The results of total arch graft implantation with open stent-graft placement for type A aortic dissection

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Background: One problem that conventional ascending treatment for type A aortic dissection has not satisfactorily resolved is chronic enlargement of residual dissection in the aortic arch and descending aorta. To address this problem, we have developed a new method for type A aortic dissection: total arch graft implantation with open-style stent-graft placement.

Methods: From October 1994 through October 1999, 19 patients with type A aortic dissection (13 acute and 6 chronic dissections) underwent total arch graft implantation with open-style stent-graft placement. After achievement of general anesthesia and hypothermic extracorporeal circulation, we replaced the dissected ascending aorta and neck vessels with a 4-branched graft and repaired the descending aorta with a stent graft to close the entry site completely and to obtain better peripheral perfusion. We then examined the acute-phase and chronic-phase results and the outcomes of the false lumen and dissected aorta.

Results: There were 1 (5.3%) hospital death and 2 late deaths. The survivals at 1 and 3 years were 89.5% and 82.6%, respectively. The following complications occurred in the perioperative period: 1 stroke, 2 cases of temporary paraparesis, 2 cases of temporary hemodialysis, and 3 cases of mediastinitis. No pulmonary complications were observed. Six months postoperatively, the targeted entry sites were completely closed in all cases, 80% (8/10) of preoperatively patent false lumina were clotted at the level of the end of the stent graft, and 60% (9/15) of the false lumina and 40% (6/15) of the dissected aorta had shrunk significantly. Two (13.3%) of 15 cases of postoperative dilatation in the dissected aorta were observed, and reoperation related to residual dissected aorta was performed in only 1 (1/17 [5.9%]) patient during the mean follow-up period of 2.4 ± 1.6 years.

Conclusion: Our preliminary review of the total arch graft implantation with a stent graft suggests that this new procedure for type A aortic dissection might provide better results in both the acute and the chronic phase, especially with regard to the outcome for the false lumen and dissected aorta.

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Conventional surgical treatment for proximal aortic dissection (ie, type A aortic dissection) is graft replacement or resection of the entry site in the ascending aorta to prevent intrapericardial rupture.¹⁻⁴ However, because this surgical treatment has improved the life prognosis for the acute phase in recent years,⁵⁻⁹ the discussion has been changing from the acute-phase mortality rate to postoperative morbidity and the prognosis of residual dissection in the chronic phase.¹⁰⁻¹⁶ The shift has been prompted by relatively high late mortality^{7,10-12} and experience with reoperation for enlargement of residual dissection in the aortic arch and descending aorta after the conventional operation to repair the ascending aorta.¹¹⁻¹⁶

Therefore for patients with type A aortic dissection who are forecast to have enlargement of residual dissection with only conventional ascending treatment, such as patients who are young (≤ 60 years), have Marfan syndrome, or have residual entry in the arch or descending aorta,^{11,12,14,16} we have introduced a method in which we implant the stent graft in the descending aorta from the surgically opened aortic arch simultaneously with graft replacement of the ascending aorta and the aortic arch.^{17,18} The purpose is to avoid enlargement of the residual dissected aorta and difficult reoperations in the chronic phase. This new method is intended to obtain clotting formation and shrinkage of the false lumen by having the stent graft ensure entry-site closure in the aortic arch or descending aorta and continuous compression on the false lumen.

We evaluated the results of our procedure in terms of mortality and morbidity in the acute phase, late survival, and the outcome for the false lumen and dissected aorta in patients with type A aortic dissection.

Methods

Patients

From October 1994 through October 1999, 19 patients (11 men and 8 women) with type A aortic dissection underwent open-style stent-graft implantation after approval of the procedure by the hospital ethics committee of Osaka Prefectural Hospital. We obtained informed consent in each case. The average age of the patients was 59.7 ± 12.5 years (range, 41-78 years). Thirteen (68%) were in the acute stage (within 2 weeks from the onset of dissection), and 6 had chronic dissection (ie, 4 patients with chronic dissection were treated within 2 months of onset, and the date of onset was unclear in 2 patients). Emergency surgery was performed in the 13 patients whose onset of symptoms was within 48 hours before arrival at the hospital or who had rupture, cardiac tamponade, or both. Four of the 19 patients had a previous cerebral accident, 1 had atypical angina pectoris, 1 had a greater than 75% coronary artery stenosis in a major branch, and 2 had congestive heart failure with severe aortic regurgitation. One patient had chronic renal failure and had received a renal transplant 2 months earlier. Previous aortic operations had been performed in 3 pa-

tients: 2 for abdominal aortic aneurysm and 1 for thoracoabdominal aneurysm. There were 2 patients with suspected Marfan syndrome.

