 (60)	
Hemodynamic status*			.02			.05			—
Stable	176	21 (12)		104	13 (12)		72	8 (11)	
Hypotensive	23	5 (22)		23	5 (22)		0		
Shock	6	3 (50)		6	3 (50)		0		
Emergency operation			.2			.5			.6
No	89	9 (10)		23	2 (8)		66	7 (11)	
Yes	119	20 (17)		112	19 (17)		7	1 (14)	
Chest pain			.6			.2			.2
No	50	6 (12)		22	1 (4)		28	5 (18)	
Yes	155	23 (15)		112	20 (18)		43	3 (7)	
Oliguria			.1			.1			.9
No	194	26 (13)		124	18 (14)		70	8 (11)	
Yes	9	3 (33)		8	3 (38)		1	0 (0)	
Pulse deficit			.8			.8			.6
No	152	22 (15)		93	15 (16)		59	7 (12)	
Yes	53	7 (13)		41	6 (15)		12	1 (8)	
Paraplegia			.4			.3			.9
No	201	28 (14)		131	20 (15)		70	8 (11)	
Yes	3	1 (33)		2	1 (50)		1	0 (0)	
Pulsus paradoxus			.4			.3			.9
No	201	28 (14)		131	20 (15)		70	8 (11)	
Yes	3	1 (33)		2	1 (50)		1	0 (0)	
Use of angiography									
1978-1984			.4			.6			.5
No	10	1 (10)		8	1 (12)		2	0 (0)	
Yes	20	6 (30)		10	3 (30)		10	3 (30)	
1984-1990			.6			.6			—
No	13	2 (15)		13	2 (15)		—	—	
Yes	55	5 (9)		31	3 (10)		24	2 (8)	
1990-1995			.08			.06			.6
No	36	8 (22)		30	8 (27)		6	0 (0)	
Yes	74	7 (9)		43	4 (9)		31	3 (10)	
Associated conditions									
Ischemic heart disease			.8			.6			.6
No	175	24 (14)		115	18 (16)		60	6 (10)	
Yes	33	5 (15)		20	3 (15)		13	2 (15)	
Hypertension			.07			.4			.10
No	76	15 (20)		53	10 (19)		23	5 (22)	
Yes	131	14 (11)		82	11 (13)		49	3 (6)	

Continued on next page.

Table I. *Cont'd*

Variable	Total			Acuity of dissection					
	n	Hospital mortality		Acute (n = 135)			Chronic (n = 73)		
		No. (%)	P	n	Hospital mortality No. (%)	P	n	Hospital mortality No. (%)	P
Previous cardiac surgery			.4			.6			.7
No	157	20 (13)		105	15 (14)		52	5 (10)	
Yes	51	9 (18)		30	6 (20)		21	3 (14)	
Operative findings									
Blood in pericardium			.01			.007			.6
No	165	18 (11)		97	10 (10)		68	8 (12)	
Yes	42	11 (26)		38	11 (29)		4	0 (0)	
Free rupture			.009			.009			.9
No	192	23 (12)		121	15 (12)		71	8 (11)	
Yes	15	6 (40)		14	6 (43)		1	0 (0)	

NYHA, New York Heart Association.

*Logistic test for trend.

ascending aortic graft replacement underwent supracoronary aortic root reconstruction with three layers of Teflon felt.

The distal extent of aortic replacement was governed by the extent of the intimal tear (Appendix Table V). If the intimal tear was localized to the ascending aorta, the distal aortic anastomosis was constructed just proximal to the innominate artery (85%). If the intimal tear extended into or originated in the aortic arch, aortic replacement extended into the arch (13%) or proximal descending aorta (2%). Just enough aortic arch was resected and replaced to excise adequately the arch intimal tear and reconstruct the aortic arch. Although most arch reconstructions were hemi-arch replacements, several patients required a total transverse arch replacement. When the false lumen extended beyond the site of aortic replacement in acute dissections, three layers of felt were used to reconstruct the aorta to prevent antegrade flow into the false lumen. However, in chronic aortic dissection, when distal organs were perfused by only the false lumen, arterial blood flow into the false lumen was not interrupted. When re-entry intimal tears were located in the descending thoracic aorta, the aortic resection was not extended into the descending aorta.

