Secondary surgical procedures after endovascular stent grafting of the thoracic aorta: Successful approaches to a challenging clinical problem

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Objective: To evaluate the results of open surgical repair for complications after endovascular thoracic aorta stenting.

Methods: A total of 14 patients (8 male, mean age 59.8 ± 14.8 years) underwent conventional surgical therapy at our institution over a 5-year period after previous thoracic aortic stent implantation. The indications for surgery, intraoperative strategy, and perioperative and follow-up results were analyzed.

Results: The indication for stent implantation was type B aortic dissection in 10 patients, expanding degenerative thoracic aneurysm in 3 patients, and pseudoaneurysm in 1 patient. The median interval to conventional surgery after stent implantation was 4.5 months (range 0.1–49 months). The indication for surgery was persistent type I endoleak with progressive aneurysm enlargement in 7 patients, aorto-esophageal fistula in 2 patients, retrograde type A dissection in 2 patients, infection of the endoprosthesis in 2 patients, and aortic valve insufficiency caused by perforation of noncoronary and right coronary cusps in 1 patient. The endograft had to be removed in 9 (64%) patients, and 5 (36%) patients required replacement of the thoracoabdominal aorta. In-hospital mortality was 7% (1 patient). No patients had a postoperative stroke or paraparesis. Eleven (79%) patients are alive after a mean follow-up of 13.5 ± 10.1 months (range 1–36 months).

Conclusions: Secondary surgical procedures after stenting of the thoracic aorta can be performed with very good results, despite the challenging clinical scenarios. Identification of successful surgical strategies for this difficult clinical problem is important in the era of increasing endovascular therapy.

Since its introduction in the early 1990s,¹ endovascular treatment of the descending thoracic aorta has become the most important therapeutic option for high-risk patients with thoracic aortic disease. The increasing use and growing expertise in this field stimulated the expansion of indications to a wide spectrum of aortic diseases, although the long-term results of thoracic endografting are still unknown.² The limitations and late complications associated with endovascular therapy have become increasingly evident over time.²⁻⁶ However, relatively little is known about late complications of endovascular stenting because of their fairly recent clinical introduction and because few centers have a large clinical experience. Some groups have reported conventional surgical procedures for complications associated with endovascular therapy, but the conclusions from these studies are limited by their small sample sizes.^{3,7-9} In this publication, we present our experience with secondary surgical procedures after thoracic aortic stenting.

METHODS

A total of 194 patients underwent thoracic aortic stenting at our institution and 14 (7.2%) patients (8 male, mean age 59.8 ± 14.8 years) required subsequent open surgical procedures between July 2002 and August 2007. Surgical strategies and perioperative and medium-term results were analyzed.

Endovascular Procedures

The indications for endovascular stent graft treatment of the thoracic aorta included type B aortic dissection in 10 patients (acute in 1 and chronic in 9), expanding degenerative thoracic aortic aneurysm in 3 patients (with contained rupture in 2 patients), and pseudoaneurysm in 1 patient. All patients with chronic type B aortic dissection had progressive dilatation of the perfused false channel in the descending thoracic aorta. The indication for endovascular therapy in acute type B dissection was subtotally narrowed true channel at the level of the lower abdominal aorta with signs of peripheral malperfusion. Four different stent graft systems were used over the study period: Talent (Medtronic Vascular, Santa Rosa, Calif) in 8 patients, Excluder (TAG; W. L. Gore & Associates, Inc, Flagstaff, Ariz) in 2 patients, Endofit (Endomed, Inc, Phoenix, Ariz) in 2 patients, and Valiant (Medtronic Vascular) in 2 patients. The proximal landing site was distal aortic arch (ie, proximal to the left subclavian artery) in 8 patients and descending thoracic aorta in 6 patients. Three patients required more than 1 stent graft implantation at the time of primary endovascular intervention. Secondary endovascular procedures were performed in 2 patients for persistent type I endoleaks 1 and 4 months after the primary intervention.

Indications for Surgery

The indications for secondary conventional surgical procedures included progressive enlargement of the aneurysm sac with a type I endoleak in 7 patients, retrograde type A aortic dissection in 2 patients, aorto-esophageal fistula in 2 patients, infection of the endoprosthesis with sepsis in 2 patients,

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Abbreviation and Acronym

CT = computed tomography

and significant aortic valve insufficiency after perforation of the noncoronary and right coronary cusps in 1 patient. The operation was performed on an emergency basis in 7 patients.