The 19 patients were selected for total arch graft implantation with open stent-graft placement because the entry site was located in the aortic arch or descending aorta and they had an enlarged aortic arch or descending aorta (>40 mm in aortic diameter), neck vessel dissection (in patients <60 years), or Marfan syndrome. The entry site was detected only in the ascending aorta in 3 patients, the ascending aorta and arch or descending aorta in 3 patients, and the arch or descending aorta in 13 patients. The locations of these entry sites were ascertained by means of aortography, transesophageal echocardiography, and direct intraoperative diagnosis. Dilatation of the aortic arch or descending aorta was seen in 3 patients. Neck vessel dissections were also observed in 12 patients and 23 arteries. In association with aortic dissection, 3 had a neurologic disorder, 3 had cardiac tamponade with shock, 1 had respiratory dysfunction, 3 had leg ischemia, and 2 had suspected intestinal ischemia. The clinical characteristics of the 19 patients are shown in Table 1.

During the same 5-year period, 25 patients with type A dissection who were excluded from the foregoing indications (19 acute and 6 chronic dissections) underwent the conventional surgical procedure (graft replacement of the ascending aorta or the ascending aorta with proximal arch). No surgical deaths, 2 cerebral complications, 3 respiratory complications, 2 episodes of hemodialysis, and 1 episode of mediastinitis were observed in this conventional surgical operation.

Imaging Protocol

All 19 patients underwent chest radiography and spiral computed tomographic scanning, and 17 underwent aortography or digital subtraction angiography before the surgical procedure. The true luminal diameter (D) of the descending aorta was calculated from the planimetered circumference (Cf) of the true lumen measured by means of enhanced computed tomographic scanning as follows:

$$D = Cf/\pi.$$

Description of the Device

The surgical stent graft (Figure 1, A and B) was composed of a stainless-steel Z-shaped stent and polyester graft material. The triple tandem-type Gianturco stent (William Cook Europe A/S) was inserted in the distal part of a noncoated polyester fabric graft (Toray Medicals or Inter Vascular, Inc) with the crimp ironed out. These polyester grafts are usually used as the implanting graft in conventional thoracic and abdominal aortic aneurysm surgery. The stent was attached to the graft with a series of interrupted 5-0 polypropylene sutures. The device was described in detail in a previous study.¹⁷

For each patient, the diameter selected for the polyester graft was 100% to 120% of the diameter of the true lumen at the intended distal level of the dissected portion. The diameter of the Gianturco stent was proportional to that of the polyester graft: A 40-mm-diameter stent was selected for a 28-mm or larger graft, and a 30-mm-diameter stent was selected for a 26-mm or smaller graft.

TABLE 1. Pre-operative characteristics of 19 patients

Patient	Sex	Age (y)	Acute(A) or chronic(C)	Past history// preoperative condition	Position of primary entry	Dilation in arch or descending aorta	Dissection of cervical artery	Position of abdominal re-entry
1	F	45	C	HT, CRF, s/p renal transplant // NS	Ascending, arch	N	Y	Between SMA and IMA, aortic bifurcation
2	F	66	A	HT, cerebral bleeding // shock with tamponade, coronary dissection	Descending	N	N	(—)
3	F	67	C	HT, AR // NS	Ascending	Y	N	(—)
4	M	72	A	HT, s/p graft replacement for AAA, OCl // LOC	Ascending, arch	N	Y	Celiac artery
5	M	64	A	AAE, AR, Marfan // CHF	Descending	N	Y	Intercostal artery, Left RA
6	M	42	C	HT, HL // NS	Descending	N	N	Left RA, Intercostal and lumbar artery
7	M	41	A	HT, AAE, IHD // shock with tamponade, intubated, ischemia in lower body	Arch	N	Y	Proximal of celiac artery, Right RA
8	M	47	A	Marfan // ischemia in bilateral legs	Descending	N	N	Celiac artery
9	F	75	A	HT, s/p graft replacement for AAA, atypical angina // NS	Ascending	Y	N	(—)
10	M	70	A	HT, DM, OCl // LOC	Descending	N	Y	(—)
11	F	62	A	HT, s/p graft replacement for TABA // LOC, shock with tamponade	Ascending	Y	Y	(—)
12	M	65	A	HT, DM, rectal cancer, ileus // NS	Arch	N	Y	Unknown
13	F	54	A	HT, DM // NS	Arch	N	Y	Right RA
14	M	66	C	HT // cardiac tamponade	Arch	N	Y	(—)
15	F	78	A	HT // NS	Arch	N	Y	Unknown
16	F	76	A	HT // ischemia in lower body	Arch	N	N	Unknown
17	M	53	C	AR, MR // CHF	Ascending, descending	N	Y	Right iliac artery, celiac artery
18	M	43	C	HT // NS	Descending	N	Y	RA
19	M	48	A	HT, OCl // cardiac tamponade	Descending	N	N	Unknown