Operations were performed through a median sternotomy. Cannulation of the femoral artery or axillary artery was used for cardiopulmonary bypass. Cold cardioplegia was used for myocardial protection. Hypothermia to 15°C to 20°C and circulatory arrest were used in all operations involving replacement of the aortic arch or the proximal descending aorta. It was also used electively in 118 patients undergoing operations involving only replacement of the ascending aorta to allow close inspection of the aortic arch, to allow accurate construction of the distal anastomosis, and to avoid trauma to the aorta. The use of circulatory arrest increased across time to nearly 100% of cases ($P < .0001$, Appendix Fig 1, B). Retrograde cerebral perfusion of arterial blood into the superior vena cava was used during circulatory arrest in the most recent cases.

Follow-up. Patients were followed up periodically by mail; cross-sectional follow-up for this analysis was by mailed questionnaire, telephone interview, and examination at The Cleveland Clinic Foundation. Three patients were untraced, two shortly after their operations in 1992 and 1993 and the third 3 years after the last follow-up. Total follow-up was 802 patient-years, with mean follow-up among survivors of 4.7 ± 3.8 years, median 3.5 years. Follow-up extended beyond 7.6 years in 25%, but beyond 10 years in only 10%.

Statistical analysis

Outcomes. Time-related outcomes were all-cause death and reoperation for either proximal or distal aortic complications. Nonparametric estimates utilized the Kaplan-Meier estimator. The instantaneous risk across time (the hazard function) was estimated parametrically.¹³ Analyses stratified according to patient or repair variables were compared by means of the log-rank test.

Multivariable analyses. Potential risk factors were organized for entry into the various analyses (Appendix). A nonautomated directed technique of stepwise variable entry was used.¹⁴ It was supplemented by bootstrap resampling, whereby the relative frequency of occurrence of variables in 1000 automated models was used to inform final variable selection.¹⁵ Particular attention was given to the calibration of scale of continuous and ordinal variables and to understanding confounding by changes in prevalence of some variables across time (Appendix Fig 1). Because of the unconventional inclusion of both acute and chronic dissections, we explored interactions between variables and acuteness of dissection, and we incorporated the propensity score for acute dissection into the multivariable analyses derived from Appendix Table III.^{16,17} The P value criterion for retaining variables in the final models was .1.

Presentation. Regression coefficients are presented ± 1 standard error. For consistency, all asymmetric confidence limits (CL) for proportions, Kaplan-Meier estimates, and parametric time-related estimates are 68%, equivalent to 1 standard error.

Results

Time-related survival. Survival was 87%, 81%, 68%, and 52% at 30 days and 1, 5, and 10 years, respectively (Fig 2, A). The instantaneous risk of death (hazard function) was highest immediately after operation, falling to a low value by 6 months, then slowly rising (Fig 2, B).

Early mortality. Twenty-nine (14%; CL 11%-17%) in-hospital deaths occurred. Hospital mortality by patient characteristics (Table I) and status and management of the aorta (Table II) were compared according to acuteness of dissection. Modes of death were myocardial infarction ($n = 8$), renal failure or sepsis ($n = 8$), cerebrovascular accident ($n = 7$), postoperative hemorrhage ($n = 2$), mesenteric infarction ($n = 1$), rupture of descending thoracic aortic false lumen ($n = 1$), ventricular arrhythmia ($n = 1$), and sudden unexplained death ($n = 1$).

Risk factors for death in the early hazard phase were increasingly unstable preoperative hemodynamic condition, repair with the use of composite aortic root and ascending aortic replacement (Fig 3), earlier date of operation, concomitant CABG, and failure to use circulatory arrest, but also duration of circulatory arrest longer than about 60 minutes (Table III). An unstable hemodynamic condition was more common when blood was present in the pericardium ($P = .0001$), the patient had a history of hypertension ($P = .005$), or the known distal extent of the dissection was greater ($P = .005$).

Late mortality. After hospital discharge, 4 patients died of ruptured distal aortic aneurysms that resulted from the initial aortic dissection. Of all late deaths, 57% were due to cardiac causes, ruptured aneurysms, or sudden death (Table IV). Of the 8 patients dying suddenly, 5 had a residual distal dissected aorta.

Late survival improved across time (Table III). This improvement was unveiled after accounting for aortic arch replacement, which decreased late survival (Fig 4) but which had been used with increasing frequency in recent years (Appendix Fig 1, C).

Non-risk-adjusted time-related survival was similar for patients with acute and chronic dissections (Fig 5). No significant interaction ($P > .1$) of variables with acuity per se was found, nor was further adjustment by the propensity score significant. Survival was also similar no matter how extensive the known level of dissection, the location of the intimal tear, the extent of aortic replacement, and whether or not residual dissected distal aorta was present at the end of the operation.

