Total Arch Replacement Combined With Stented Elephant Trunk Implantation

A New "Standard" Therapy for Type A Dissection Involving Repair of the Aortic Arch?

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Background—Appropriate surgical management of type A dissection is a critical factor for achieving satisfactory outcome, but the choice of optimal procedure is controversial. We retrospectively reviewed our experience with aortic arch replacement for type A dissection involving the arch.

Methods and Results—Excluding 14 cases of subtotal or total aortic replacement, 411 of 544 patients with type A dissection (stented elephant trunk=291, conventional surgical repair=120) underwent aortic arch replacement between January 2003 and September 2008. In-hospital mortality was 3.09% (9 of 291) for stented (acute=4.73%, 7 of 148; chronic=1.40%, 2 of 143) and 5.00% (6 of 120) for conventional repairs (acute=6.06%, 4 of 66; chronic=3.70%, 2 of 54). Spinal cord injury was 2.41% (7 of 291) in the stented and 0.83% (1 of 120) in the conventional group. The overall prevalence of stroke was 1.95% (8 of 411) (stented=2.41%, 7 of 291; conventional=0.83, 1 of 120). Secondary intervention was 2.34% (5 of 214) for acute dissection (stented=1 and conventional=4; $P=0.031$) and 3.05% (6 of 197) for chronic dissection (stented=4 and conventional=2; $P=0.661$) during follow-up. Obliteration of the false lumen around the stented elephant trunk occurred in 94.2% (130 of 138) of patients with acute dissection and in 92.0% (126 of 137) of patients with chronic dissection.

Conclusions—Total arch replacement combined with stented elephant trunk implantation demonstrated the superiority of the combination of the surgical and interventional approaches while avoiding the weaknesses associated with the individual methods. The encouraging surgical results could enable this procedure to become the new "standard" therapy for type A dissection involving repair of the aortic arch. **(*Circulation*. 2011;123:971-978.)**

Key Words: aortic dissection ■ aortic surgery ■ stented elephant trunk procedure ■ total arch replacement

Type A dissection involving the aortic arch remains an inherently lethal condition. Surgical treatment is needed, and several surgical approaches have been introduced.[1–8] The appropriate approach for patients with type A dissection involving the aortic arch remains controversial.

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We retrospectively reviewed our experience and evaluated the effectiveness of surgical treatment for acute and chronic type A dissection involving the aortic arch using aortic arch replacement.

Methods

The study protocol was approved by the Institutional Review Board of the Chinese Academy of Medical Science and Peking Union Medical College (Beijing, China). Informed consent was obtained from each patient involved in this study.

Patient Data

Between January 2003 and September 2008, 544 patients with type A dissection underwent surgical treatment at Fuwai Hospital (Beijing, China). The acute phase of aortic dissection was defined as being within 2 weeks from symptom onset to the institution of therapy. Total arch replacement was undertaken in patients with type A dissection if (1) the primary tear was in the transverse arch or the descending aorta; (2) there was aneurysm formation in the aortic arch or the distal aorta (aneurysm size ≥40 mm); (3) there was the involvement of, aneurysm formation in, and occlusion of the brachiocephalic artery; or (4) Marfan syndrome was present. If aortic dissection extended beyond the distal arch, a stented elephant trunk (SET) was implanted into the distal aorta. A total of 291 patients (acute=148, chronic=143) with type A dissection underwent total arch replacement combined with SET implantation during this

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Table 1. Preoperative Characteristics

	Acute Dissection			Chronic Dissection		
Variable	SET (n=148)	CSR (n=66)	*P*	SET (n=143)	CSR (n=54)	*P*
Age (±SD), y	45±11	46±13	0.401	45±10	45±14	0.847
Male, n (%)	126 (85.1)	36 (54.5)	0.000	112 (78.3)	36 (66.7)	0.091
Hypertension, n (%)	107 (72.3)	36 (54.5)	0.011	100 (69.9)	30 (55.6)	0.057
Marfan syndrome, n (%)	19 (12.8)	5 (7.6)	0.350	24 (16.8)	12 (22.2)	0.378
Diabetes mellitus, n (%)	6 (4.1)	2 (3.0)	1.000	5 (3.5)	1 (1.9)	1.000
Acute myocardial infarction, n (%)	2 (1.4)	0	1.000	1 (0.7)	0	1.000
Coronary artery disease, n (%)	5 (3.4)	0	0.327	12 (8.4)	3 (5.6)	0.764
Acute cardiac tamponade, n (%)	3 (2.0)	8 (12.1)	0.004	0	0	
Acute left heart failure, n (%)	2 (1.4)	1 (1.5)	1.000	1 (0.7)	0	1.000
Cerebral ischemia, n (%)	1 (0.6)	0	1.000	0	0	
Cerebral infarction, n (%)	0	1 (1.5)	0.308	5 (3.5)	4 (7.4)	0.261
Acute visceral ischemia, n (%)	3 (2.0)	0	0.554	0	0	
Acute renal dysfunction, n (%)	4 (2.7)	1 (1.5)	1.000	0	0	
Chronic renal dysfunction, n (%)	5 (3.4)	0	0.327	3 (2.1)	0	0.563
Lower-extremity ischemia, n (%)	8 (5.4)	3 (4.5)	1.000	6 (4.2)	1 (1.9)	0.676
Dissection limited to TA, n (%)	0	18 (27.3)	0.000	0	25 (46.3)	0.000
Dissection extending beyond TA, n (%)	148 (100)	48 (72.7)	0.000	143 (100)	29 (53.7)	0.000