C, Chronic; HT, hypertension; CRF, chronic renal failure; s/p, status post; SMA, superior mesenteric artery; IMA, inferior mesenteric artery; A, acute; AR, aortic regurgitation; NS, nothing special; AAA, abdominal aortic aneurysm; OCl, old cerebral infarction; LOC, loss of consciousness; AAE, annuloaortic ectasia; CHF, congestive heart failure; RA, renal artery; HL, hyperlipidemia; IHD, ischemic heart disease; DM, diabetes mellitus; TABA, thoracoabdominal aneurysm; MR, mitral regurgitation.

Procedure

All procedures are performed with the patients under general anesthesia sustained by means of endotracheal intubation and mechanical ventilation. A Swan-Ganz catheter, left radial and unilateral temporal arterial line, and probe for transesophageal echocardiographic monitoring are inserted.

The patient is placed in a supine position, and median sternotomy is the surgical approach. Systemic heparinization (300 U/kg) is initiated before vessel cannulation. The arterial return cannula is placed in the right axillary artery. The femoral artery is also cannulated from the bifurcated arterial return line (Figure 2, A). Bicaval venous cannulas are usually inserted through the right atrium. Cardiopulmonary bypass is initiated, and flow rates are maintained between 2.4 and $2.8 \text{ L} \cdot \text{min}^{-1} \cdot \text{m}^{-2}$.

During core cooling to a bladder temperature of 24°C , the ascending aorta is clamped with a Fogarty clamp, and cold crystalloid cardioplegic solution is injected retrogradely to achieve cardiac arrest. A collagen- or gelatin-coated woven Dacron graft with 4 branches is sutured to the ascending aorta in the usual

manner, with 3-0 polypropylene sutures (Figure 2, B). After proximal anastomosis has been completed in the ascending aorta, bypass anastomoses from the 4-branch graft to the left subclavian artery and left carotid artery are performed, and the perfusion for these cervical branches is restarted from the 4-branch graft, through which the return cannula has been inserted (Figure 2, B). Perfusion to the lower body is discontinued when the brachiocephalic artery is perfused through the right axillary return cannula and left carotid artery, left subclavian artery, and coronary arteries through the 4-branch graft at around $1000 \text{ mL} \cdot \text{min}^{-1} \cdot \text{m}^{-2}$ (Figure 2, B and C).

The aortic arch is transected at the predetermined proximal anastomotic line (between the brachiocephalic artery and the left carotid artery). During transesophageal echocardiographic monitoring, a 30F catheter sheath (Figure 1, C) that has been curved to correspond to the aortic arch for the individual patient and has been loaded with the stent graft is inserted through the proximal incision site to the intended distal attachment portion (ie, to the point at which tight contact between the stent graft and vascular wall is possible over

Figure 1. Stent graft and device for delivery. *A* and *B*, Complete form of stent graft composed of polyester graft and a self-expandable Z-stent inserted into the distal portion of the graft. The stent was attached to the graft by a series of interrupted 5-0 polypropylene sutures in the distal and proximal tips of the stent. *C*, A 30F catheter sheath and pushing rod for the delivery of the stent graft. The catheter sheath was curved to correspond to the aortic arch.