Aortic reoperation. Thirteen patients underwent cardiac or aortic reoperations. Freedom from reoperation was 98%, 96%, 91%, and 85% at 1, 3, 5, and 10

years, respectively, after the operation, with a slightly declining risk of about 2% per year after 3 months. Of these 13 reoperations, 5 were for proximal aortic or aortic valve complications (Table V). Aneurysmal aortic sinuses and aortic regurgitation developed after supracoronary aortic graft replacement in 2 patients; both underwent composite aortic valve and ascending aortic graft replacement at 4 and 8 years after their primary operations. Endocarditis developed in 3 patients; the prosthetic aortic valves were affected in 2 patients and the supracoronary ascending aortic graft, with resultant pseudoaneurysm of the proximal suture line, in 1 patient. All 3 received a composite aortic valve and ascending aortic graft at reoperation. Freedom from reoperation for an aortic valve replacement or proximal aortic problems was 96% (CL 93%-98%) and 93% (CL 89%-96%) at 5 and 10 years, respectively. Proximal aortic reoperations among patients with their native aortic valve occurred with similar frequency as those with their aortic valve replaced (Fig 6).

Eight patients underwent reoperations on the distal aorta (Table VI). In 5, distal aortic disease present before the original operation was repaired: 2 underwent repair of an abdominal aortic aneurysm, 1 repair of a thoracoabdominal aortic aneurysm, and 2 repair of a DeBakey type III aortic dissection. In the other 3 patients, operations were performed to repair aortic defects developing as a result of the ascending aortic dissection. These had DeBakey type I aortic dissections at their primary presentation. Two required thoracoabdominal replacement and the third, aortic arch replacement. Freedom from reoperation for distal aortic problems was 95% (CL 92%-97%) and 91% (CL 87%-94%) at 5 and 10 years, respectively. Distal aortic reoperation was similar in those with and without residual dissected aortas (Fig 7).

We were unable to identify risk factors for reoperation.

Discussion

Evaluation of operative strategy. To accomplish the goals of operation for acute and chronic dissection of the ascending aorta, we and others^{18,19} have pursued relatively conservative operative strategies. Despite advances in surgical experience and technology, operations for ascending dissections are still associated with substantial risk, particularly when carried out for critically ill patients with acute dissections. For more extensive operations to make sense, such as routine aortic arch replacement or complex aortic valve-sparing operations, a high failure of these conservative, reproducible strategies would be required.

Table II. Hospital mortality related to the preoperative status and operative management of the aorta

Variable	Acuity of dissection								
	Total			Acute (n = 135)			Chronic (n = 73)		
	n	Hospital mortality No. (%)	P	n	Hospital mortality No. (%)	P	n	Hospital mortality No. (%)	P
Aorta									
Extent of dissection			.9			.7			.4
Ascending	64	9 (14)		26	3 (12)		38	6 (16)	
Arch	45	5 (11)		33	4 (12)		12	1 (8)	
Descending	34	5 (15)		27	4 (15)		7	1 (14)	
Abdominal	65	10 (15)		49	10 (20)		16	0 (0)	
Site of tear			.6			.7			.6
Ascending	177	25 (14)		118	18 (15)		59	7 (12)	
Arch	31	4 (13)		17	3 (18)		14	1 (7)	
Management									
Operation			.1			.3			.2
Resuspension	135	15 (11)		94	12 (13)		41	3 (7)	
Composite graft	47	11 (23)		31	7 (22)		16	4 (25)	
Graft + AVR	26	3 (12)		10	2 (20)		16	1 (25)	
Extent of aortic replacement			.7			.2			.8
Ascending	177	25 (14)		118	18 (15)		59	7 (12)	
Ascending + arch	27	3 (11)		16	2 (12)		11	1 (9)	
Ascending + arch + descending	4	1 (25)		1	1 (100)		3	0 (0)	
Residual distal dissected aorta			.5			.2			.4
No	76	9 (12)		34	3 (9)		42	6 (14)	
Yes	132	20 (15)		101	18 (18)		31	2 (6)	
Concomitant CABG			.002			.09			.01
No	161	16 (10)		104	13 (12)		57	3 (5)	
Yes	47	13 (28)		31	8 (26)		16	5 (31)	
Cannulation site			.6			.9			.6
Aorta	3	0 (0)		1	0 (0)		2	0 (0)	
Femoral artery	107	15 (14)		76	12 (16)		31	3 (10)	
Axillary artery	13	1 (8)		6	1 (17)		7	0 (0)	
Use of circulatory arrest			.03			.3			.02
No	59	13 (22)		34	7 (20)		25	6 (24)	
Yes	149	16 (11)		101	14 (14)		48	2 (4)	
Circulatory arrest time (min)			.006			.01			.9
≤45	108	8 (7)		72	6 (8)		36	2 (6)	
46-60	26	5 (19)		20	5 (25)		6	0 (0)	
≥61	15	3 (20)		9	3 (33)		6	0 (0)	
“Elective” use of circulatory arrest (excluding arch replacement)			.03			.4			.02
No	59	13 (22)		34	7 (20)		25	6 (24)	
Yes	118	12 (10)		84	11 (13)		34	1 (3)	
Year of operation*			.2			.5			.3
1978-1984	30	7 (23)		18	4 (22)		12	3 (25)	
1984-1990	68	7 (10)		44	5 (11)		24	2 (8)	
1990-1995	110	15 (14)		73	12 (16)		37	3 (8)	

