Total Arch Repair for Acute Type A Aortic Dissection With 2 Modified Techniques: Open Single-Branched Stent Graft Placement and Reinforcement of the Dissected Arch Vessel Stump With Stent Graft

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Background—In total arch replacement for patients with acute type A aortic dissection, anastomoses of the graft to the left subclavian artery and descending aorta are often difficult, and the arch vessel anastomosis is frequently performed at the site of dissection. To make this procedure easier and safer, we developed 2 modified techniques: open single-branched stent graft placement into the left subclavian artery and the descending aorta and reinforcement of the dissected arch vessel stump with a stent graft neointima. The feasibility and initial clinical results of these 2 new techniques are reported.

Methods and Results—Total arch repair with the 2 new techniques was performed in 26 patients with acute Stanford type A aortic dissection. Most patients had an uneventful postoperative course, and there were no surgical deaths. All implanted stent grafts were fully opened and not kinked, and there was no space or blood flow surrounding any of the stent grafts. The false lumen of the descending thoracic aorta closed with thrombus formation in 22 of 26 patients. Disappearance of the false lumen and recovery of the true lumen was observed in all of the dissected arch vessels.

Conclusions—Open single-branched stent graft placement into the left subclavian artery and the descending aorta and reinforcement of the dissected arch vessel stump with a stent graft neointima are 2 simple and effective techniques that should make total arch repair an easier and safer procedure for acute type A aortic dissection. (Circulation. 2011;123:2536-2541.)

Key Words: dissection ■ stents ■ surgery

Acute type A aortic dissection is a life-threatening cardiovascular disease that frequently requires emergency surgical treatment.1,2 The main purpose of an emergency operation is to prevent death resulting from aortic rupture. Because the dissected segment of the ascending aorta is most likely to rupture and is the most common site of the primary tear, graft replacement of the ascending aorta is widely accepted as the conventional treatment for acute type A aortic dissection.2,3 However, residual dissection in the arch and downstream aorta can still occur after the conventional operation, and may significantly affect the long-term prognosis.4–7 To improve the late surgical outcome, surgeons have recently switched from limited replacement of the ascending aorta to simultaneous replacement of the ascending aorta and total arch.8

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Although many surgical techniques have been attempted, total arch replacement is still a highly invasive and risky procedure for patients with acute type A aortic dissection, mainly because it requires elaborate anastomoses of the graft to the descending aorta and 3 arch vessels.2 Anastomoses of the graft to the descending aorta and the left subclavian artery are usually very difficult because of the deep surgical field,9,10 and may cause phrenic and recurrent laryngeal nerve injury. Moreover, in acute type A aortic dissection, arch vessels are usually involved in the dissection, and anastomosis to the arch vessel is frequently performed at the dissected site. After an acute dissection, the dissected arch vessel wall is so fragile that the anastomosis between a dissected arch vessel stump and the graft branch often results in intraoperative or postoperative hemorrhage caused by tissue tearing at the suture lines.11

In an effort to reduce such problems in total arch replacement for acute type A aortic dissection, we developed a triple-branched stent graft placement technique. Instead of direct surgical repair, our new technique could be performed simply by open placement of a triple-branched stent graft into the proximal descending aorta, aortic arch, and 3 arch vessels.12 However, this new technique could not be used in all patients with acute type A aortic dissection, mainly because the diameters of the native aortic arch and arch vessels and the distances between 2 neighboring arch vessels did not always match the available sizes of the triple-branched stent grafts. With the intention of making total arch repair a much easier and safer procedure for...
those patients who were not candidates for a triple-branched stent graft, we developed 2 new techniques: open single-branched stent graft placement into the left subclavian artery and the descending aorta and reinforcement of the dissected arch vessel stump with a stent graft neointima. Here, we describe our application of these 2 new techniques for total arch repair in patients with acute type A aortic dissection. In addition, we report our initial clinical results in 26 patients.