Figure 2. Operative method. *A*, Type A aortic dissections in which the entry site is in the aortic arch, descending aorta, or both. *T*, True lumen; *F*, false lumen; *E*, entry; *RE*, re-entry; *CPB*, cardiopulmonary bypass. *B*, The stent graft is implanted into the descending aorta through surgically opened aortic arch by using the 30F catheter sheath (*C*). *C*, Implanted stent graft (*S-G*) is sutured with the graft (*4BG*) that replaced the ascending aorta and neck vessels. *D*, The entry site in the thoracic aorta is expected to close completely, and the false lumen is expected to thrombose.

a length of 25 mm; Figure 2, *B*). Once the sheath is placed across the entry in the descending aorta and the pushing rod is advanced within the sheath, the stent graft is deployed by holding the rod in position and withdrawing the sheath (Figure 2, *B*).

After the stent graft is deployed, a 14F Foley balloon is inserted into the graft and inflated to confirm that the stent graft is fully opened and not twisted or kinked. Blood is allowed to return from the femoral arterial cannulation to expel the air and atheromatous

Figure 3. Serial size changes of the diameter of the false lumen and the dissected aorta at the 3 measurement levels before and after the operation in 17 patients. ○, Data of each case in which false lumen at the level is patent; ●, data of each case in which false lumen at the level is completely thrombosed; †, mean $\pm$ SD.

plaque that might have been dislodged by the stent-graft implantation. Subsequently, the proximal side of the stent graft is cut, its edges are trued up with those of the transected aortic arch, and an anastomotic stoma is created comprising the dissected aorta and the Teflon strip reinforcement externally by using interrupted mattress sutures (Figure 2, C). Finally, this anastomotic stoma is sutured together with the distal portion of the 4-branched graft in end-to-end anastomotic style.

After the air is eliminated from the femoral artery, the cardiopulmonary bypass is resumed, and surface and core rewarming are initiated. During the rewarming, the right brachiocephalic artery is reconstructed with one of the 4 branched grafts from the ascending aorta (Figure 2, D).

Patient Follow-up

The patients were followed until March 2000 at the outpatient clinic or through telephone contact. The follow-up was 100% complete. The mean follow-up period was 2.4 ± 1.6 years, and the longest period was 5.5 years.

The effectiveness of stent-graft implantation in the acute phase was estimated by the closure of the targeted entry site and clot formation in the false lumen, as confirmed by means of transesophageal echocardiography on the day of the operation and enhanced computed tomography at 2 weeks after the operation.

The effectiveness of stent-graft treatment in the chronic phase was estimated from the change in diameter of the false lumen and dissected aorta. All cases, except one acute-phase death, were given prospective follow-up by means of enhanced computed tomography at approximately 2 weeks (10-25 days after treatment), 6 months (4-6 months after treatment), 1 year (10-14 months after treatment), and annually thereafter.

The diameters of the dissected aorta and false lumen were measured at 3 predetermined levels in each computed tomographic examination, including the preoperative computed tomographic scan (Figure 3). The first measurement level was at the maximum diameter of the descending aorta in the short axis, the second was at the distal end of the stent graft, and the third was 50 mm distal to the second measurement.

At each of these levels, the diameter of the dissected aorta was measured in short-axis diameter, and the diameter of the false lumen was measured as the distance between 2 parallel lines, which were also parallel to the line connecting the 2 attachment points of the intimal flap. The outer of the 2 parallel lines was drawn through the outermost point of the false lumen, and the inner line was drawn through the outermost point of the intimal flap. These measurement methods were described in detail in a previous study.¹⁸

Statistical Analysis

All continuous data are expressed as means $\pm$ SD. Survival was estimated by using the Kaplan-Meier method. Changes in the diameters of the false lumen and dissected aorta between the preoperative period and 6 months after the operation were analyzed with the paired *t* test. All calculations were performed with a Statcel for Excel 98 on a Mac OS.