AVR, Aortic valve replacement.

*Logistic test for trend.

A possible disadvantage of the conservative operative strategy is that the patient is left with a dissected (although reconstructed) aortic root and aortic valve, and with a distal aorta that in many cases has a residual

false lumen. Late complications of aortic valve failure and distal aneurysm formation may occur after aortic dissection repair,²⁰⁻²³ leading some to suggest more radical approaches such as routine aortic arch replace-

Fig 3. Survival after operations for ascending aortic dissection stratified by type of repair: resuspension and graft (triangles), aortic valve replacement (AVR) and graft (squares), and composite graft (circles). The nonparametric estimates are presented as in Fig 2. The numbers of patients surviving at 1 year for each of the three types of repair, respectively, were 99, 21, and 32; at 5 years, 43, 11, and 14; and at 10 years, 11, 5, and 3.

Table III. Incremental risk factors for death (multivariable multi-phase hazard function regression)

Risk factors	Coefficient $\pm$ SD	P
Early hazard phase		
Clinical status		
Poorer hemodynamic status*	0.76 $\pm$ 0.38	.04
Aortic rupture into pericardium	1.23 $\pm$ 0.47	.009
Procedure		
Use of composite graft technique	1.07 $\pm$ 0.40	.008
Concomitant CABG	1.43 $\pm$ 0.43	.0009
Support		
Failure to use circulatory arrest	-1.72 $\pm$ 0.50	.0005
Longer duration of circulatory arrest (min)	0.0146 $\pm$ 0.0050	.004
Experience		
Early date of operation†	0.197 $\pm$ 0.085	.02
Late hazard phase		
Demography		
Old age‡	0.67 $\pm$ 0.31	.03
Clinical status		
Higher BUN§	0.70 $\pm$ 0.33	.03
Procedure		
Aortic arch replacement	1.32 $\pm$ 0.49	.007
Experience		
Earlier date of operation	-0.104 $\pm$ 0.046	.02

CABG, Coronary artery bypass grafting; BUN, blood urea nitrogen.

*Where 0 = stable, 1 = hypothermic, and 2 = arresting.

†(1/[years since January 1, 1978])² inverse squared transformation.

‡(age/50)² squared transformation.

§ln (blood urea nitrogen) natural logarithmic transformation.

||Years since 1978.

ment.¹⁻³ Thus, the focus of this investigation was to establish the long-term outcomes resulting from our selective approach and to document late proximal and distal treatment failures.

The proximal aorta. A possible disadvantage of supracoronary reconstruction and aortic graft replace-

ment is that the patient is left with a dissected (although reconstructed) aortic root and aortic valve. Some have advocated routine composite graft replacement of the aortic root¹ and operations similar to those described by David and Feindel²⁴ and Yacoub and associates,²⁵ in which the aortic sinuses are resected but the aortic

Fig 4. Survival after operation for ascending aortic dissection, stratified according to the use (*squares*) or not (*circles*) of aortic arch replacement with or without distal extension to proximal descending aorta. The nonparametric estimates are presented as in Fig 2. However, because the last death was in the longest-term survivor, Nelson-Aalen estimates are shown. The numbers of patients alive at 1 year for each group, respectively, were 18 and 136; at 5 years, 5 and 63; and at 10 years, 0 and 18.

