Extensive Primary Repair of the Thoracic Aorta in Acute Type A Aortic Dissection by Means of Ascending Aorta Replacement Combined With Open Placement of Triple-Branched Stent Graft

Early Results

Liang-Wan Chen, MD; Xiao-Fu Dai, MD; Lin Lu, MD; Gui-Can Zhang, MD; Hua Cao, MD

Background—To simplify extensive primary repair of the thoracic aorta in acute type A aortic dissection, we developed the open triple-branched stent graft placement technique. The early results of this new technique are reported.

Methods and Results—Between June 2008 and November 2009, 30 patients with acute Stanford type A aortic dissection underwent extensive primary repair of the thoracic aorta by means of ascending aorta replacement combined with open placement of triple-branched stent graft. Placement of the triple-branched stent graft into the true lumen of the descending aorta, arch, and 3 arch vessels was technically successful in all patients. The mean cardiopulmonary bypass time, aortic cross-clamp time, and lower body arrest time were 151.8±16.69, 84.1±6.97, and 31.17±5.34 minutes, respectively. The postoperative mechanical ventilation support period and duration of intensive care unit stay were 17.93±2.35 and 62.10±9.24 hours, respectively. All implanted stent grafts were fully opened and not kinked; there was no space or blood flow surrounding the triple-branched stent graft and no sidearm graft stenosis or occlusion. The false lumen of the descending aorta distal to the stent graft closed with thrombus in 25 of 30 patients at their first postoperative scans and in 26 of 30 at the 3-month postoperative scan.

Conclusions—Open triple-branched stent graft placement is an effective technique with satisfactory early results. With this technique, extensive primary repair of the thoracic aorta may become easier and safer for acute type A aortic dissection. (Circulation. 2010;122:1373-1378.)

Key Words: aorta ▪ dissection ▪ surgery

Surgical replacement of the ascending aorta is widely accepted as the conventional treatment for acute Stanford type A aortic dissection. However, the residual dissection in the aortic arch and downstream aorta after the conventional operation still exists, and it has been proven to be an essential factor in the determination of prognosis. When continuous enlargement of the residual dissection occurs, the chances of survival might remain uncertain, and reoperation is usually inevitable. Therefore, for patients with acute type A aortic dissection who are predicted to have enlargement of residual dissection after conventional ascending replacement such as patients who are <55 years of age, those with Marfan syndrome, or those who have intimal tear in the arch or proximal descending aorta, extensive primary repair of the thoracic aorta is desirable if it can be performed safely.

Clinical Perspective on p 1378

Extensive primary repair of the thoracic aorta is highly invasive if it is performed with the conventional method, which makes the risk of this procedure very high in patients with acute type A aortic dissection. Recently, Kato and coworkers developed a hybrid technique in which the ascending aorta and aortic arch were replaced with a 4-branched graft and a conventional straight stent graft was implanted into the descending aorta for acute type A aortic dissection. This hybrid technique not only provided easy management of the distal aortic anastomosis but also was an effective way to close the residual false lumen of the descending aorta. It could be a safe procedure to complete extensive primary repair of the thoracic aorta and might contribute to better long-term outcomes for acute type A aortic dissection. Therefore, this hybrid technique has been accepted as the preferred surgical treatment for acute type A aortic dissection when extensive thoracic aorta repair is needed. However, the hybrid technique of Kato et al is still a far more complex procedure than conventional ascending replacement, mainly because it still requires careful manipulation of the arch and elaborate anastomoses to the distal arch and 3 arch vessels.
In an effort to simplify extensive primary repair of the thoracic aorta, we developed a simple open triple-branched stent graft (branched 1-piece stent graft) placement technique in which extensive primary repair of the thoracic aorta could be performed simply by both open placement of the triple-branched stent graft into the proximal descending aorta, arch, and 3 arch vessels and graft replacement of the ascending aorta. We describe the initial clinical results of our application of this new technique in 30 patients with acute type A aortic dissection.