Results

Procedural Success

The stent-graft deployment within the true lumen of the descending aorta from the transected aortic arch was technically successful in all 19 patients, and wide expansion of

TABLE 2. Result of 19 patients who received total arch-graft implantation with a stent graft for aortic dissection

Patients	Combined operation	Post-operative complication	Mortality in hospital (A = alive, D = death)	Late mortality (A = alive, D = death)	Late morbidity
1	Suspension of AV + 1 CABG	(-)	A	A	Removal of seroma
2	Reconstruction of coronary orifice	(-)	A	A	AMI, bedridden
3	AVR	(-)	A	A	(-)
4	(-)	(-)	A	D (AMI, pneumonia)	AMI, pneumonia
5	Aortic root replace	Mediastinitis, stroke	D(MOF)	(-)	(-)
6	(-)	(-)	A	A	(-)
7	Aortic root replace + 1 CABG	MNMS, ARF, probe laparotomy	A	A	(-)
8	Suspension of AV	Reperfusion injury of left leg	A	A	(-)
9	(-)	Temporary paraparesis	A	A	Bedridden
10	Suspension of AV	(-)	A	A	TPEG
11	Suspension of AV	(-)	A	A	Hepatitis
12	Suspension of AV	(-)	A	A	Operation for rectal cancer
13	Suspension of AV	Retrograde leakage from left SCA	A	A	(-)
14	(-)	(-)	A	D (suicide)	(-)
15	Suspension of AV	Mediastinitis	A	A	(-)
16	Bare stent placement in abdominal aorta and iliac artery	(-)	A	A	(-)
17	Aortic root replace + MAP	Hoarseness	A	A	(-)
18	(-)	Retrograde leakage from left SCA	A	A	(-)
19	(-)	Mediastinitis, ARF, temporary paraparesis	A	A	(-)

AV, Aortic valve; CABG, coronary artery bypass grafting; A, alive; AMI, acute myocardial infarction; AVR, aortic valve replacement; D, deceased; MOF, multiorgan failure; MNMS, myonephropatic metabolic syndrome; ARF, acute renal failure; TPEG, transluminal-placed endovascular graft; SCA, subclavian artery; MAP, mitral annuloplasty.

the stent was confirmed on the postoperative chest x-ray films. Complete resection and sealing of the targeted entry sites with our procedure were confirmed by means of intraoperative color Doppler transesophageal echocardiography. In one patient a postoperative ischemic event indicated a new intimal tear formation 3 cm distal to the distal end of the stent graft and subsequent narrowing of the true lumen. Simultaneous with stent-graft implantation, 2 patients received coronary artery bypass grafting, 1 received aortic valve replacement, 3 received aortic root reconstruction, and 1 received mitral annuloplasty. The operative time ranged from 418 to 815 minutes (mean, 564 ± 25 minutes [9 hours and 24 minutes]), and the cardiopulmonary bypass time ranged from 172 to 454 minutes (mean, 244 ± 15 minutes [4 hours and 4 minutes]). Circulatory arrest in the lower body (and selective cerebral perfusion) was required for 18 to 70 minutes (mean, 42 ± 3 minutes).

Postoperative computed tomographic scanning 1 to 4 weeks after the operation depicted complete thrombosis of the aneurysm or the false lumen surrounding the stent graft in all but 2 patients. In these 2 patients we had ligated the left subclavian artery from inside the opened aortic arch and observed retrograde leakage from the ligated left subclavian artery to the false lumen. Even in these patients, complete thrombosis of the false lumen was observed on the com-

puted tomographic scan after coil embolization to the root of the left subclavian artery by using transbrachial catheter intervention. In the patients with a preoperative narrowed true lumen in the descending aorta, aortography and computed tomographic scanning after stent-graft implantation documented remarkable recovery of the true lumen to a round shape and thrombosis of the false lumen. Bypass grafts for the cephalic vessels were patent in all patients.

Early Mortality and Morbidity

The early results of total arch graft implantation with a stent graft are shown in Table 2. One of the 19 patients died (9 days postoperatively), for an in-hospital mortality of 5.3%. This operative death occurred in the patient with annuloaortic ectasia who received aortic root reconstruction simultaneously with total arch graft implantation (patient 5). The patient died as a result of postoperative stroke, low-output syndrome, mediastinitis, and consequent multiorgan failure.

No other patient had a cerebrovascular accident. Temporary paraparesis was noted in 2 patients, whose circulatory arrest times in the lower body were 30.5 and 34 minutes, and both patients almost fully recovered (ie, were able to walk with a cane).