Table IV. Etiologies of deaths after hospital discharge

Etiology	No.	Percent of late deaths (n = 40)
Cardiac (MI, cardiomyopathy, CHF)	11	27
Sudden (etiology unknown)	8	20
Cerebrovascular accident	5	12
Ruptured aneurysm	4	10
Cardiac reoperation	3	7
Tamponade	1	2
Other (renal failure, respiratory failure, sepsis, cancer)	9	22

CHF, Congestive heart failure; MI, myocardial infarction.

valve leaflets preserved. However, in this study, supra-coronary aortic valve resuspension demonstrated excellent long-term durability with few late failures, an observation noted by others.^{18,19,26,27} Fann and associates¹⁹ reported freedom from aortic valve replacement for resuspended aortic valves of 100% and 80% at 5 and 10 years, respectively. Mazzucotelli and colleagues²⁷ reported freedom from reoperation for failure of the native aortic valves of 83% and 79% at 5 and 10 years. More recently, von Segesser and coworkers¹⁸ reported freedom from reoperation for failure of a resuspended aortic valve of 97% and 91% at 5 and 10 years. This high freedom from failure of supra-coronary reconstruction leads us to infer that more complex aortic root operations are usually not justified, particularly

because of the high operative risk noted by even experienced surgeons for these complex procedures.²⁵

The distal aorta. Distal aneurysm formation may occur after ascending aortic dissection, and some have advocated routine aortic arch replacement as a possible means of decreasing that late complication.¹⁻³ On the other hand, Crawford and colleagues²⁸ recommended replacing the arch only when it is aneurysmal and when there is excessive enlargement and impending or actual rupture of the false channel, not to treat the presence of a false lumen in the arch. That has been our policy, and the low prevalence of distal aortic complications based on the ascending dissection appears to validate that policy. However, when the intimal tear extends into the arch, we believe hemi-arch, and occasionally total arch, replacement is indicated. In patients with acute ascending aortic dissections caused by an intimal tear located in the arch, the Stanford group found a somewhat lower in-hospital mortality for the patients undergoing concomitant arch replacement compared with those who did not have their arch resected (29% vs 37%), but the confidence limits were wide.⁴ Similarly, there appeared to be improved long-term survival, increased freedom from arch aneurysm, and fewer distal aortic ruptures in patients who underwent resection of the intimal tear in the arch. They concluded that it is probably prudent to perform concomitant hemi-arch or total arch replacement in healthy patients with aortic dissection caused by an arch tear.

Fig 5. Survival after operations for ascending aortic dissection stratified according to acuity of the dissection (acute, squares; chronic, circles). The nonparametric estimates are presented as in Fig 2.

Table V. Reoperations for proximal aortic complications

Primary pathology	Primary operation	Secondary pathology	Secondary operation	Result
Type I dissection	AV replacement and AA graft	Sinus aneurysm	CG	Died
Type I dissection	AV resuspension and AA graft	Sinus aneurysm	CG	Well
Type I dissection	AV replacement and AA graft	Endocarditis and periprosthetic leak	CG	Well
Type I dissection	AV resuspension and AA graft	Graft infection and pseudoaneurysm	CG	Died
Type I dissection	CG	Endocarditis	CG	Well

AV, Aortic valve; AA, ascending aortic; CG, composite aortic valve and ascending aortic graft.

Thus, our approach is to resect and replace the aortic arch in acute dissections when the intimal tear originates in or extends into the arch. We found no difference in early mortality in patients who underwent concomitant arch resection compared with those who underwent only ascending aortic replacement. However, an unexplained finding was that it was associated with decreased late survival. None of the late deaths in the patients undergoing aortic arch resection were sudden or due to distal aortic rupture.

In this study, the presence of residual dissected distal aorta did not increase the risk of rupture. We believe these findings are due to our prevention of antegrade flow into the false lumen in acute dissections by resecting the intimal tear (even if located in the arch) and constructing atraumatically the graft to aortic anastomosis with three layers of felt.

Acute versus chronic dissection. Unconventionally, for this study we have included both patients with acute and chronic dissection. Neither multivariable analyses nor analyses of interactions nor propensity matching

suggested that these historical patient subgroups responded fundamentally differently to treatment. We have identified, however, that patients coming to operation in a poor hemodynamic condition, a rather uncommon occurrence in this study, but one confined to acute dissection, are at high early risk.

Limitations. The general findings of this study, and those more specific to the details of the operation itself, are limited by the experience of a single institution, by evolution of the operation and support techniques across the years, and by our inability in some cases to understand fully the reasons for some risk factors, even after intense study.