SET indicates stented elephant trunk; CSR, conventional surgical repair; and TA, transverse arch.

period. For patients with type A dissection with the primary tear located in the ascending aorta without the features mentioned above, total arch replacement was not carried out in 229 cases: hemiarch replacement in 110 (acute=65, chronic=45) and only ascending aortic replacement in 119 (acute=60, chronic=59) patients. In patients with a large distal aorta (distal aortic arch or proximal descending aorta), total arch replacement combined with proximal descending aortic replacement was undertaken if the aortic aneurysm could be manipulated via a standard median sternotomy. Only 2 patients underwent this procedure. Otherwise, subtotal or single-stage total aortic replacement was required. Total or subtotal aortic replacement was carried out in 14 subjects. Other procedures, including total arch replacement without a SET, were carried out in 8 patients: 2 patients with chronic aortic dissection could not undergo implantation of the SET because of the very small true lumen of the distal aorta, and 6 patients had aortic dissection limited to the arch (acute=1, chronic=5). To illustrate the fate and secondary intervention of the distal aorta in patients with a SET, we used hemiarch replacement and total arch replacement without SET implantation (conventional surgical repair [CSR]) as a historical control. Comorbidity and preoperative complications are listed in Table 1.

The tear site was at the ascending aorta in 103 patients in the SET group, at the transverse arch in 51, and at the proximal descending thoracic aorta in 68. A multi-intimal tear was seen in 41 patients; an entry tear was not detected in 13 patients; and previous cardiovascular surgery was carried out in 15 patients. Postoperative computed tomography with contrast enhancement was done routinely to assess the state of the residual false lumen during follow-up.

Surgical Procedure

All procedures were carried out by a median sternotomy and total cardiopulmonary bypass (CPB) with selective cerebral perfusion (SCP). Cannulation of the right axillary artery was used for CPB and SCP. The arterial line was bifurcated for the right axillary artery and for antegrade perfusion through 1 limb of a 4-branch prosthetic graft. Aortic root procedures were done (if indicated) during cooling. Circulatory arrest was instituted if the nasopharyngeal temperature reached 18°C to 22°C. Unilateral SCP was started through the right axillary artery after the brachiocephalic arteries were cross-clamped and the brain was perfused.

In patients requiring hemiarch replacement, the lesser curvature of the aortic arch was resected. A beveled incision was made for the distal end of a vascular graft to replace the arch. After completion of the open distal anastomosis, the graft was cross-clamped, and antegrade systemic perfusion was resumed through a side branch.

The SET technique has been described in detail by our research team.[4,9–11] Briefly, a stent graft (MicroPort Medical Co Ltd, Shanghai, China) and a 4-branch prosthetic graft (Boston Scientific Inc, Boston, MA) were used in total arch replacement combined with SET implantation. After the left subclavian artery was transected circumferentially 0.5 to 1.0 cm distal to its origin, the proximal segment was sutured. The SET was inserted into the true lumen of the distal aorta in a bound, compressed state after the distal aorta was transected between the origin of the left subclavian artery and the left carotid artery. The distal aorta incorporating the stent graft was firmly attached to the distal end of the 4-branch prosthetic graft using the "open" aortic procedure. After the anastomosis was completed, blood perfusion of the lower body was started via the perfusion limb of the 4-branch prosthetic graft.

The strategy used for total arch replacement by our surgical team varied over time. In the early days, the sequence of anastomosis to the prosthetic graft was carried out from the left subclavian artery, left common carotid artery, innominate artery, and proximal aortic stump in succession. Soon after, the sequence of anastomosis to the prosthetic graft was changed to the left common carotid artery, innominate artery, left subclavian artery, and proximal aortic stump (which decreased the SCP time). Finally, the sequence of anastomosis to the prosthetic graft was chosen to be the left common carotid artery, proximal aortic stump, innominate artery, and left subclavian artery (which decreased the hypothermia time and CPB time). After the anastomosis to the left common carotid artery was accomplished, SCP was discontinued, CPB gradually resumed to normal flow, and rewarming started.