Surgical Procedures

The surgical technique used was dependent on the type of aortic disease (see below). Full cardiopulmonary bypass or isolated left heart bypass were used in all patients. The axillary artery was directly cannulated in most patients requiring surgery on the aortic arch. Selective antegrade cerebral perfusion was performed in most of these patients by clamping the brachiocephalic artery and by inserting a perfusion catheter into the left common carotid artery. The head was packed externally in ice during circulatory arrest.

In the 2 patients with retrograde type A dissection, diagnosed 1 week and 4 months after the endovascular procedure, a median sternotomy was performed. The aortic root procedure was performed during systemic cooling. When the systemic temperature reached 23°C, circulatory arrest was induced and antegrade selective cerebral perfusion was initiated. The distal aorta was trimmed to the level of the stent graft and an elephant trunk anastomosis, incorporating aortic wall and proximal edge of the stent graft, was accomplished. The supra-aortic orifices were implanted into the prosthesis as a Carrel patch.

In 2 patients with type Ia endoleak and isolated enlargement of the distal arch/proximal descending aorta, surgery was conducted in the same manner as described above. This approach via a median sternotomy was chosen

only if the distal aorta was confirmed to have no endoleak and no enlargement on serial computed tomographic (CT) scans. For better exposure of the proximal descending aorta, the incision was extended superiorly in a left anterolateral direction. One patient had two previous endovascular reinterventions for type Ia endoleak with the proximal endograft extension abutting directly onto the bicarotid trunk (Figure 1). The uncovered end and proximal branches of the stent graft were removed during surgery to produce an adequate anastomotic line, which was performed with an elephant trunk technique as described above.

The patient with aortic insufficiency caused by leaflet perforation was operated on 3 days after the endovascular procedure via an upper L-shaped ministernotomy. Perforation of the noncoronary and right coronary cusps with adjacent tissue hematoma was confirmed intraoperatively, presumably caused by guidewire manipulation. Aortic valve reconstruction with an autologous pericardial patch could be successfully performed.

Open repair was required in 2 patients because of stent graft infection 3.5 months and 1.5 months after the endovascular procedure. The first patient had recurrent sepsis and a positive white blood cell scan. Because of the stent graft position in the mid-descending aorta extending to the diaphragm, a thoracoabdominal incision was used. Left heart bypass was performed with mild hypothermia (32°C) via cannulation of the femoral vessels. The whole descending aorta along with the infected endoprosthesis was removed and backbleeding intercostal arteries were oversewn. A silver-coated woven 22-mm Vascutek prosthesis (Sulzer Medica Ltd, Renfrewshire, Scotland) was used. The second patient had hemodynamic collapse necessitating cardiopulmonary resuscitation (CPR) 1 day before the operation, with documented migration of the stent graft and rupture of the distal aortic arch/proximal descending aorta (Figure 2). Because of the proximal location of the endoprosthesis and the presence of concomitant coronary artery disease, a clamshell incision was performed. The distal arch and descending aorta were replaced with the aid of circulatory arrest at 24°C using an extra-anatomically (ie, retrocardially) positioned Dacron prosthesis. Inspection of the

FIGURE 1. Persistent type Ia endoleak after two endovascular reinterventions.

FIGURE 2. Mycotic aortic aneurysm after stent graft implantation.

ruptured aneurysmal sac revealed a distally migrated stent with complete leakage of the posterior aortic wall. Both ends of the blind aneurysmal sac were oversewn and a saphenous vein bypass graft to the right coronary artery was performed during rewarming.

Two patients underwent emergency surgery for aorto-esophageal fistula 49 and 3.5 months after endovascular intervention. The first patient was brought to our hospital with massive hematemesis and cardiopulmonary resuscitation with blood aspiration, and surgery was performed under emergency, extremely high-risk conditions. Because of the proximal location of the stent graft, a median sternotomy with left anterolateral extension into the second intercostal space was chosen. The distal elephant trunk anastomosis was performed to the mid-descending thoracic aorta after completely removing the stent under hypothermic circulatory arrest (22°C). Inspection of the esophagus showed a wall defect 2.5 cm in diameter, which was closed with interrupted sutures and covered with an autologous pericardial patch. The patient had to be reoperated on for recurrent esophageal leakage with signs of mediastinitis 2 weeks after the initial operation. He was treated by an esophagectomy with closure of the distal esophageal stump and cervical esophagostomy. The second patient with an aorto-esophageal fistula was referred from a peripheral hospital 3.5 months after stent graft placement for contained rupture of a distal descending aneurysm. The gastroscopy and CT scan (Figure 3) demonstrated stent graft protrusion through the anterior aortic wall into the esophagus. Surgical exposure was achieved through a thoracoabdominal incision. After removal of the endoprosthesis, the descending aorta was replaced with a Dacron vascular graft. Resection of the perforated esophageal segment (Figure 3) with oversewing of the