One specific shortcoming of our clinical records and pathologic specimens is that because of relatively small numbers of patients with Marfan syndrome, a firm statement about Marfan syndrome and its possible influence on late outcome was not possible. Our recommendations about conservative aortic root and arch operations for patients with dissections do not apply to patients with Marfan syndrome.

Fig 6. Freedom from reoperation for aortic valve or proximal aortic problems, stratified by preservation (*squares*, $n = 135$) or not (*circles*, $n = 73$) of the native aortic valve. Note the expanded vertical axis. The numbers of patients alive without reoperation at 1 year were 97 and 50, respectively; at 5 years, 40 and 23; and at 10 years, 10 and 6.

Table VI. Reoperations for distal aortic complications

Primary pathology	Primary operation	Secondary pathology	Secondary operation	Result
Type I dissection	AV resuspension and AA graft	Arch aneurysm and TAA	Arch replace	Well (died later, TAA)
Type I dissection	AV resuspension and AA graft	TAA	TAA repair	Well
Type I dissection	CG	TAA	TAA repair	Well
Type I dissection	AV resuspension, AA, and arch graft	Previous AAA	AAA repair	Well
Type I dissection	AV resuspension and AA graft	Previous AAA	AAA repair	Well
Type II dissection	AV resuspension and AA graft	TAA (previous)	TAA repair	Well
Type II dissection	AV resuspension and AA graft	Type III dissection (previous)	Type III repair	Died
Type II dissection	CG	Type III dissection (previous)	Type III repair	Well (died later)

AA, Ascending aortic; AAA, abdominal aortic aneurysm; AV, aortic valve; CG, composite aortic valve and ascending aortic graft; TAA, thoracoabdominal aortic aneurysm.

Another limitation is that only patients who underwent operations for repair of an ascending aortic dissection are included. Specifically, patients dying before operation, before or during transfer or evaluation, are not included. Therefore, generalizing our results to all patients with ascending aortic dissections is not possible.

A difference in this study compared with others is the prevalence of patient characteristics. A large proportion of our patients had prior cardiac operations, and in an unusually large number of patients the aortic dissection was limited to the ascending aorta. These differences may relate to the referral nature of our institution. Therefore, our overall outcomes may not be representative of all patients with ascending aortic dissection. However, to some major degree, multivariable analyses should adjust for differences in patient characteristics, rendering the inferences from them more generally applicable.

Finally, we do not have routine periodic imaging of the distal aorta during follow-up in all patients. Therefore, we are unable to determine which patients with residual distal dissection of the aorta actually have a patent false lumen.

Clinical inferences. We infer from this study that aortic valve resuspension and supracoronary aortic root reconstruction provide effective long-term results in non-Marfan syndrome patients with ascending aortic dissection who have normal sinuses and a normal aortic valve. Aggressive routine composite aortic valve, sinus, and ascending aorta replacement do not appear justified. Aortic resection should include the ascending aorta and intimal tear, even when the tear is located in the arch. Hypothermia and circulatory arrest are safe within prudent time constraints and are useful in constructing the distal anastomosis. Residual distal dis-

Fig 7. Freedom from reoperation for distal aortic problems, stratified by completeness (circles, $n = 76$) or not (squares, $n = 132$) of distal lumen repair. Note the expanded vertical axis. The numbers of patients alive and without reoperation at 1 year were 94 and 53; at 5 years, 40 and 23; and at 10 years, 9 and 7, respectively.

sected aorta does not decrease late survival and has a low risk of aneurysmal change and reoperation for at least 10 years.

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Appendix: Variables examined for association with outcomes

Patient variables

Demography: age, sex

Presentation: acute versus chronic dissection, interval between symptom onset and operation in acute dissection, NYHA class (I-IV), emergency operation, hemodynamic state at operation (0 = stable, 1 = unstable, 2 = cardiogenic shock), nonexertional chest pain, neurologic deficit

Status of aorta: known distal extent of dissection (ascending aorta, arch, descending, abdominal), site of intimal tear (ascending aorta, arch), aortic valve regurgitation

Comorbidity: ischemic heart disease, angina, chronic heart failure, dyspnea or exertion, previous myocardial infarct, preoperative blood urea nitrogen, hypertension, previous cardiac surgery, conduction disturbance (first-, second-, or third-degree heart block)