No pulmonary complication resulted, and there was one case of postoperative hoarseness. The postoperative intuba-

tion period was 5 days or less in 15 patients and more than 5 days in 4 patients, and no patients needed tracheostomy. Two (10.5%) patients required temporary hemodialysis. In one patient (patient 7) hemodialysis was performed for reperfusion injuries in the leg and intestine that were related to a preoperative ischemic condition. This patient also required a laparotomy for investigation, but no resection of the intestine was necessary. The second patient for whom hemodialysis was administered (patient 19) had a postoperative ischemic event in the visceral artery and both legs. This postoperative ischemia was successfully treated by means of bare stent implantation into the narrowed true lumen of the thoracoabdominal aorta on the second postoperative day. There were 3 cases of mediastinitis, all of which were treated with mediastinal washing, irrigation, and drainage. In 2 of the patients, we were able to perform omental flap implantation after thorough washing and drainage, and the third patient was the only case of death in this series (patient 5). The early results of total arch graft implantation with the stent graft are shown in Table 2.

Late Mortality and Morbidity

The survivals for all patients 1 and 3 years postoperatively were 89.5% and 82.6%, respectively. There were 2 late deaths: One patient committed suicide 3 months after the operation, and the other patient died of cardiac and pulmonary complications.

Two nonfatal events related to the operation were noted in the chronic phase. In one patient a reoperation was required for seroma in the mediastinum caused by the bypass graft (polytetrafluoroethylene graft) to the cervical branch. The other patient required an additional stent-graft implantation from the femoral artery (transluminal-placed endovascular graft) 1 year after the initial operation to close an intrathoracic residual entry site that was not detected before the initial operation. This patient (patient 10) is the only one who needed reoperation related to dissection of the aorta. The late mortality and morbidity of all patients are shown in Table 2.

Outcome for the Dissected Aorta and False Lumen

With the aid of 46 examinations, we observed serial size changes in the false lumen and the dissected aorta in 17 patients at the first 6 months after the stent-graft placement and thereafter. Computed tomographic examinations were performed according to schedule in 15 patients, but follow-up computed tomographic examinations were discontinued in 2 patients at 6 months and 2 years because aging kept them from unassisted walking and they could not come to our outpatient clinic for follow-up. At the level of the end of the stent graft, the data on 2 patients were omitted from serial follow-up data because in both patients there was no aortic dissection and false lumen at that level through the

entire period. At the level 5 cm distal to the stent graft, the data on 5 patients were omitted for the same reason.

Postoperative computed tomographic examinations at 6 months showed that all 17 false lumens at the level of maximum aortic diameter had clotted, that the diameter of the false lumen at that level had been reduced by more than 50% in 16 (94.1%) patients, and that the aortic diameter had been reduced by more than 20% in 11 (64.7%) patients. Two more patients had a greater than 20% reduction of the aortic diameter after 6 months. The mean diameter of the false lumen at 6 months was 4.1 ± 6.4 mm (vs 22.1 ± 7.9 mm preoperatively), the mean aortic diameter was 32.4 ± 8.9 mm (vs 42.1 ± 6.7 mm preoperatively), and both were significantly decreased compared with preoperative diameters. At the same level, the mean diameters of the false lumen and the dissected aorta were 2.1 ± 3.4 and 30.5 ± 6.2 mm, respectively, at 1 year and 3.0 ± 4.8 and 31.0 ± 7.2 mm, respectively, at 2 years. The changes in the diameter of the false lumen and the aorta are shown in Figure 3. In the follow-up period no patient had an enlargement of the aortic diameter greater than 20% from the preoperative state at this level.

At the level of the end of the stent graft, the false lumen was absent in 2 patients and already clotted at the initial (preoperative) computed tomographic examination in 5 others. Of the 10 patent false lumina at this level, 8 (80%) were completely clotted at 6 months. There was a residual patent false lumen at this level in one patient (patient 7) as a result of back flow from an abdominal re-entry site near the celiac artery. The other instance of a patent false lumen resulted from flow from an intrathoracic residual entry site that could not be detected at the initial operation (patient 10). In one case of a preoperatively clotted false lumen, a postoperatively reopened false lumen with a postoperative new entry site was noted as the result of a postoperative ischemic event in the lower body (patient 19).