Statistical Analyses

All analyses were performed with SPSS version 13.0 software (SPSS Inc, Chicago, IL). The Student t test was used for continuous variables. Categorical variables were analyzed by the χ^2 test or the Fisher exact probability test (if necessary). The Kaplan-Meier method was used to estimate the survivor functions. The difference

Table 2. Concomitant Procedures and Intraoperative Data

	Acute Dissection			Chronic Dissection		
Variable	SET (n=148)	CSR (n=66)	*P*	SET (n=143)	CSR (n=54)	*P*
Bentall procedure, n (%)	32 (21.6)	17 (25.8)	0.506	38 (26.6)	22 (40.7)	0.054
Cabrol procedure, n (%)	1 (0.7)	1 (1.5)	0.523	4 (2.8)	1 (1.9)	1.000
Wheat procedure, n (%)	0	2 (3.0)	0.094	3 (2.1)	2 (3.7)	0.616
David procedure, n (%)	0	1 (1.5)	0.308	1 (0.7)	0	1.000
Reconstruction of the sinus of Valsalva, n (%)	13 (8.8)	1 (1.5)	0.069	6 (4.2)	3 (5.6)	0.708
Aortic valvuloplasty, n (%)	16 (10.8)	4 (6.1)	0.320	7 (4.9)	5 (9.3)	0.316
Replacement of the aortic valve, n (%)	4 (2.7)	2 (3.0)	1.000	4 (2.8)	1 (1.9)	1.000
Coronary artery bypass graft, n (%)	17 (9.5)	3 (4.5)	0.131	8 (5.6)	4 (7.4)	0.739
Hemiarch replacement, n (%)	0	65 (98.5)	0.000	0	45 (83.3)	0.000
Total arch replacement, n (%)	148 (100)	1 (1.5)	0.000	143 (100)	9 (16.7)	0.000
Axillary–axillary artery bypass, n (%)	1 (0.7)	0	1.000	0	0	
Ascending aorta–axillary artery bypass, n (%)	1 (0.7)	0	1.000	0	0	
Ascending aorta–femoral artery bypass, n (%)	1 (0.7)	0	1.000	3 (2.1)	1 (1.9)	1.000
Femoral artery–femoral artery bypass, n (%)	1 (0.7)	1 (1.5)	0.523	0	0	
Ascending aorta–abdominal aorta bypass, n (%)	0	0		1 (0.7)	0	1.000
CPB time (±SD), min	197±47	153±44	0.000	182±38	157±83	0.038
Cross-clamping time (±SD), min	107±27	75±27	0.000	102±28	80±35	0.000
SCP time (±SD), min	24±9	18±7	0.000	24±6	20±16	0.097

SET indicates stented elephant trunk; CSR, conventional surgical repair; CPB, cardiopulmonary bypass; and SCP, selective cerebral perfusion.

in survival function between the 2 groups was tested by the log-rank test. A value of $P<0.05$ was considered significant.

Results

Surgical Data

Male gender, hypertension, and acute cardiac tamponade were more common in patients with acute dissection with the CSR than in those with the SET and differed significantly between groups (Table 1). Other preoperative risk factors were similar between the SET and CSR groups in patients with acute and chronic dissection. However, dissection limited to the arch was observed in 18 of 66 patients (27.3%) with acute type A dissection and in 25 of 54 patients (46.3%) with chronic type A dissection using CSR. In patients with acute and chronic dissection who underwent concomitant procedures, no differences were found between the SET and CSR groups (Table 2). In patients with chronic dissection, the CPB time and cross-clamping time were both significantly shorter in the CSR group than in the SET group. However, intraoperative data differed significantly between groups in patients with acute dissection (Table 2).

Morbidity and Mortality

Although the distal propagation and involvement of aortic dissection were less in the CSR group than in the SET group, postoperative outcomes did not differ between the SET and CSR groups in patients with acute and chronic dissection (Table 3). In patients with acute dissection, in-hospital mortality was 4.7% (7 of 148) and 6.1% (4 of 66) in the SET and CSR groups, respectively. Similar surgical results were