Methods

Patients
From August 2008 through July 2010, 26 patients with acute Stanford type A aortic dissection underwent simultaneous surgical repair of the ascending aorta and total arch with 2 new techniques: open single-branched stent graft placement into the left subclavian artery and the descending aorta and reinforcement of the dissected arch vessel stump with a stent graft neointima. These 2 procedures were approved by the ethics committee of our hospital, and written informed consent was obtained from each patient. There were 19 men and 7 women. The mean age was 47.73 ± 6.58 years (range, 35 to 63 years). The preoperative diagnosis was made on the basis of electron beam computed tomography, magnetic resonance imaging, and echocardiography. All patients had intraoperative transesophageal echocardiography to confirm the diagnosis. The primary intimal tears were located in the ascending aorta in 10 patients, in the arch in 7, and in the proximal descending aorta with retrograde extension of the dissection into the arch and ascending aorta in 9. The innominate artery was involved in the dissection in all 26 patients, and the left common carotid artery was involved in 23 patients. There were some preoperative dissection-related complications, including aortic valvular regurgitation in 11 patients, cardiac tamponade in 2, transient right leg ischemia in 1, and transient brain ischemia in 1. Fifteen patients had hypertension without effective control. Five patients had classic Marfan syndrome. The interval from the onset of pain to the operation varied from 1 to 6 days, with an average of 3.62 ± 1.79 days. All operations were performed within 4 hours after the diagnosis was confirmed.

The 26 patients were selected for simultaneous surgical repair of the ascending aorta and total arch with the 2 new techniques because they had an indication for simultaneous replacement of the ascending aorta and total arch, but were not eligible for open placement of a triple-branched stent graft. The simultaneous replacement of the ascending aorta and total arch in Stanford type A aortic dissection was on the basis of one of the following indications: (1) The intimal tear was located in the transverse arch or proximal descending aorta that could not be resected by hemiarch replacement; (2) there was serious involvement of the arch vessels; (3) Marfan syndrome was present; or (4) the patient was <55 years of age.

Stent Grafts and 3-Branched Dacron Graft
The single-branched stent grafts used in this study were handmade and constructed in the operating room (Figures 1 and 2). The graft was constructed by adding a sidearm stent graft to a conventional straight aortic stent graft. The conventional straight aortic stent graft (Microport Medical Corp, Shanghai, China) was 100 mm long and 26 to 30 mm in diameter. It consisted of a Gianturco-type self-expandable metallic stent and a high-porosity woven Dacron graft. At 1 end, there was a 10-mm-long stent-free sewing margin. The sidearm stent graft (Yuhengjia Science and Technology Co Ltd, Beijing, China) was 25 mm long and 10 to 14 mm in diameter; it consisted of a self-expanding nitinol or metallic stent and polyester vascular graft fabric. The stent graft implanted into the arch vessel stump was 20 to 40 mm long and 12 to 18 mm in diameter (Figure 1). This arch vessel stent graft consisted of a self-expanding nitinol or metallic stent and polyester vascular graft fabric (Yuhengjia Science and Technology Co Ltd). The 3-branched Dacron graft (26 or 28 mm in diameter; Figure 1) was a product of Intergard, Intervascular, Dataspore Co (Montvale, NJ). The diameter of the stent graft selected was 10% to 20% larger than the size of the corresponding landing zone.9,10

Operative Technique
After the induction of general anesthesia, arterial blood pressure in both the upper and lower limbs was monitored, and a probe for transesoph-
Ageal echocardiographic monitoring was placed. The patient was placed in a supine position. A right subclavian incision was made, and the right axillary artery was exposed. A median sternotomy was performed, and cardiopulmonary bypass was established by 2 venous cannulas placed in the right atrium and the arterial return cannula placed in the right axillary artery. The arterial line was bifurcated for the right axillary artery and for the perfusion branch of the 3-branched Dacron graft. Cardiopulmonary bypass flow was maintained between 2.4 and 2.6 L·min⁻¹·m⁻². Myocardial protection was achieved by multiple antegrade administration of cold blood cardioplegia (4°C).

During core cooling, the innominate and left common carotid arteries were dissociated from surrounding tissue and exposed for as much length as possible. The ascending aorta was clamped at the base of the innominate artery. The aorta just distal to the sinotubular junction was transected, and a very limited dissection was made around the aortic stump. Proximal manipulations such as aortic valve repair and sinus of Valsalva reconstruction were also performed. The transected proximal stump of the ascending aorta was reconstructed with both inner and outer Teflon felt.

