Changes in aneurysm morphology and stent-graft configuration after endovascular repair of aneurysms of the descending thoracic aorta

Timothy Resch, MD, PhD[a]
Bansi Koul, MD, PhD[d]
Nuno V. Dias, MD[b]
Bengt Lindblad, MD, PhD[c]
Krassi Ivancev, MD, PhD[b]

Objective: We sought to study changes in morphology and stent-graft configuration of descending thoracic aortic aneurysms after endovascular repair.

Methods: Twenty-three patients treated with custom-made stent-grafts were studied. The stent-graft consisted of continuous, stainless-steel Z stents mounted within a polyester graft. In the last 11 cases the stents were interconnected with 3 longitudinal wires. Contrast-enhanced spiral computed tomography was performed preoperatively and at 1, 3, and every 6 months postoperatively. Angiography was used preoperatively and at 1-year follow-up. Proximal and distal necks were assessed for diameter and length. Aneurysm diameter, endoleaks, stent-graft migration, and changes in stent-graft configuration were evaluated.

Results: During follow-up (median, 18 months; range, 1-48 months), excluded aneurysms decreased in diameter by 4 mm (0.5-10 mm, P = .0018). Endoleaks prevented size decrease. Five patients displayed neck dilatation, 4 at both the proximal and distal fixation sites and 1 only distally. In 7 (30%) patients there was proximal migration of the distal end of the stent-graft. Three (13%) patients displayed both distal migration of the proximal end of the stent-graft and proximal migration of the distal end of the stent-graft. There was a significant correlation between stent-graft kinking and appearance of proximal or distal stent-graft migration ($P = .05$ and $P = .0007$, respectively). In no case did the migration lead to appearance of an endoleak before intervention was performed.

Conclusion: Excluded descending thoracic aortic aneurysms decrease in size on midterm follow-up. A subgroup of patients prone to neck dilatation might exist. A combination of neck dilatation and vector forces acting on stent-grafts in the tortuous thoracic aorta might lead to stent-graft migration.

From the Departments of Surgery,[a] Radiology,[b] and Vascular Surgery,[c] Malmö University Hospital, Malmö, Sweden, and the Department of Thoracic and Cardiovascular Surgery,[d] Lund University Hospital, Lund, Sweden.

Received for publication July 20, 2000; revisions requested Oct 24, 2000; revisions received Nov 13, 2000; accepted for publication Nov 14, 2000.

Address for reprints: Krassi Ivancev, Department of Radiology, Malmö University Hospital, S-205 02 Malmö, Sweden (E-mail: krassi.ivancev@rontgen.mas.lu.se).

J Thorac Cardiovasc Surg 2001;122:47-52

0022-5223/2001 $35.00 + 0 **12/1/113025**

doi:10.1067/mtc.2001.113025

Open surgical procedures are the current treatment of choice for descending thoracic aortic aneurysms (TAAs). Although improvements in surgical technique have led to reduced operative risks, open surgical procedures still carry significant morbidity and mortality.[1-3] Preliminary studies of TAA endovascular repair have indicated that this might be a less traumatic treatment alternative, especially for high-risk surgical candidates.[4-11] Despite these early promising clinical results, little is known regarding changes in morphologic characteristics of thoracic aneurysms after endovascular stent-graft repair and the implications this might have on midterm and long-term outcome. In the endovascular arena of abdominal aortic aneurysms, morphologic changes in the native aorta have been shown to have a significant effect on the durability of the aneurysm repair, and fears are that this may be valid for TAA repair as well.

In the present study we have studied morphologic TAA changes after endovascular stent-graft repair, as well as the structural integrity of the stent-graft itself.