Table 3. Postoperative Outcomes

	Acute Dissection			Chronic Dissection		
Variable	SET (n=148)	CSR (n=66)	*P*	SET (n=148)	CSR (n=66)	*P*
Injury to recurrent nerves, n (%)	0	0		3 (2.1)	0	0.563
Stroke, n (%)	4 (2.7)	1 (1.5)	1.000	3 (2.1)	0	0.563
Paraplegia, n (%)	2 (1.4)	0	1.000	0	0	
Paraparesis, n (%)	1 (0.7)	1 (1.5)	0.523	4 (2.8)	0	0.577
Acute renal failure, n (%)	1 (0.7)	2 (3.0)	0.226	2 (1.4)	0	1.000
Ventilator support of duration >5 d, n (%)	14 (9.5)	5 (7.6)	0.797	7 (4.9)	1 (1.9)	0.450
Return to operating room for bleeding, n (%)	5 (3.4)	2 (3.0)	1.000	10 (7.0)	5 (9.3)	0.560
Drainage of pericardial sac, n (%)	1 (0.7)	0	1.000	2 (1.4)	1 (1.9)	1.000
In-hospital death, n (%)	7 (4.7)	4 (6.1)	0.741	2 (1.4)	2 (3.7)	0.302

SET indicates stented elephant trunk; CSR, conventional surgical repair.

Table 4. Fate of the Descending Thoracic and Abdominal Aortas After Surgery in Patients With SET

	Acute Dissection			Chronic Dissection		
Diameter (Mean±SD), mm	Preoperative	Postoperative	n	Preoperative	Postoperative	n
False lumen of DTA	21.09±5.38		138	24.48±6.51		137
Shrinkage of DTA	34.67±5.13	28.29±2.43	126	36.78±5.03	28.65±2.62	116
Enlargement of DTA	39.1±7.25	46.63±8.0	12	41.89±6.94	50.76±7.73	21
No obvious change in AA	27.75±4.20	28.14±3.96	125	27.85±4.49	28.03±4.49	122
Enlargement of AA	28.12±2.60	35.85±6.98	13	33.24±7.42	40.79±7.38	15

SET indicates stented elephant trunk; DTA, descending thoracic aorta; and AA, abdominal aorta.

obtained between groups in patients with chronic dissection. This indicated that this procedure was not associated with increased surgical risk. Preoperative conditions such as mesenteric ischemia, acute renal failure, and cerebral infarction were key factors for postoperative death.

Injury to the spinal cord remained a challenging problem with the SET procedure for patients with type A dissection. The prevalence of stroke was greatly reduced using this procedure with unilateral SCP. The prevalence of in-hospital morbidity is summarized in Table 3.

Imaging

Two hundred seventy-five patients underwent postoperative imaging with computed tomography in the SET group. Complete thrombus formation around the SET was observed in 94.2% (130 of 138) and 92.0% (126 of 137) of patients with acute and chronic dissection, extending to the diaphragmatic level in 75.2% (103 of 138) and 68.6% (94 of 137), at the diaphragmatic level in 66.4% (91 of 138) and 56.2% (77 of 137), below the diaphragmatic level in 31.9 (44 of 138) and 24.1% (33 of 137), and at the level of the celiac trunk in