When core cooling to a 22°C rectal temperature was achieved, cardiopulmonary bypass was discontinued. After we cross-clamped the left common carotid artery (4 cm above the arch) and innominate artery (5 cm above the arch), selective cerebral perfusion via the right axillary artery cannula was established at a rate of ~10 to 15 mL·kg⁻¹·min⁻¹, and the proximal arch was transected at a predetermined line between the innominate artery and the left common carotid artery. The left common carotid artery was transected at its ostium, and the proximal stump was closed with 4-0 monofilament suture (Figure 3A). A cannula was placed into the left common carotid artery through the transectomy site. After the clamp on the left common carotid artery was removed, the balloon attached to the tip of the cannula was inflated, and selective cerebral perfusion through the left common carotid artery was initiated. Through the transverse incision in the proximal aortic arch, the single-branched stent graft was inserted into the true lumen of the proximal descending aorta and the left subclavian artery (Figure 3B). Once the aortic stent graft and the sidearm stent graft were properly positioned, the restraining strings were withdrawn and the aortic stent graft and the sidearm stent graft were deployed. Finally, the aortic graft and the sidearm graft were dilated with balloon catheters under transesophageal echocardiographic guidance to confirm that they were fully opened and not kinked. The transected distal aortic stump was reconstructed by the inner proximal stent-free sewing margin of the single-branched stent graft and outer Teflon felt and subsequently anastomosed to the 3-branched Dacron tube graft (Figure 3C). Then, the reinforced left common carotid artery was anastomosed to the corresponding branch of the Dacron tube graft. The proximal aortic anastomosis was performed, and finally, the reinforced innominate artery stump was anastomosed to the corresponding branch of the Dacron tube graft.

Follow-Up
All patients were followed up after they were discharged from the hospital. They were contacted by telephone or direct interview in our department, and contrast-enhanced computed tomographic scans were performed before discharge, 3 months after the surgery, and annually thereafter. The diameter of the dissected aorta at the diaphragmatic level and diameters of both the dissected aorta and false lumen at the level of the superior mesenteric artery were measured in each computed tomographic examination, including the preoperative scan. The methods used to measure these diameters have been described in detail in a previous report.¹³

Statistical Analysis
Continuous data were expressed as mean±SD. The diameters of the dissected aorta and false lumen were collected for statistical analysis. All data were normally distributed. A repeated measures ANOVA was used...
to compare the diameters of the dissected aorta and false lumen before surgery, before discharge, and at 3 months after surgery. The differences over the 3 time points were compared with a 2-df test; the individual time points could then be compared by use of a mixed model approach if the differences were significant. Data were analyzed with the use of SAS 9.0 Software (SAS Institute Inc, Cary, NC). Differences were considered significant at values of $P<0.05$.

### Results

**Operative Data**

Placement of the single-branched stent graft into the true lumen of the proximal descending aorta and the left subclavian artery from the transected proximal aortic arch was technically successful in all 26 patients, and could easily be finished within 1 to 3 minutes. All implanted single-branched stent grafts were in a good position with wide expansion, which was confirmed on postoperative chest x-ray films. Complete resection and sealing of the targeted entry sites with our procedure were confirmed by intraoperative transesophageal echocardiography.

Reinforcement of the dissected arch vessel stump with open placement of the stent graft into the true lumen was successfully performed in all 49 dissected arch vessels (26 innominate and 23 left common carotid arteries) and was completed within 1 minute. Wide expansion of the stent graft was observed on the postoperative chest x-ray films.

The mean cardiopulmonary bypass time was 161.62±11.59 minutes; aortic cross-clamp time was 95.35±7.60 minutes; selective cerebral perfusion was 40.85±3.13 minutes; and lower-body arrest time was 31.69±2.78 minutes.

Concomitant procedures included aortic valve repair in 9 patients, aortic valve replacement in 1 patient, Bentall procedure in 1 patient, sinus of Valsalva reconstruction in 17 patients, and coronary artery bypass graft in 1 patient.

**Morbidity**

We did not encounter any difficult bleeding after the anastomoses. Hemostasis was not a problem in any patient, and the time for chest closure was 91.65±10.11 minutes. No patient required reopening to correct excessive bleeding. There were no postoperative neurological complications such as coma or paraplegia, and there was no recurrent or phrenic nerve palsy or malperfusion of organs. No pulmonary complications were observed in 26 patients. The postoperative mechanical ventilation support period was 18.00±2.95 hours; the time in the intensive care unit was 62.00±8.79 hours. Postoperative mediastinitis occurred in 1 patient, who fully recovered after 1 month of treatment with mediastinal washing, irrigation, and drainage.