Methods

Patients

From June 2008 through November 2009, 30 patients (21 men and 9 women) with acute Stanford type A aortic dissection underwent extensive primary repair of the thoracic aorta by means of ascending aorta replacement combined with open placement of triple-branched stent graft. The ethics committee of Union Hospital approved the experimental procedure. We obtained written informed consent from each patient. The average age of those patients was 47.50±9.22 years (range, 25 to 65 years). The diagnosis was based on electric-beam computed tomography and echocardiography. The primary intimal tears were located in the ascending aorta in 16 patients, in the arch in 3 patients, and in the proximal descending aorta with retrograde extension of the dissection into the arch and the ascending aorta in 11 patients. Ten patients had classic Marfan diseases; 14 patients had hypertension without effective control. There were some preoperative dissection-related complications, including aortic valvular regurgitation in 12 patients, cardiac tamponade in 5, transient ischemia in 3, and acute renal dysfunction in 2. The intervals from the onset of pain to the beginning of the operations varied from 1 to 11 days, with an average of 4.17±2.48 days. All operations were performed within 4 hours after the diagnosis was confirmed.

The 30 patients were selected for extensive primary repair of the thoracic aorta by means of ascending aorta replacement combined with open placement of triple-branched stent graft because they satisfied following inclusion and exclusion criteria. The indications of the extensive primary repair of the thoracic aorta were acute Stanford type A aortic dissection with (1) the intimal tear located in transverse arch or proximal descending aorta that could not be resected by hemiarch replacement, (2) serious involvement of the arch vessels, (3) Marfan syndrome, and (4) age <55 years. Patients scheduled for the extensive primary repair of the thoracic aorta were selected for the open triple-branched stent graft placement technique if the diameters of the native aortic arch and arch vessels and the distances between 2 neighboring arch vessels (measured by preoperative 3-dimensional computed tomography) matched the corresponding sizes of the triple-branched stent graft available. The diameters of the native aortic arch and arch vessels were 10% to 20% smaller than the diameters of the corresponding stent grafts, and the distances between 2 neighboring arch vessels were equal to the distances between 2 corresponding sidearm stent grafts. The following preoperative and intraoperative exclusion criteria for open placement of triple-branched stent graft were applied: history of carotid artery disease, acute type A aortic dissection with arch or proximal descending aortic aneurysm, and all 3 arch branch ostia that could not been seen clearly from the arch true lumen through the transverse incision of the distal ascending aorta.

During the same 18-month period, 21 patients with acute type A dissection who were excluded from extensive primary repair of the thoracic aorta underwent conventional graft replacement of the ascending aorta or the ascending aorta with proximal arch. In another 13 patients who had indications for extensive primary repair of the thoracic aorta but could not satisfy the inclusion and exclusion criteria of open placement of triple-branched stent graft, extensive repair of the thoracic aorta with the hybrid technique of Kato et al.9,10 was performed.

Description of the Device

The triple-branched stent graft was a branched 1-piece graft consisting of a self-expandable nitinol stent and polyester vascular graft fabric (Yuhengjia Sci Tech Corp Ltd, Beijing, China; Figure 1A). It comprised a main graft and 3 sidearm grafts. The main graft was tapered and flexible enough to conform to the curved aortic arch. The tapered main graft was 145 mm in length, 30 mm in proximal diameter, and 26 mm in distal diameter. At its proximal end, there was a 10-mm-long stent-free sewing Dacron tube. The first sidearm graft was 35 mm long and 14 or 16 mm in diameter. Both the second and third sidearm grafts were 25 mm long and 12 or 14 mm in diameter. The distance between 2 neighboring sidearm grafts was 3 mm. The main graft and 3 sidearm grafts were individually mounted on 4 catheters and restrained by 4 silk strings.

Operative Technique

All procedures were performed with patients under general anesthesia. The arterial blood pressure of both the upper and lower limbs was monitored, and a probe for transesophageal echocardiographic monitoring was inserted.