proximal and distal stumps was performed at the first stage. Esophageal continuity was restored 7 days later with a gastric pull-up procedure.

The remaining 5 patients with chronic type B dissection were operated on for persistent type I endoleak associated with continuous enlargement of the whole thoracoabdominal aorta. Four of these patients had residual false channel perfusion directly after stent implantation and 1 patient had a secondary type Ib endoleak. A thoracoabdominal incision was used for surgical exposure in all cases. Cerebrospinal fluid drainage to minimize the risk of paraplegia was used routinely, with a goal to keep the pressure below 10 cm H₂O. Three patients required circulatory arrest because of proximal extension of the stent graft into the aortic arch (ie, directly adjacent to the origin of the left carotid artery). Circulatory arrest was induced at 22°C while the aorta was crossclamped on the lower descending segment. The lower body was subsequently perfused at 1.0 L/min via the femoral cannula. The stents were completely removed and an open distal hemiarch replacement was accomplished with a Dacron prosthesis with a sidearm graft. Perfusion of the upper body was restored via the sidearm of the prosthesis after careful deairing of the heart and supra-aortic vessels. The abdominal aorta was replaced with a Dacron graft under selective perfusion of the abdominal organs with cold blood. Distal perfusion was reinstituted via the femoral cannula, and the proximal-to-distal prosthetic anastomosis was accomplished as the last stage. The sidearm of the proximal prosthesis was used for the reconstruction of the left subclavian artery. Two patients with the more distal location of the aortic endoprosthesis in the descending aorta were operated on with the aid of left heart bypass and mild hypothermia (32°C).

Statistical Analysis

Standard definitions were used for patient variables and outcomes. Operative mortality was defined as death during hospitalization. Categorical variables are expressed as percentages and continuous variables are expressed as mean $\pm$ SD throughout the manuscript. All statistical analyses were performed with the SPSS 14.0 software (SPSS, Inc, Chicago, Ill). Long-term survival was analyzed with the Kaplan–Meier method.

RESULTS

The median time interval between endovascular intervention and secondary surgical procedure was 4.5 months (range 3 days to 49 months). Proximal intimal tears were found in both patients with type A dissection, located in the ascending aorta in the first and in the distal arch (proximal landing zone of the stent) in the second patient. All 7 patients operated on for type I endoleak showed insufficiently sealed entry sites intraoperatively.

FIGURE 3. Protrusion of the stent graft into the esophagus.

The duration of cardiopulmonary bypass or left heart bypass was 162 ± 70 minutes. Aortic crossclamping was required in 10 patients with a mean time of 80 ± 38 minutes. Nine patients had to be operated on with the aid of circulatory arrest (mean duration 25 ± 17 minutes) at a rectal temperature of $22.3^\circ\text{C} \pm 1.1^\circ\text{C}$. Simultaneous selective antegrade cerebral perfusion was performed in 6 of these patients. The stent grafts were removed in 9 (64%) and left in situ in the remaining 5 patients.

One patient died while in the hospital, for a mortality rate of 7.1%. The predicted logistic EuroSCORE risk of mortality for the entire patient cohort was $39.4\% \pm 25.6\%$. The single patient who died was the one with aorto-esophageal fistula who required reoperation for recurrent esophageal leakage and mediastinitis. He died of septic multiorgan failure after a 39-day stay in the intensive care unit.

The median length of stay in the intensive care unit was 3 days (range 1–39 days). Four (28.6%) patients required reoperation because of excessive postoperative bleeding. The median time supported by mechanical ventilation was 26 hours (range 7–960 hours). Two patients required temporary tracheostomy for prolonged weaning from the mechanical ventilator. No new neurologic deficits (stroke or paraplegia) were observed postoperatively. Preoperative paraplegia persisted in 1 patient who was admitted with a contained rupture of the distal false channel. The hospital stay ranged from 8 to 40 days postoperatively (mean stay 20.1 ± 10.1 days). PredischARGE echocardiography in the 2 patients who underwent aortic valve repair (ie, pericardial patch repair and David procedure) revealed mild and trivial aortic insufficiency, respectively.