At this level, the false lumen had been reduced by more than 50% from the preoperative diameter in 9 (60%) of 15 patients at 6 months, and the aortic diameter had been reduced by more than 20% in 6 (40%) of 15 patients. After 6 months, the aortic diameter showed this amount of reduction in 2 other patients. The mean diameter of the false lumen at 6 months was 6.6 ± 8.0 mm (vs 15.5 ± 8.1 mm preoperatively), and the mean aortic diameter was 31.4 ± 8.5 mm (vs 34.3 ± 4.7 mm preoperatively); both were significantly decreased compared with preoperative diameters. At the same level, mean diameters of the false lumen and the dissected aorta at 1 year were 3.2 ± 5.9 mm and 28.4 ± 8.0 mm, respectively, and the respective mean diameters were 4.3 ± 4.8 mm and 28.0 ± 7.2 mm, respectively, at 2 years. In the follow-up period, 2 (13.3%) patients had greater than 20% enlargement of the aortic diameter compared with its preoperative state at this level; in both

patients (patients 7 and 19) the computed tomographic scans showed a patent false lumen 6 months after the operation. There were no cases in which the aortic diameter was larger than 60 mm (ie, should have been considered for reoperation).

The following measurements all pertain to the level 5 cm distal to the stent graft. Among 9 patent false lumina (a false lumen was absent in 5 patients and already clotted at the initial computed tomographic examination in 3 patients), 3 (33.3%) patients had total clotting 6 months after the operation. A greater than 50% reduction of the false lumen diameter compared with the preoperative diameter was observed in 6 (50%) of the 12 patients, and greater than 20% reduction of the aortic diameter was observed in 2 (16.7%) of the 12 patients 6 months after the operation. The mean diameter of the false lumen 6 months after the operation was 11.4 ± 9.3 mm (vs 17.1 ± 7.3 mm preoperatively), a significant decrease compared with preoperative diameter, and the mean aortic diameter was 30.1 ± 5.9 mm (vs 30.8 ± 3.4 mm preoperatively). The mean diameters of the false lumen and the dissected aorta at 1 year were 7.8 ± 10.1 and 27.3 ± 6.1 mm, respectively, and those at 2 years were 16.0 ± 14.5 and 33.0 ± 8.7 mm, respectively. In the follow-up period, 3 (25%) patients had greater than 20% enlargement of the aortic diameter relative to the preoperative state. Two of them were the same patients (patients 7 and 19) with enlargement at the level of the end of stent graft; the other (patient 8) had the case of suspected Marfan syndrome, in which there was a large re-entry site near the celiac artery. There were no cases in which the aortic diameter was larger than 60 mm (ie, should have been considered for reoperation).

Discussion

The purpose of our total arch graft implantation method is to obtain complete closure of intrathoracic entry sites for type A aortic dissection with less invasiveness than with the conventional total arch graft implantation. Open-style stent-graft placement provides distal anastomotic fixation by using a self-expandable stent, obviating the need for a distal anastomotic suture. Unlike the conventional total arch graft implantation, which requires dissection, incision, and sutures on both the proximal and distal ends, our open-style stent-graft implantation requires these troublesome manipulations only on the proximal anastomotic side. This method also provides a high probability of clotting and shrinkage of the false lumen with a result of complete entry-site closure and maintenance of a wide true lumen, secured by the expansile force of the stent graft, that was often narrowed preoperatively by the dilated false lumen. Hence our new graft-implanting method with open-style stent-graft placement for type A aortic dissection might well provide better results in the acute phase and the subsequent posttreatment chronic phase.

The surgical mortality for graft replacement of the ascending aorta for type A dissection has been reported as ranging from 9% to 21.8%,^{5,11,19} and that of total arch graft replacement has been reported as ranging from 17% to 55%.¹⁹⁻²⁷ Surgical mortality in our series was 5.3%. The rate of cerebral, respiratory, and renal complications has been reported as 2.5% to 11.8%, 6% to 19%, and 5% to 12.2%, respectively, in the conventional surgical treatment.^{3,5-7,19} In our series the rates of cerebral and renal complications (5.3% and 10.6%, respectively) were comparable with those of conventional treatment. The rate for respiratory complication in our series (0%, no patient needed a tracheostomy) was much lower than that seen in previous reports because our technique does not require us to touch the recurrent nerve and phrenic nerve or to open the thorax and compress the left lung. Also, even in 3 patients (patients 7, 8, and 16) with preoperative critical ischemia of the leg or organs, the patients recovered after the initial operation. (Postoperatively, however, a new entry site was observed in a different patient [patient 19], followed by ischemia in the visceral organs and both legs.) These good results in the acute phase seemed to be associated with the stent-graft procedure's reduced invasiveness, complete entry-site closure, and secure perfusion to the lower body.