Procedure

Findings: blood in pericardium, free aortic rupture

Operation: composite graft, aortic valve replacement and ascending aortic replacement, aortic valve resuspension and ascending aortic replacement, aortic valve replacement versus resuspension, distal extent of aortic replacement (ascending aorta, and arch, and descending), residual distal dissected aorta

Support: use of circulatory arrest, duration (minutes) of arrest

Experience: date of operation

Appendix Table I. Patient characteristics according to acuteness of ascending aortic dissection

Variable	Total		Acuity of dissection				P
	n	(% of 208)	n	(% of 135)	n	(% of 73)	
Demography							
Age (y)*							.7
<30	10	(5)	7	(5)	3	(4)	
30-50	43	(21)	29	(21)	14	(19)	
50-60	51	(24)	36	(27)	15	(21)	
60-70	63	(30)	37	(27)	26	(36)	
≥70	41	(20)	26	(19)	15	(21)	
Sex							.8
Male	145	(70)	95	(70)	50	(68)	
Female	63	(30)	40	(30)	23	(32)	
Presentation							
NYHA*							.001
I	52	(25)	43	(33)	9	(12)	
II	70	(34)	37	(28)	33	(45)	
III	46	(22)	20	(15)	26	(37)	
IV	37	(18)	32	(24)	5	(7)	

Appendix Table I. Cont'd

Variable	Total		Acuity of dissection				P
	n	(% of 208)	Acute		Chronic		
			n	(% of 135)	n	(% of 73)	
Hemodynamic status*							<.001
Stable	176	(86)	104	(78)	72	(100)	
Hypotensive	23	(11)	23	(17)	0	(0)	
Shock	6	(3)	6	(5)	0	(0)	
Emergency operation							.001
No	89	(43)	23	(17)	66	(90)	
Yes	119	(57)	112	(83)	7	(10)	
Chest pain							.001
No	50	(24)	22	(16)	28	(39)	
Yes	155	(76)	112	(84)	43	(61)	
Oliguria							.2
No	194	(96)	124	(94)	70	(99)	
Yes	9	(4)	8	(6)	1	(1)	
Pulse deficit							.03
No	152	(74)	93	(69)	59	(83)	
Yes	53	(26)	41	(31)	12	(17)	
Paraplegia							1.0
No	201	(98)	131	(98)	70	(99)	
Yes	3	(2)	2	(2)	1	(1)	
Pulsus paradoxus							1.0
No	201	(98)	131	(98)	70	(99)	
Yes	3	(2)	2	(2)	1	(1)	
Use of angiography							
1978-1984							.2
No	10	(33)	8	(44)	2	(17)	
Yes	20	(67)	10	(56)	10	(83)	
1984-1990							.003
No	13	(19)	13	(30)	0	(0)	
Yes	55	(81)	31	(70)	24	(100)	
1990-1995							.009
No	36	(33)	30	(41)	6	(16)	
Yes	74	(67)	43	(59)	31	(84)	
Associated conditions							
Ischemic heart disease							.6
No	175	(84)	115	(85)	60	(82)	
Yes	33	(16)	20	(15)	13	(18)	
Hypertension							.3
No	76	(37)	53	(39)	23	(32)	
Yes	131	(63)	82	(61)	49	(68)	
Previous cardiac surgery							.3
No	157	(76)	105	(78)	52	(71)	
Yes	51	(24)	30	(22)	21	(29)	
Operative findings							
Blood in pericardium							.001
No	165	(80)	97	(72)	68	(94)	
Yes	42	(20)	38	(28)	4	(6)	
Free rupture							.02
No	192	(93)	121	(90)	71	(99)	
Yes	15	(7)	14	(10)	1	(1)	

NYHA, New York Heart Association.

*Logistic test for trend using all data.

Appendix Table II. Status and management of the aorta according to acuteness of ascending aortic dissections