Median sternotomy was performed and cardiopulmonary bypass was established by 2 venous cannulas through the right atrium and 2 arterial return cannulas placed in the femoral and right axillary arteries. Cardiopulmonary bypass flow was maintained between 2.4
and 2.6 L·min⁻¹·m⁻². Myocardial protection was achieved by multiple administrations of cold blood cardioplegia (4°C).

During core cooling, the innominate and left common carotid arteries were clamped at the base of the innominate artery and transected just above the sinotubular junction. Proximal manipulations such as aortic valve repair and sinus of Valsalva reconstruction were performed. The transected proximal stump of the ascending aorta was reconstructed by both inner and outer Teflon felts, and subsequently continuous anastomosis to the 1-branched Dacron tube graft was made.

When core cooling to a 22°C rectal temperature was achieved, selective cerebral perfusion via the right axillary artery was established at a rate of ~10 to 15 mL·kg⁻¹·min⁻¹, and perfusion to the lower body was discontinued. After we cross-clamped the left common carotid artery (4 cm above the arch) and innominate artery (5 cm above the arch), we transected the ascending aorta at the base of the innominate artery. Through the transverse incision of the ascending aorta, the main graft of the triple-branched stent graft was inserted into the true lumen of the arch and proximal ascending aorta, and then each sidearm graft was positioned one by one into the aortic branch. Once the main graft and sidearm grafts were properly positioned, the restraining strings were withdrawn and then the main graft and sidearm grafts were deployed. Finally, the main graft and sidearm grafts were dilated with balloon catheters under the guidance of transesophageal echocardiography to confirm that they were fully opened and not kinked. The transected distal stump of the ascending aorta was reconstructed by the inner proximal stent-free Dacron tube of the main graft and outer Teflon felt, and subsequently continuous anastomosis to the 1-branched Dacron tube graft was made in an end-to-end fashion. The air was carefully flushed out from the triple-branched stent graft with femoral and right axillary blood return. Then, antegrade systemic perfusion from the branch of the Dacron tube graft was started, and the patient was rewarmed.

Follow-Up
All patients were contacted by telephone or direct interviews in our department. All patients were followed up prospectively by means of contrast-enhanced computed tomographic scan and echocardiographic examination on the following schedule: before discharge, 3 months after the operation, 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 computed tomographic scan. Methods used to measure those diameters are described in the literature.¹⁰

Statistical Analysis
Continuous data are expressed as mean±SD. The diameters of the dissected aorta and false lumen were collected for statistical analysis. All data were approximately normally distributed. A repeated-measures mixed-effect model was used to compare the diameters of the dissected aorta and false lumen in the preoperative period, before discharge, 3 months after the operation, and annually thereafter.

The differences over the 3 time points were compared with a 2-df test; the individual time points could be compared if the differences were significant. Data were analyzed with SAS 9.0 software (SAS Institute Inc, Cary, NC). Differences were considered significant at *P<0.05.*

Results
Operative Data
Placement of the triple-branched stent graft into the true lumen of the proximal descending aorta, arch, and 3 arch vessels was technically successful in all 30 patients and could be finished within 3 to 6 minutes. Postoperative chest x-rays showed that all placed triple-branched stent grafts had good position and wide expansion. Complete resection and sealing of the targeted entry sites were confirmed by intraoperative transesophageal echocardiography. Concomitant procedures were aortic valve repair in 9 patients, aortic valve replacement in 3 patients, and sinus of Valsalva reconstruction in 19 patients.

The mean cardiopulmonary bypass time was 151.80±16.69 minutes; aortic cross-clamp time was 84.10±6.97 minutes; and selective cerebral perfusion and lower-body arrest time was 31.17±5.34 minutes. The time for chest closure was 91.67±12.54 minutes.

Morbidity
We did not encounter any difficult bleeding from aortic anastomoses. No patient required additional surgery to correct excessive postprocedural bleeding. Transient neurological dysfunction was observed in 1 patient, who fully recovered within 5 days. Temporary hemodialysis was performed in 2 patients who had preoperative acute renal failure. No pulmonary complication resulted, and postoperative hoarseness did not occur in those patients. The postoperative mechanical ventilation support period was 17.93±2.35 hours. The duration of intensive care unit stay was 62.10±9.24 hours.