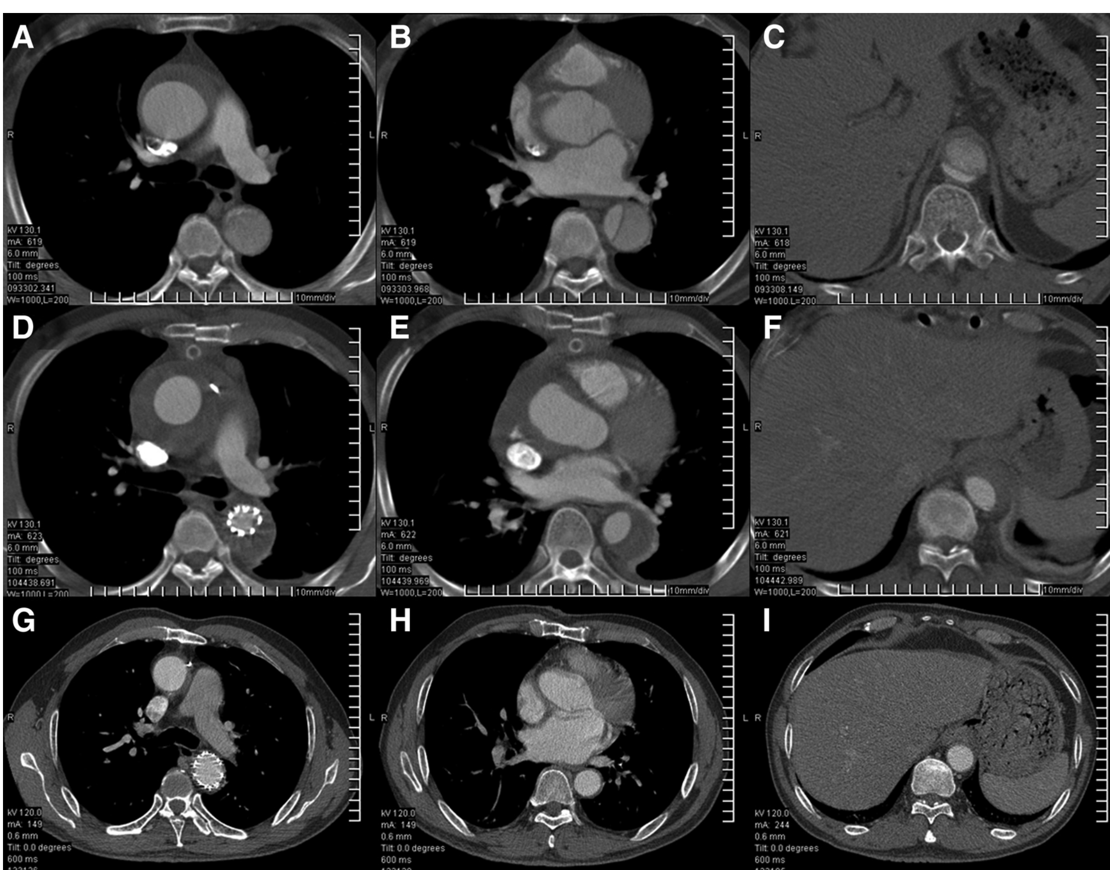

Figure 1. Computed tomography of a patient with chronic type A dissection before surgery (A through C) and 2 weeks (D through F) and 53 months (G through I) after surgery. The true lumen was compressed by a huge false lumen (A through C). Thrombosis of the false lumen was observed around the stented graft (D), distal to the edge of the stented graft (E), and at the diaphragmatic level (F) 2 weeks after surgery. The true lumen was enlarged (D through F), and the surgical stent graft was compressed by the false lumen (D). The false lumen thrombosis was reabsorbed; the stented graft expanded to its full diameter; and the true lumen in the descending aorta resumed completely (G through I). After remodeling of the 2 layers of the dissected aortic wall, shrinkage of the entire aorta was seen, and the distal aorta returned to nearly or completely normal size (G through I).

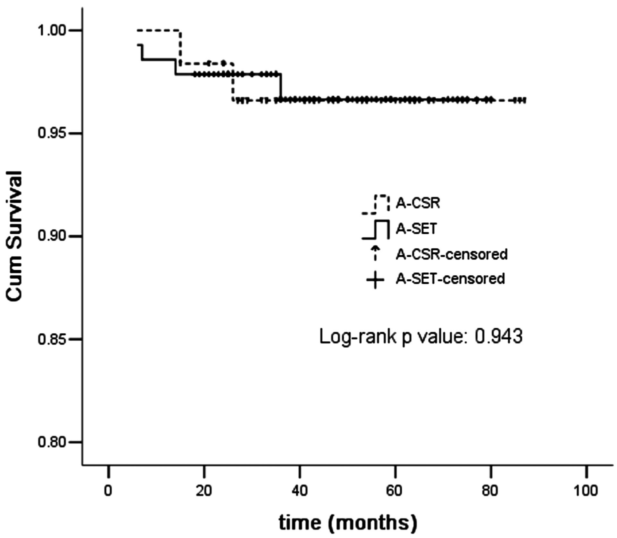

Figure 2. The survivor functions (excluding in-hospital deaths) were not significantly different between the stented elephant trunk (SET) group and conventional surgical repair (CSR) group in patients with acute (A) dissection (P=0.943).

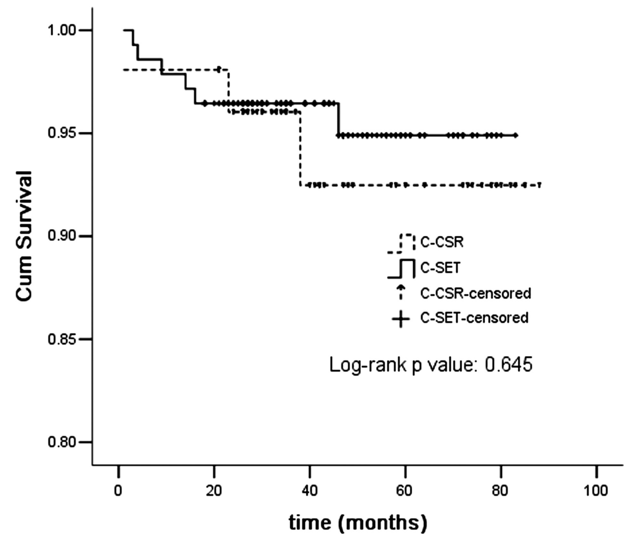

Figure 3. The survivor functions (excluding in-hospital deaths) showed no significant difference between the stented elephant trunk (SET) group and conventional surgical repair (CSR) group in patients with chronic (C) dissection (P=0.645).