Follow-up information was available for all discharged patients. After a mean follow-up period of 13.5 ± 10.1 months (range 1–36 months), 11 patients were alive and doing well. No aortic reinterventions were required in any patient. A total of 2 patients died during follow-up. The first patient underwent repair of a type A dissection and died suddenly while in convalescence. No autopsy was performed. The second patient died 1.5 months after aortic arch replacement for type Ia endoleak as a result of necrotizing pancreatitis. One- and 2-year survival was $78\% \pm 11.3\%$.

DISCUSSION

With the growing number of interventional thoracic aortic procedures and liberalization of indications, the number of patients requiring open surgery after stent implantation may be increasing. Several surgical groups have reported their initial experience with open repair of different diseases of the thoracic aorta after endovascular therapy.^{2,7-9} Our own data show a tendency toward a growing incidence of secondary surgical interventions in more recent years (6 patients in 2007 compared with 3, 1, and 2 patients in the previous years). As described above, the indications for open surgery consisted of expanding aortic aneurysm, retrograde

type A dissection, infected stent graft prosthesis, aorto-esophageal fistula, and acute aortic valve insufficiency.

The reported incidence of retrograde type A dissection after thoracic stent graft implantation worldwide is approximately 1% to 2%, although some groups published a rate of 5% to 6.8%.^{3,10} Both of our patients with type A dissection underwent a prior endovascular procedure for chronic type B dissection with positioning of the proximal stent graft in the distal aortic arch.^{2,9,10} One of the 2 patients underwent endovascular reintervention for type Ia endoleak 1 month after initial stent graft deployment, with repeated balloon dilations to achieve a tight seal. It is plausible that a type A dissection in this case was triggered by repeated endoaortic manipulations (eg, wire and sheath manipulation or balloon dilatation). Furthermore, an intramural hematoma involving the aortic arch and ascending aorta could be identified on the preprocedural CT scan retrospectively, performed before the initial endovascular procedure. Intramural hematomas in the stent graft landing areas in the distal aortic arch (ie, covering the left subclavian artery) in patients with type B dissection have been reported to predispose to formation of retrograde dissection.^{2,3} Excessive angulation (70°) of the aortic arch was also noted in our patient. The second patient reported having mild nonspecific chest pain after her endovascular procedure. We were surprised to find a retrograde type A dissection on routine CT scan performed 1 week after the intervention. This finding reinforces the importance of postprocedural surveillance CT scans.

Perforation of the right and noncoronary aortic valve cusps was seen in 1 of our patients. To the best of our knowledge, such a complication has not been previously published in the literature. The cause of this adverse event was presumably guidewire manipulation during stent implantation. Fortunately, valve repair with autologous pericardial patch augmentation was successful in this 23-year-old female patient.

Two patients in our series underwent surgery for endoprosthesis infection, which was confirmed by culture of the explanted endograft and aortic thrombus (*Staphylococcus aureus* in the first and *Staphylococcus epidermidis* in the second patient). The relatively short time interval after endovascular intervention (3.5 months and 1.5 months, respectively) indicates a periprocedural infection. Moreover, both of these patients had evidence of systemic inflammatory reaction after the endovascular intervention. An extensive inflammatory process of the posterior mediastinum with contained aortic rupture required an extra-anatomic solution in 1 patient. No signs of recurrent infection have occurred in these patients during follow-up. Alternatively, thoracic aortic homografts have been successfully used in selected cases of infected thoracic aortic fabric grafts, aorto-esophageal fistulas, and other situations.¹¹

Aorto-esophageal fistula is an uncommon but well described complication after thoracic aortic stenting.^{4,5,12,13}

FIGURE 4. Type Ib endoleak after stenting of chronic type B dissection.