Computed Tomographic Scans and Echocardiographic Study
The postoperative computed tomographic scans and echocardiographic examinations showed that all stent grafts were fully opened and not kinked; there was no space or blood flow surrounding the triple-branched stent graft (Figure 2). No sidearm graft stenosis or occlusion was found, but a slight increase in flow velocity (<2.5 m/s) in 1 sidearm graft (the first sidearm) was seen (Figure 3). During follow-up, the flow velocity did not increase further.

At the diaphragmatic level, the false lumen of the descending aorta distal to the stent graft closed with thrombus in 25 of 30 patients at their first postoperative scans and in 26 of 30 at the 3-month postoperative scan. The diameter of the dissected aorta at this level was 29.33±2.38 mm preoperatively, 27.60±2.55 mm before discharge, and 26.83±2.34 mm at 3 months postoperatively. Statistical analysis demonstrated a significant...
difference in diameters at this level over the 3 time points ($P<0.05$). Compared with the preoperative data, diameters before discharge and at 3 months postoperatively were decreased significantly ($P<0.05$ for each), but there was no significant change between the predischarge and 3-month postoperative diameters ($P=0.2188$).

At the level of the superior mesenteric artery, a patent false lumen was observed in all patients' first and second postoperative computed tomographic scans. The diameter of the dissected aorta at this level was $26.23\pm2.54$ mm preoperatively, $26.03\pm2.38$ mm before discharge, and $25.90\pm2.31$ mm at 3 months postoperatively. The diameters of the dissected aorta at this level preoperatively, before discharge, and 3 months postoperatively were not significantly different ($P=0.8302$). The diameter of the false lumen was $15.17\pm2.10$ mm preoperatively, $9.00\pm2.39$ mm before discharge, and $8.27\pm1.93$ mm at 3 months postoperatively. Statistical analysis demonstrated a significant difference in the diameters of the false lumen at this level over the 3 time points ($P<0.05$). Compared with the diameter of the false lumen preoperatively, diameters before discharge and at 3 months postoperatively were decreased significantly ($P<0.05$ for each), but there were no significant changes between the predischarge and 3-month postoperative diameters ($P=0.1896$).

**Follow-Up**

All patients were discharged from the hospital and followed up to the end date of this study (February 2010). The follow-up was 100% complete. The mean follow-up period was $7.60\pm4.61$ months (range, 3 to 20 months). There were no late deaths and no need for reoperation. All patients resumed normal life. Nineteen patients accepted only antihypertensive therapy.

**Discussion**

Endovascular stent graft placement has widely been confirmed as an effective aortic repair technique for acute aortic dissection, which can seal off the intimal tear and lead to quick clot formation and shrinkage of the false lumen. Our technique was designed to repair the proximal descending aorta, arch, and 3 arch vessels simultaneously by the simple open placement of triple-branched stent graft into the descending aorta, arch, and 3 arch vessels instead of direct surgical repair. In this study, we successfully applied our open triple-branched stent graft placement technique combined with graft replacement of the ascending aorta in extensive primary repair of the thoracic aorta in 30 patients with acute type A aortic dissection. Placement of these triple-branched stent grafts into the descending aorta, arch, and 3 arch vessels was easily finished in 3 to 6 minutes during the procedure. Most patients had an uneventful postoperative course and were discharged from hospital without complications. Their postoperative computed tomographic scans showed that all stent grafts were fully opened and not kinked; there was no space or blood flow surrounding the triple-branched stent graft and no sidearm graft stenosis or occlusion. Open placement of the conventional straight stent graft into descending aorta in the hybrid technique of Kato et al has been proven to be an effective way of closing the residual false lumen of the descending aorta. In our series, both the scope of the repaired thoracic aorta and the short-term outcome of residual false lumen of our technique were comparable with the hybrid technique. These preliminary results demonstrated that the open triple-branched stent graft placement is a feasible and effective technique for extensive primary repair of the thoracic aorta in acute type A aortic dissection.