During the 2-year study period, 59 patients with acute type A dissection underwent conventional surgery (graft replacement of the ascending aorta and proximal arch). The complications after conventional surgery included 3 surgical deaths, 3 cerebral complications, 4 respiratory complications, 2 episodes of hemothorax, and 1 reexploration for bleeding. Fifty-three patients with acute type A dissection who had an indication for simultaneous replacement of the ascending aorta and total arch underwent total arch repair with an open triple-branched stent graft. In this group, there were 2 surgical deaths, 3 cerebral complications, 3 episodes of hemothorax, 1 respiratory complication, and 1 tracheotomy. Five patients who had an indication for the simultaneous replacement of the ascending aorta and total arch but were not eligible for open placement of a single-branched stent graft because neither the innominate nor the left common carotid artery was involved in the dissection or these vessels were completely transected at sites above the dissection. No postoperative complications occurred in these 5 patients.

**Computed Tomography**

Postoperative computed tomography showed that all implanted single-branched stent grafts and arch vessel stent grafts were fully opened and not kinked, and there was no space or blood flow surrounding all stent grafts. Complete thrombus obliteration of the false lumen in the descending thoracic aorta was observed.

At the diaphragmatic level, there was complete thrombus obliteration of the false lumen in the descending thoracic aorta distal to the single-branched stent graft in 22 of 26 patients at their first and second postoperative scans. The diameter of the dissected aorta at this level was 29.65±2.10 mm preoperatively, 27.88±1.97 mm before discharge, and 26.84±1.54 mm at 3 months after surgery. A significant change in the diameters at this level over the 3 time points was found ($P<0.05$). Compared with the preoperative diameter of the dissected aorta, diameters before discharge and at 3 months after surgery were decreased significantly ($P<0.05$ for each). However, there was no significant change in the diameter of the dissected aorta between before discharge and at 3 months after surgery ($P=0.22$).

At the level of the superior mesenteric artery, a patent false lumen was observed in the first and second postoperative...
computed tomographic scans in all patients. The diameter of the dissected aorta at this level was 26.19±2.23 mm preoperatively, 25.85±1.78 mm before discharge, and 25.23±1.77 mm at 3 months after surgery. The diameters of the dissected aorta at this level preoperatively, before discharge, and at 3 months after surgery were not significant different (P=0.20). The diameter of the false lumen was 15.12±1.82 mm preoperatively, 8.96±2.27 mm before discharge, and 8.42±1.77 mm at 3 months after surgery. A significant difference in the diameters of the false lumen at this level over the 3 time points was found (P<0.05). Compared with the diameter of the false lumen preoperatively, diameters before discharge and at 3 months after surgery were decreased significantly (P<0.05). However, there was no significant change in the false lumen diameter between before discharge and at 3 months postoperatively (P=0.19).

Follow-Up
All patients were discharged from the hospital and followed up until death or the end date of this study (October 2010). The follow-up period ranged from 4 to 26 months (mean, 14.31±7.48 months). Severe complications related to the surgery or residual dissection was not observed during follow-up. There was no need for reoperation owing to residual aortic dissection. One patient died of injuries sustained in a car accident 6 months after the operation. All survivors resumed normal activities. Fifteen patients remained on antihypertensive therapy.

Discussion
In total arch replacement with the separated graft technique for acute Stanford type A aortic dissection, the left subclavian artery is usually anastomosed to the respective branch of the Dacron graft in an end-to-end fashion, and the distal aortic anastomosis is often made at the descending aorta beyond the subclavian artery. Performing these 2 anastomoses through a median sternotomy is usually very difficult and may cause phrenic or recurrent laryngeal nerve injury. Moreover, once bleeding occurs after the anastomoses, hemostasis in this deep field is difficult. With open placement of our single-branched stent graft, we avoided the left subclavian artery anastomosis and distal anastomosis at the descending aorta. We performed the distal aortic anastomosis at the proximal arch between the innominate artery and the left common carotid artery, which provided a better surgical view, and the anastomosis and hemostasis were much easier than with conventional total arch replacement. Placement of the single-branched stent graft in the descending aorta and the left subclavian artery was easily completed in 1 to 3 minutes. During the procedure, the distal arch and proximal descending aorta did not require dissection, incision, and suturing; phrenic and recurrent laryngeal nerve injury was avoided. Postoperative computed tomography showed that all implanted single-branched stent grafts were fully opened and not kinked, and there was no space or blood flow surrounding any of the single-branched stent grafts. Therefore, open single-branched stent graft placement is an effective technique to avoid left subclavian artery anastomosis and distal anastomosis at the descending aorta in total arch repair for patients with acute type A aortic dissection.