16.7% (23 of 138) and 8.03% (11 of 137), respectively. In patients with SET, the fate of the descending thoracic and abdominal aorta after surgery is demonstrated in Table 4. Thrombus obliteration of the false lumen, reabsorption of false-channel thrombosis, enlargement of the true lumen, and shrinkage in the diameter of the entire aorta developed in a continuous dynamic process until the aorta returned to normal (Figure 1). The distal end of the stent graft was observed entering the false lumen in 4 patients with acute dissection who had Marfan syndrome and in 1 patient with chronic dissection. Detailed follow-up was initiated in these subjects.

Follow-Up

Survival curves (excluding in-hospital deaths) from both techniques have not shown statistical significance for both acute dissection and chronic dissection, as shown in Figures 2 (P=0.943) and 3 (P=0.645), respectively. The mean time of follow-up differed significantly between groups in patients with acute dissection (42 versus 49 months; $P<0.01$) and did not differ significantly in patients with chronic dissection. The prevalence of thrombosis of the false lumen was lower in the CSR group than in the SET group in patients with acute and chronic dissection (acute, 14.5% versus 94.2%; chronic, 10.3% versus 92.0%; Table 5). Secondary surgical intervention (thoracoabdominal aortic replacement) differed significantly between the SET and CSR groups in patients with acute dissection (1 versus 4; P=0.031 and $P<0.05$). There was no statistically significant difference between the SET and CSR groups in patients with chronic dissection. In contrast to 2 patients undergoing the distal procedure in the CSR group, 3 patients underwent late thoracoabdominal aortic replacement and 1 patient received endografting as a result of the true lumen being compressed by the false lumen in the SET group. However, 26 of 55 patients had aortic dissection limited to the aortic arch for analyses of the distal false lumen in the CSR group. Furthermore, the extent of involvement of the aorta and branch was less in the CSR group than in the SET group. In terms of late death, there was no significant difference between the SET and CSR groups in patients with acute and chronic dissection (acute, 2.8% versus 3.2%; chronic, 6.3% versus 5.8%).

One patient with acute dissection with paraplegia did not recover and refused to be followed up. Injury to the spinal cord and organ ischemia was not observed during follow-up. Patients had a normal life with antihypertensive therapy after hospital charge.

Discussion

Type A dissection is the most lethal disease of the aorta and has a high morbidity and mortality. The primary objective of surgical treatment of type A dissection is to save the life of the patient.[12] The simplest, shortest, and safest method is to adopt a conservative approach using only replacement of the ascending aorta or limited replacement of the ascending aorta with resection of the intimal tear.[13] Thanks to advances in the strategic planning and techniques of surgery and anesthesia, organ protection techniques, and perioperative care, routine extended aortic replacement can be undertaken to reduce the prevalence of late complications of the distal aorta.[10,11,14] In addition to patient survival, the other important objectives of surgical treatment of type A dissection are resecting all native aortic tissue prone to further dilation, promoting thrombosis of the false lumen in the distal aorta and remodeling of the aortic wall, and facilitating staged aortic replacement if late reoperation is required.

The conventional elephant trunk was introduced by Borst[5] to achieve a stronger distal anastomosis and to facilitate subsequent surgery on the distal aorta. However, placing the prosthetic graft into the true lumen of a type A dissection[15] is very difficult. Deaths caused by rupture of the remaining aortic aneurysm in the interval between the 2 procedures have been reported, and some patients did not return for the second stage of the procedure.[16] In centers experienced in this procedure, the cumulative mortality from stage 1 and stage 2

Table 5. Follow-Up Results

	Acute Dissection			Chronic Dissection		
Variable	SET (n=141)	CSR (n=62)	*P*	SET (n=141)	CSR (n=52)	*P*
Follow-up time (±SD), mo	42±18	49±20	0.007	43±19	46±22	0.408
Out of follow-up, n (%)	6 (4.3)	5 (8.1)	0.316	8 (5.7)	3 (5.8)	1.000
Thrombosis of the false lumen, n (%)	130 (94.2)	7 (14.5)	0.000	126 (92.0)	3 (10.3)	0.000
Secondary surgical intervention, n (%)	1 (0.7)	4 (6.5)	0.031	4 (2.8)	2 (3.8)	0.661
Follow-up death, n (%)	4 (2.8)	2 (3.2)	1.000	6 (4.3)	3 (5.8)	0.704

SET indicates stented elephant trunk; CSR, conventional surgical repair.

procedures and during the interval between the 2 procedures was >20% during an interval of 4.9±7.5 months.[17] Selecting an appropriate interval between the 2 procedures was also problematic.[16,17] To avoid the complications of the conventional elephant trunk procedure resulting from the "flapping" action of the prosthetic graft,[18] a self-expandable stent that could sustain the distal end of the elephant trunk was designed by Kato et al[3] and Karck et al.[2] However, it had some limitations because only the distal part of the prosthetic graft segment could be sustained by a self-expandable stent. Selecting the appropriate size of the frozen elephant trunk size was also difficult and carried a high risk of damage to the intima.[19]