The purpose of our technique is to obtain extensive primary repair of the thoracic aorta for acute type A aortic dissection with less invasiveness. In the hybrid procedure of
Kato et al, careful manipulation of the arch and elaborate anastomoses to the distal aortic arch and 3 arch vessels are time-consuming and could induce phrenic and recurrent laryngeal nerve injury. Moreover, performing anastomosis and hemostasis at the descending aorta and the left subclavian artery is usually very difficult, mainly because of the deep surgical field. Our open triple-branched stent graft placement technique can reduce such problems. In our technique, extensive primary repair of the thoracic aorta could be performed simply by both open placement of the triple-branched stent graft into the proximal descending aorta, arch, and 3 arch vessels and graft replacement of the ascending aorta, which could reduce the risk and technical difficulties of extensive thoracic aorta repair to close to those of the conventional ascending graft replacement with open distal anastomosis. Therefore, in our series, cardiopulmonary bypass time, aortic cross-clamp time, and selective cerebral perfusion and lower body arrest time were shorter than in the Kato et al hybrid technique seen in previous reports and were comparable to those of conventional ascending replacement with open distal aortic anastomosis.

Postoperative bleeding is still one of the most devastating complications of the surgical management of acute aortic dissection, mainly because the aortic wall is friable after an acute dissection and blood coagulability is decreased after dissection and a long time on cardiopulmonary bypass. With our open triple-branched stent graft placement, we have observed a short time for chest closure (mainly because there was less bleeding) and did not encounter any difficult bleeding from aortic anastomoses. No patient required additional surgery to correct excessive postprocedural bleeding. Three reasons might contribute to this consequence. First, anastomoses to 3 arch vessels were totally avoided. Second, we performed the distal aortic anastomosis at the distal ascending aorta, which provided a better surgical view for performing anastomosis and hemostasis. Finally, shorter time on cardiopulmonary bypass contributed to the quick recovery of postoperative blood coagulability.

With our open triple-branched stent graft placement, all patients had a short time on postoperative mechanical ventilation and a short stay in the intensive care unit. These results seemed to be associated with the reduced invasiveness of our technique. Recurrent nerve injury after arch surgery is reported to be an independent predictor of postoperative pulmonary complications and leads to a longer hospital stay. Postoperative vocal cord paralysis was not observed in our patients, mainly because the dissection, incision, and sutures of the distal arch and the descending aorta were not necessary and thus recurrent nerve injury was avoided.

Moderate hypothermia (22°C) combined with cold selective antegrade cerebral perfusion via the right axillary artery was applied for cerebral protection in our patients with satisfactory results. Right axillary artery cannulation for both extracorporeal circulation and antegrade cerebral perfusion has been performed routinely in our dissection surgical practice, mainly because it is rarely involved in dissection. Transient neurological dysfunction was observed in 1 patient, who fully recovered within 5 days. These results suggest that our hypothermic antegrade selective cerebral perfusion for brain protection is effective in those patients. The morbidity of cerebral disorders in those patients was low compared with that in the literature, probably because our patients were relatively young, and the atherosclerotic changes in the aortic wall were not severe.

Postoperative computed tomographic scans showed that all sidearm stent grafts were fully opened and not kinked; there was no sidearm stent graft endoleak. For these good results, diameters of the 3 sidearm grafts, distances between 2 neighboring sidearm grafts, and proper placement of the triple-branched stent grafts were crucial. The proper size of each graft was key for quick clot formation and shrinkage of the false lumen and for preventing new intimal trauma resulting from the continuous compression of the oversized stent graft on the dissected and frangible intimal wall. For each patient, the diameters of the selected grafts should be 10% to 20% bigger than the diameters of the native aortic arch and arch vessels, respectively. The distances between 2 neighboring sidearm grafts should be equal to the distances between 2 corresponding arch vessels, which would keep sidearm stent grafts from being twisted or kinked after deployment. Some potential complications might occur during deployment of the stent graft. Blind insertion of the stent graft posed the risk of creating a new intimal tear. To prevent this, we performed the interpolation and dilation procedures carefully, usually under transesophageal echocardiography guidance.