Variable	Total		Acuity of dissection				P
			Acute		Chronic		
	n	(% of 208)	n	(% of 135)	n	(% of 73)	
Aortic pathology							
Known distal extent of dissection							.001
Ascending	64	(31)	26	(19)	38	(52)	
Arch	45	(22)	33	(24)	12	(16)	
Descending	34	(16)	27	(20)	7	(10)	
Abdominal	65	(31)	49	(36)	16	(22)	
Site of tear							.2
Ascending	177	(85)	118	(87)	59	(81)	
Arch	31	(15)	17	(13)	14	(19)	
Management							
Operation							.009
Resuspension	135	(65)	94	(70)	41	(56)	
Composite graft	47	(23)	31	(23)	16	(22)	
Graft + AVR	26	(12)	10	(7)	16	(22)	
Extent of aortic replacement							.2
Ascending	177	(85)	118	(87)	59	(81)	
Ascending + arch	27	(13)	16	(12)	11	(15)	
Ascending + arch + descending	4	(2)	1	(1)	3	(4)	
Residual distal dissected aorta							.001
No	76	(36)	34	(25)	42	(58)	
Yes	132	(64)	101	(75)	31	(42)	
Concomitant CABG							.9
No	161	(77)	104	(77)	57	(78)	
Yes	47	(23)	31	(23)	16	(22)	
Cannulation site							.09
Aorta	3	(2)	1	(1)	2	(5)	
Femoral artery	107	(87)	76	(92)	31	(77)	
Axillary artery	13	(11)	6	(7)	7	(18)	
Use of circulatory arrest							.2
No	59	(28)	34	(25)	25	(34)	
Yes	149	(72)	101	(75)	48	(66)	
Circulatory arrest time (min)*							.4
≤45	108	(73)	72	(71)	36	(75)	
46-60	26	(17)	20	(20)	6	(12)	
≥61	15	(10)	9	(9)	6	(12)	
“Elective” use of circulatory arrest (excluding arch replacement)							.07
No	59	(33)	34	(29)	25	(42)	
Yes	118	(67)	84	(71)	34	(58)	
Year of operation							.8
1978-1984	30	(14)	18	(13)	12	(16)	
1984-1990	68	(33)	44	(33)	24	(33)	
1990-1995	110	(53)	73	(54)	37	(51)	

AVR, Aortic valve replacement; CABG, coronary artery bypass grafting.

*Logistic test for trend using all data.

Appendix Table III. Factors associated with acute versus chronic ascending aortic dissection (multivariable logistic regression)

Variable	Coefficient $\pm$ SD	P
Clinical status		
Lower NYHA functional class	-3.0 ± 1.03	.004
Higher NYHA functional class*	0.69 ± 0.205	.0008
Absence of nonexertional chest pain	-0.89 ± 0.431	.04
Operative findings		
Blood in pericardium	1.44 ± 0.591	.02
Cardiac comorbidity		
Absence of dyspnea	-1.66 ± 0.434	.0001
Known extent of dissection		
Dissection beyond ascending aorta	-1.27 ± 0.400	.002
Intercept	3.47 ± 1.11	

SD, Standard deviation; NYHA, New York Heart Association.

*[NYHA class]² squared transformation.

Appendix Table IV. Completeness of resection of distal aortic suture line

	Residual dissection at completion of operation			P
	n	No.	(%)	
Acuity of disease				.001
Acute	135	101	(75)	
Chronic	73	31	(42)	
Extent of disease				.001
Ascending	64	0	(0)	
Arch	45	33	(73)	
Descending	34	34	(100)	
Abdominal	65	65	(100)	
Extent of replacement				.9
Ascending	177	113	(64)	
Ascending/arch	27	15	(56)	
Ascending/arch/descending	4	4	(100)	

Appendix Table V. Known extent of aortic dissection and extent of aortic replacement overall and according to acuteness of dissection

Known extent of aortic dissection	Extent of aortic replacement					
	Ascending		+ Arch		+ Descending	
	n	(%)	n	(%)	n	(%)
Total						
Ascending	64	(100)	0	(0)	0	(0)
Arch	33	(73)	12	(27)	0	(0)
Descending	23	(68)	10	(29)	1	(3)
Abdominal	57	(88)	5	(8)	3	(5)
Acute						
Ascending	26	(100)	0	(0)	0	(0)
Arch	25	(76)	8	(24)	0	(0)
Descending	21	(78)	6	(22)	0	(0)
Abdominal	46	(94)	2	(4)	1	(2)
Chronic						
Ascending	38	(100)	0	(0)	0	(0)
Arch	8	(67)	4	(33)	0	(0)
Descending	2	(29)	4	(57)	1	(14)
Abdominal	11	(69)	3	(19)	2	(12)

Appendix Fig 1. Trends across time in management of patients with ascending aortic dissection. In these graphs, each circle represents a yearly proportion. The solid line is the continuous probability by logistic regression. **A**, Proportion of patients whose repair included the composite aortic valve and ascending aortic graft replacement technique. **B**, Proportion of patients in whom circulatory arrest was used. **C**, Proportion of patients in whom the aortic arch was replaced.