Kouchoukos et al[20] introduced the "arch-first" procedure and bilateral anterior thoracotomy incision to treat chronic type A dissection. The 1-stage arch-first procedure was also a safe and suitable alternative for patients with chronic dissection. However, both internal thoracic arteries were euthanized, and a high prevalence of pulmonary complications was observed.[21] In addition, the 1-stage, arch-first procedure was limited to patients whose aneurysms did not extend below the diaphragm.

Endovascular placement of a stent graft is emerging as a new treatment. Combined surgical and endovascular treatment was introduced to treat type A dissection by certain research teams.[1,22,23] Certain variations in surgical procedures were reported to treat type A dissection: correction of an ascending dissection and endoluminal exclusion of the arch and distal aorta,[22] transluminal stent grafting into the descending aorta,[1] and total arch replacement combined with transfemoral stenting of the distal aorta.[23] We believe that delivering the stent graft in a retrograde fashion via the femoral artery is problematic.[22,23] There is no extravascular graft at the end of the stent graft to be used for sewing, so it is difficult to manage if late reoperation of the distal aorta is needed. In addition, the complications associated with endovascular treatment cannot be prevented.

Because of the problems stated above, some modifications of the elephant trunk procedure were postulated by Sun (called the Sun procedure).[4] This procedure combined the advantages of open surgical treatment and interventional methods while simultaneously avoiding the shortcomings of these approaches. The SET procedure has the advantages of good intraoperative handling and postoperative recovery.[24] With respect to the former, the SET procedure had several advantages over the procedures discussed above.

First, the aortic segment (from the proximal aortic lesion to the distal aortic arch), which is prone to further dilation, was resected. The site of the intimal tear was resected concomitantly. Second, this procedure simplified conventional total arch replacement. The distal aorta was transected between the origin of the left subclavian artery and the left common carotid artery. One limb of the 4-branch prosthetic graft was anastomosed to the left subclavian artery distal to its origin at ≈0.5 to 1.0 cm. This procedure not only avoided the difficulty of carrying out the distal anastomosis in the descending aorta but also prevented injury to the recurrent laryngeal nerve. Third, the stent graft was firmly fixed to the distal end of the 4-branch prosthetic graft using the suture line. Some complications of the interventional approach were avoided. Fourth, surgery was done under deep hypothermic circulatory arrest with SCP; this avoided injury to the aortic wall caused by endografting under aortic pulsation. Fifth, an end-to-end anastomosis had good hemodynamics. Sixth, with the antegrade approach, implanting the stent elephant trunk in a bound, compressed state into the true lumen of the distal aorta under direct vision is very easy, in contrast to the conventional elephant trunk procedure. Finally, it was very easy to achieve hemostasis at the distal anastomosis because the distal aorta was expanded by the rigidly spread surgical stent. Compared with the procedure described by Kouchoukos et al, sacrifice of the internal thoracic arteries was avoided and the prevalence of pulmonary complications was significantly reduced.

This procedure inherited the advantages of the interventional approach. The entire length of the elephant trunk was sustained by an expandable stent, and the radial force it gave the fragile aortic wall was uniform. This avoided the possibility of distortion of the prosthetic graft (the segment of the prosthetic graft without an expandable stent as described by Kato et al[3]). This procedure was therefore applicable to patients with an abnormally shaped aorta. Furthermore, the intimal tear could be sealed off after implantation of the SET where the surgical stent graft was reached. Stabilization of the distal aortic arch and proximal descending aorta was also achieved. More important, it enlarged the true lumen, reestablished flow in the true lumen and the side-branches, approximated the 2 dissected layers, promoted thrombosis of the distal residual dissected aorta, helped to remodel the dissected aortic wall, and contributed to shrinkage of the aorta. It also obviated the shortcomings of endovascular treatment. The proximal and distal ends of the surgical stent graft had 1 cm of extravascular graft, facilitating proximal anastomosis to the prosthetic graft and a late-staged procedure in the distal aorta. The size of the SET could therefore be close to the diameter of the proximal descending aorta of healthy subjects matched for age, sex, and height. The radial force exerted by the SET was relatively low, and injury to the aortic wall caused by the SET was minimal.