In this study, no sidearm graft stenosis or occlusion was observed. A slight increase in flow velocity (<2.5 m/s) in 1 sidearm graft was found, but the flow velocity did not increase further during follow-up. These results demonstrate that our sidearm grafts had a good short-term patency. The long-term patency of those sidearm grafts should be carefully evaluated. However, it is expected to be satisfactory because simple endovascular stenting for cervical branch provides satisfactory patency even in stenotic obstructive pathologies.

Endovascular stent graft has been proven to have poor outcome in Marfan patients because fixation zones for endografts are prone to future dilation and endoleaks resulting from the continuous compression of endografts on the weakened abnormal aortic wall in those patients. Therefore, endovascular stent graft is not the recommended management of aortic dissection in Marfan patients. However, open placement of stent graft was routinely performed in the Kato et al hybrid procedure for Marfan patients. The usual purpose of open stent graft placement in Marfan patients was to obtain easy management of the distal anastomosis and to make late thoracoabdominal aortic replacement safer because it would be easier to carry out the anastomosis between the distal end of the stent graft and Dacron prosthesis. During follow-up, some satisfactory results were found. Open placement of a stent graft in descending aorta in Marfan patients with acute type A aortic dissection resulted in less late dilation of the dissected descending aorta, which prolonged the reoperation interval or reduced the number of late thoracoabdominal aortic replacements. Two major advantages of open stent graft placement over endovascular stent graft technique might contribute to this consequence. First, in the open stent graft placement technique, the transected distal stump of the aorta was reconstructed by the inner proximal end of the stent graft and outer Teflon felt and subsequently anastomosed to the Dacron tube graft, which decreased the risk of dangerous endoleaks. Attachment to the aortic wall of the endograft was
achieved only by the radial force of the stent graft in patients undergoing endovascular stent graft treatment. Second, open placement of the stent graft was performed under lower body hypothermic circulatory arrest, which avoided injury to the aortic wall resulting from endografting under aortic pulsation. Enlightened by these findings, we performed open triple-branched stent graft placement in 10 Marfan patients. During the follow-up, no endoleak or false aneurysm was found in the Marfan patients. Although our early results in Marfan patients appear to be acceptable, long-term effectiveness remains to be demonstrated. The true success of stent graft repair is determined by long-term results; therefore, rigorous long-term follow-up and further extensive clinical trials are needed before open triple-branched stent graft placement can become the primary treatment in Marfan patients.

Conclusions
Open triple-branched stent graft placement is a simple and effective technique with satisfactory early results. With this technique, extensive primary repair of the thoracic aorta may become easier and safer for acute type A aortic dissection. Careful long-term follow-up and further extensive clinical trials are necessary before this technique can become a recommended alternative to surgical extensive primary repair of the thoracic aorta for acute type A aortic dissection.

Disclosures
None.

References

CLINICAL PERSPECTIVE
In surgical extensive primary repair of the thoracic aorta for acute type A aortic dissection, careful manipulation of the arch and elaborate anastomoses to the distal arch and 3 arch vessels are time-consuming and could induce phrenic and recurrent laryngeal nerve injury. Our results suggest that extensive primary repair of the thoracic aorta for acute type A aortic dissection can be performed simply by both open placement of the triple-branched stent graft into the proximal descending aorta, arch, and 3 arch vessels and graft replacement of the ascending aorta, which can reduce the risk and technical difficulties of extensive thoracic aorta repair to close to those of the conventional ascending graft replacement with open distal anastomosis. Therefore, with open placement of triple-branched stent graft, extensive primary repair of the thoracic aorta may become easier and safer for acute type A aortic dissection. Careful long-term follow-up and further extensive clinical use are necessary to completely evaluate the efficacy of this new technique.
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Liang-Wan Chen, Xiao-Fu Dai, Lin Lu, Gui-Can Zhang and Hua Cao

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