The ordinary motivation for total arch graft replacement for type A dissection is to prevent enlargement of the residual dissection. There are few reports of meticulous follow-up of residual dissection after the ascending operation for type A dissection. The reported rate for enlargement of residual dissection was 17% at 3 years from the initial operation¹³ and 37% at 5 years.¹⁵ Enlargement after the initial operation was enhanced in patients who had a patent residual false lumen, were young, or had Marfan syndrome.^{11,12,14-16} The rate of patent residual false lumen after the ascending operation for type A dissection was 47% to 83%.^{7,14,15,28,29} Two causes have been proposed to account for these high rates: a residual entry site in the arch descending aorta or neck vessels and leakage from the distal anastomosis in ascending graft replacement. On the other hand, the dissected aorta in type B dissection is destined to enlarge if its maximum diameter is greater than 40 mm in the acute phase.³⁰ To reduce the rate of enlargement of residual dissection after the operation for type A dissection, we should completely separate the entry site from the false lumen, especially in the patient who is young, has Marfan syndrome, or has a maximum aortic diameter of greater than 40 mm in residual dissected aorta and not create a new entry site in the distal anastomotic portion. To meet these requirements, we performed total arch graft implantation with a stent graft on targeted patients who were highly likely to have aortic enlargement of residual dissection if treated only with graft replacement of the ascending aorta (ie, those who were young, had Marfan syndrome, or had a maximum

dissected aorta of >40 mm and an entry site in the arch-descending aorta or had neck vessel dissection). In our surgical treatment with the stent graft, we obtained clotting of the residual dissection in 80%; enlargement of the residual dissection was observed in only 2 (13.3%) patients at the level of the end of the stent graft, with a mean follow-up period of 2.4 years. Additional aortic treatment related to residual dissection was required in only one (5.9%) patient. The number of data on residual dissection was limited (10 patients for the level of the end of the stent graft, 9 for 5 cm distal to the stent graft), and the follow-up period was short. Nevertheless, these data concerning dilatation and additional treatment in the chronic phase were satisfactory enough, considering that the targeted patients in our series were highly likely to have enlargement of residual dissection if they had received the conventional surgical treatment. Furthermore, this total arch graft-implanting method has an advantage, even in the patient who postoperatively has residual dissection in the descending aorta, because the additional transcatheter stent-graft placement can be easily implanted through the femoral artery after achievement of local anesthesia.^{18,31-33}

In our experience with this series, some unpleasant complications were observed in exchange for satisfactory fate of the residual false lumen. There were 2 cases of paraparesis (which is a seldom-seen complication after conventional treatment); however, they were temporary. In these patients the end of the implanted stent graft was placed at the level of T6, and circulatory arrest of the lower body was accomplished within 40 minutes with hypothermia. The hypothesized reasons for this complication are air or thromboembolism caused by insertion of the stent graft or complete clotting and stoppage of blood flow to the Adamkiewicz artery that branched from the false lumen.³⁴ Meticulous air and thrombus elimination during the stent-graft insertion, along with perioperative spinal protection, might be needed to protect against this terrible complication. Also, the relatively high incidence of mediastinitis (3/19 patients) might be related to the long operative time associated with this operation. Refinements in procedure and greater facility with this new operation should reduce or eliminate these troublesome complications.

With our approach, there might be some risk of intimal trauma because of the continuous compression of the stent graft on the dissected and weakened intimal wall, but in the small number of recent reports of stent-graft placement for acute aortic dissection, there was no report about this anxiety.^{18,32,33} In postmortem examinations of our cases of surgical death, the following were observed: clotting of the false lumen, slight hyalinosis of intimal wall, and no thinning of the intimal wall. In fact, stent-graft implantation for acute aortic dissection was associated with quick clot formation and shrinkage of the false lumen after stent-graft

implantation, and this healing process might promote good blood supply to the intimal wall from the adventitia and subsequently play a role in preventing new trauma to the intimal wall. In any case the proper size adjustment of the stent graft and the device selected might be key to preventing trauma to intima that is dissected and might be fragile.

In summary, our preliminary experience with the total arch graft implantation with a stent graft for the selected patient with type A aortic dissection suggests that this new procedure might provide better surgical results in the acute and chronic phase, especially with regard to the fate of the false lumen, than does conventional treatment.

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