The elephant trunk technique has routinely been used in the past for total arch replacement in acute type A aortic dissection. To facilitate implantation into descending aorta and to avoid any kinking or flapping, a stented elephant trunk has recently been developed. Clinical results have shown that implantation of the stented elephant trunk into the descending aorta was an effective method of closing the residual false lumen of the downstream descending aorta, and primary repair of the thoracic aorta could be achieved without distal manipulation of the left subclavian artery, which might have improved long-term outcomes. On the basis of our series, the single-branched stent graft technique was comparable to the stented elephant trunk technique in terms of closing the residual false lumen.

In acute type A aortic dissection, arch vessels are usually involved in the dissection, and arch vessel anastomosis is frequently performed at the dissected site. After an acute dissection, the dissected arch vessel wall is so fragile that the anastomosis between a dissected arch vessel stump and the graft branch often results in intraoperative or postoperative hemorrhage owing to tissue tearing at the suture lines. Reinforcement of the dissected arch vessel stump is an effective way to secure good hemostasis at the suture line. Although little has been published on reinforcement of the arch vessel stump, methods that have been widely used to reinforce the aortic stump have also been used to reinforce the dissected arch vessel stump. These methods include the placement of Teflon felt and the use of glue; however, we have found that none of these methods results in a sufficiently strong dissected arch vessel stump. Recently, the stented elephant trunk has been proven to provide not only a strong distal aortic stump but also an effective way of closing the residual false lumen of the descending aorta.

On the basis of this finding, we propose open placement of the stent graft in the dissected arch vessel stump as a neointima to reinforce the stump. In this study, we successfully placed stent grafts in all of the dissected arch vessel stumps within 1 minute. With our open stent graft placement in the arch vessel stump as a neointima, there was no problem with bleeding from the arch vessel anastomoses either intraoperatively or postoperatively. The postoperative computed tomographic scans showed no space or blood flow surrounding the arch vessel stent graft. Disappearance of the false lumen and recovery of the true lumen occurred in all dissected arch vessels. Our preliminary results demonstrated that placement of the open stent graft in the true lumen is a feasible and effective technique to reinforce the dissected arch vessel stump and to provide a good way of closing the false lumen of the dissected arch vessel. The implanted stent graft effectively made the dissected layers of the arch vessel wall conglutinate, securely closed the false lumen of the arch vessel covered by the stent graft, and interrupted backflow from the false lumen, which often is a source of bleeding at the anastomosis. Furthermore, after anastomosis of the graft branch to the arch vessel stump with incorporation of the stent graft neointima, antegrade blood leakage from the sutured anastomosis into the residual false lumen was completely prevented.

With these 2 new techniques, total arch repair for patients with acute type A aortic dissection was easier and safer. In our series, satisfactory early clinical results were achieved. During the procedure, we had no difficulties with bleeding from the anastomoses and required a short time for chest closure (mainly because of less bleeding). No patient required reopening of the chest to correct excessive postprocedural bleeding. The postop-
In total arch replacement for patients with acute type A aortic dissection, anastomoses of the graft to the left subclavian artery and descending aorta are often difficult, and the arch vessel anastomosis is frequently performed at the dissected site. To reduce such problems, we performed total arch repair for acute type A aortic dissection with 2 modified techniques: open single-branched stent graft placement into the left subclavian artery and the descending aorta and reinforcement of the dissected arch vessel stump with stent graft neo-intima. Therefore, with these 2 new techniques, total arch repair may become easier and safer for acute type A aortic dissection. Rigorous long-term follow-up and further extensive clinical trials are necessary before these 2 techniques can become a reliable alternative to conventional total arch repair for acute type A aortic dissection.

**CLINICAL PERSPECTIVE**

In total arch replacement for patients with acute type A aortic dissection, anastomoses of the graft to the left subclavian artery and descending aorta are often difficult, and the arch vessel anastomosis is frequently performed at the dissected site. To reduce such problems, we performed total arch repair for acute type A aortic dissection with 2 modified techniques: open single-branched stent graft placement into the left subclavian artery and the descending aorta and reinforcement of the dissected arch vessel stump with stent graft neo-intima. The initial clinical results show that open single-branched stent graft placement is a simple and effective technique for total arch repair that avoids left subclavian artery anastomosis and distal anastomosis at the descending aorta, and reinforcement of the dissected arch vessel stump with stent graft neo-intima is a feasible and effective technique to provide a strong dissected arch vessel stump. Therefore, with these 2 new techniques, total arch repair may become easier and safer for acute type A aortic dissection. Rigorous long-term follow-up and further extensive clinical trials are necessary before these 2 techniques can become a reliable alternative to conventional total arch repair for acute type A aortic dissection.
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