With respect to postoperative recovery, the false lumen in the distal aorta was obliterated with thrombus in most patients after the implantation of the SET. After remodeling of the 2 layers of the dissected aortic wall, shrinkage of the entire aorta was seen, and the distal aorta was stabilized. In accordance with this phenomenon, the prevalence of aneurysmal dilatation of the distal aorta was reduced. Accordingly, the need for secondary intervention of the distal aorta was greatly reduced with the SET technique as demonstrated by our follow-up results. Secondary surgical intervention differed significantly between the SET and CSR groups in patients with acute dissection. Because of the smaller involvement in the CSR group, the results fail to reach statistical significance between groups for chronic dissection. Other studies have also illustrated the low prevalence of reoperation on the remaining aorta using the hybrid procedure.[19,25,26]

Our surgical procedure for total arch replacement also produced encouraging and promising surgical results. After the SET was inserted into the distal aorta, the true lumen was expanded by the stented graft. This substantiates the anastomosis between the distal end of prosthetic graft and the distal aorta and reduces the anastomotic time. Furthermore, the anastomosis to the left common carotid artery helped complete the anastomosis between the prosthetic graft and the descending aorta, thereby decreasing the SCP time. The anastomosis to the innominate artery aided the proximal anastomosis between the prosthetic graft and the ascending aorta. This reduced the hypothermia time and thus the CPB time. Moreover, the unilateral SCP procedure is also a factor in surgical outcome.[20] This procedure provides physiological antegrade perfusion of the brain throughout the entire procedure, so the risk of cerebral atheroembolization is diminished. This was demonstrated by the low prevalence of cerebral complications in the present study (2.4% of patients with stroke).

Two challenging problems were associated with this procedure. First, injury to the spinal cord was related to rapid thrombosis of the false lumen in patients in whom the intercostal arteries arose from the false lumen. The collateral circulation did not have a compensatory role in patients with acute type A dissection. Second, the distal end of the stent graft entered the false lumen in patients with Marfan syndrome. We thought that this severe complication could be avoided after careful assessment and exclusion of Marfan patients with an entry adjacent to the distal end of the surgical stent graft, a very small true lumen, and/or extremely tortuous morphology of the false lumen aorta. If this procedure is adopted in Marfan patients, shortening or lengthening of the surgical stent graft to lengthen the distance between the intimal tear and the distal end of surgical stent graft may be an option.

However, limited conclusions can be drawn from the present study because it was an observational, retrospective study. The optimal method to compare CSR and SET (frozen elephant trunk procedure) of type A dissection would be a prospective randomized trial, but several limitations to such a design exist.[27] First, patients with type A dissection are not eligible for randomization because of unstable hemodynamics, a need for emergency surgery, a broad spectrum of clinical conditions, and the different extent of the proximal and distal propagation and involvement of aortic dissection. Second, we believe that the SET procedure benefited patients with type A dissection with respect to early and late results because of its good intraoperative handling and good postoperative recovery. This has been illustrated in other studies[19,25,26] and a study using BestBETs.[28] It was unfair to patients who were randomized to the CSR group, and they were reluctant to join this group. Third, we share Bachet's[27] opinion that "Either from a human or a scientific standpoint, the quality of the operator can hardly be measured and be entered prospectively into a randomized, controlled trial."

Conclusion

Total arch replacement combined with SET implantation demonstrated the superiority of the combination of surgical and interventional approaches while avoiding the weaknesses associated with the individual methods. A low prevalence of morbidity and mortality was obtained in our study population. The encouraging surgical results and promising outcomes could enable this procedure to become the new "standard" therapy for type A dissection involving repair of the aortic arch.

Disclosures

None.

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CLINICAL PERSPECTIVE

The stented elephant trunk procedure was adapted from the conventional elephant trunk procedure. Integrating the reports of Japanese authors, the Hanover group, our surgical team, and others, the stented elephant trunk (frozen elephant trunk) procedure had 2 primary advantages over the conventional surgical repair: good intraoperative handling and good postoperative recovery. Between January 2003 and September 2008, 291 of 544 patients with type A dissection underwent total arch replacement combined with stented elephant trunk implantation. Our experience demonstrated that it was very easy to implant the stented elephant trunk (which was in a bound, compressed state) into the distal aorta. The intimal tear was sealed off where the surgical graft was reached, and the false lumen in the distal aorta was obliterated with thrombus in most patients. Follow-up data illustrated that shrinkage of the entire aorta was obtained. This stabilized the distal aorta after remodeling of the 2 layers of the dissected aortic wall. Therefore, a low prevalence of reoperation on the remaining aorta was observed. A low prevalence of morbidity and mortality was obtained with this technique at our center. Overall, this procedure had good intraoperative handling, promotion of thrombosis of the false lumen in the distal aorta, a reduction of the prevalence of late formation of thoracoabdominal aneurysms, and a decrease in the prevalence of reoperation. The stented elephant trunk procedure may become the next standard treatment in patients with type A dissection involving repair of the aortic arch.