Suggested mechanisms leading to aorto-esophageal fistula formation are chronic endoleak leading to erosion into the adjacent esophagus, penetration of the stent graft through the aortic wall into the esophagus,⁴ and ischemic necrosis of the esophageal wall resulting from stent coverage of the arteries in the midesophageal segment.⁵ Our first patient had a stent deployed in the distal aortic arch because of descending aortic aneurysm and was monitored closely for 14 months because of secondary type Ib endoleak. Chronic endoleak was therefore the most likely mechanism of the aorto-esophageal fistula. The second patient had a documented erosion of the esophageal mucosa before stent graft implantation, which had progressed to a large esophageal ulcer (4×3 cm) 3 months after endovascular sealing of a ruptured mid-descending thoracic aortic aneurysm. This clinical scenario is suggestive of ischemic pathogenesis of the fistula. Multiple combinations of treatment options have been used to deal with aorto-esophageal fistula, including in situ arterial reconstruction, extra-anatomic bypass with concomitant primary esophageal repair, or esophagectomy with cervical esophagostomy and secondary restoration of gastrointestinal tract continuity. Conservative, nonsurgical therapy results invariably in a fatal outcome owing to massive hemorrhage or chronic mediastinitis.⁴ After having lost our first patient as a result of recurrent esophageal leakage 2 weeks after primary defect repair, we changed our surgical strategy toward a more radical approach consisting of esophageal resection and restoration of esophagogastric continuity using a gastric pull-up procedure at the second stage. Our second patient survived uneventfully.

Persistent type I endoleak with progressive increase in aneurysm size is one of the major limitations of endovascular treatment. In our series, all 7 patients operated on for type I endoleak underwent initial endovascular intervention for type B dissection (chronic dissection in 6 patients and acute in 1). Despite aggressive oversizing, primary type I endoleak was documented in 6 patients, although additional stent implantations and repeated balloon dilatations were tried to seal them during the initial procedure (Figure 4). Because of proximal stent extension into the distal aortic arch to cover the entry site close to the left subclavian artery, an extensive open repair with prolonged circulatory arrest was required to repair the aortic arch in these patients. However, it is important to note that none of the patients in our series had a perioperative stroke or new paraplegia. We believe our perioperative strategies, including selective antegrade cerebral perfusion, drainage of cerebrospinal fluid, and distal perfusion of the lower body enabled us to avoid neurologic complications in these complex aortic arch procedures.

Endovascular stent grafting is an established treatment modality of the thoracic aorta, with particular benefits in emergency situations (eg, traumatic aortic transection, ruptured descending aortic aneurysm, or complicated acute type B dissection). Chronic type B dissections have been identified through growing clinical experience to be the most challenging clinical scenario for the endovascular therapy. The reasons for the increased complexity include the need to cover the distal aortic arch, the challenging anatomic characteristics of the chronically dissected aorta (ie, subtotally narrowed true lumen and rigid intimal membrane that

prevents expansion of the true lumen), and the inability to address the abdominal segment between the celiac trunk and the renal arteries, therefore leaving untreated dissected aorta with potentially distally located re-entry sites (Figure 4). Such reasons explain the relatively high incidence of persistent endoleaks, endovascular reinterventions, and secondary surgical procedures in this patient subgroup. In our own experience, 9 (64%) of 14 open surgical procedures after endovascular therapy were required in patients with previous chronic type B dissection. This experience points out the importance of appropriate patient selection for endovascular therapy. It may therefore be necessary to re-examine the indications for endovascular therapy in chronic type B dissections, considering that conventional surgical therapy may still be required in a significant proportion of these patients. The reported rate of persistent endoleaks, endovascular reinterventions, and deaths resulting from aortic rupture after thoracic aortic endovascular therapy, even from the leading interventional groups,^{6,10,14} underscores the fact that conventional surgical therapy should not be completely abandoned in this patient population. Although endovascular repair has revolutionized aortic surgery, careful evaluation and appropriate indication for this treatment modality remain essential.

Study Limitations

The limitation of our study is the small sample size, which markedly limits the statistical analyses that can be performed. However, to the best of our knowledge, our series is the largest to date in the literature. As the number of patients undergoing thoracic endovascular therapy continues to grow over time, we believe our in-depth description of the presentation and management of these patients will provide helpful insights for clinicians who are increasingly likely to encounter these very challenging clinical problems.

CONCLUSIONS

Secondary conventional surgical procedures after thoracic aortic stenting can be performed with low perioperative and medium-term risk, despite the precarious preoperative status

and increased technical challenge presented by such patients. The precise analysis of the midterm and long-term results of endovascular therapy may identify patients who are more likely to benefit from primary conventional surgery.

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