Material and Methods

Between June 1995 and September 1999, 34 patients (17 men; mean age, 74 years; age range, 47-88 years) underwent endovascular repair of the descending TAA. During the same time period, 35 patients underwent open repair of the descending TAA. Inclusion criteria for endovascular use of stent-grafts were as follows: proximal and distal aneurysm necks greater than 15 mm in length (from the left subclavian artery to the start of the aneurysm and from the end of the aneurysm to the celiac artery, respectively) and less than 36 mm in maximum transverse diameter. All patients fulfilling the criteria underwent endovascular TAA repair. Eleven patients were excluded from this study. Six patients, of whom 4 presented with aneurysm rupture, died within the first postoperative month (massive distal embolism intraoperatively, n = 2; had unsuccessful stent-graft placement, n = 2; myocardial infarction, n = 1; secondary rupture, n = 1). Additionally, 5 patients treated for nonaneurysmal disease (aortic ulcers, n = 2; acute type B dissection, n = 2; traumatic dissection, n = 1) were also excluded. The remaining 23 patients were treated for either extensive atherosclerotic (n = 20) or chronic dissecting (n = 3) descending TAA. Median radiologic follow-up was 18 months (range, 1-48 months).

Imaging Technique

All patients underwent preoperative calibrated digital subtraction angiography and contrast-enhanced spiral computed tomographic (CT) scanning (5-mm collimation, 5-mm table movement, and 3-mm reconstructed axial slices). Images were also presented as multiplanar reconstructions. These reconstructions were not used for diameter or length measurement because of the lack of appropriate software but rather to give a better understanding of the vascular anatomy and to estimate the changes in stent-graft configuration (ie, kinking; increased angulation of the stent-graft of ≥30° in any projection compared with the first postoperative CT). A set of precontrast scans was always performed to detect calcifications in the aorta that might be mistaken for endoleaks.

Follow-up consisted of intravenous contrast-enhanced spiral CT at 1, 3, 6, and every 6 months thereafter. After 1997, chest radiographs were also performed at the same intervals.

The first postoperative CT was used to define anatomic landmarks, allowing for subsequent measurements to be performed in a reproducible manner. The left subclavian artery was used as a reference point, and in addition, cross-references to anatomically fixed structures, such as the carina and vertebral bodies, were always performed.

Measurements

Vessel diameters were measured on axial CT scan hard copies with callipers and a centimeter scale provided on the film. The shortest transverse inner diameter of the artery was measured to avoid overestimation of size caused by vessel tortuosity. All measurements were done by one observer (N.V.D.).

The following parameters were evaluated preoperatively on CT: maximal TAA diameter; length of the proximal and distal necks; and aortic diameter at the position where the proximal and distal stents were finally deployed (ie, stent position). Proximal and distal necks were defined as thrombus-free portions of the aorta 15 mm or longer and 36 mm or less in diameter extending from the left subclavian artery to the proximal end of the aneurysm and from the distal end of the aneurysm to the celiac trunk, respectively.

During follow-up CT, the maximal diameters of the aneurysm and of the aorta at the stent positions were measured. The presence of endoleaks was evaluated.[12]

Displacement of the stent-graft from the original fixation points (ie, migrations) was evaluated by measuring the distances from the proximal and distal stents to the left subclavian artery and comparing these with the corresponding distances at the first postoperative CT scan. Migration of 5 mm or greater was considered significant. Changes in neck diameter of 3 mm or greater seen on multiple successive CT studies (using the first postoperative CT scan as starting point) were considered to represent neck dilatation.

Procedure

All procedures were performed in the operating room after achievement of general anesthesia.

Twenty-two Gianturco Z stent-based custom-made stent-grafts (William Cook, Europe A/S, Bjaeverskov, Denmark) and one Excluder device (W. L. Gore & Associates, Inc, Flagstaff, Ariz) were used. The median stent-graft length was 140 mm (range, 80-280 mm), and stent-grafts were oversized by 15% to the neck diameter. In the custom-made devices several stents were sutured on the inside of an uncrimped polyester graft (Cooley Veri-Soft; Meadox Medicals Inc, Oakland, NJ) with interrupted 6-0 polytetrafluoroethylene* sutures. The proximal stent had 4 sets of caudally oriented barbs and cranially oriented hooks for fixation. In all cases the stent-graft was placed with at least one stent length (25 mm) within the necks. The exception consists of the 3 patients described in the paragraph below. In the last 11 cases, 3 longitudinal interrupted stainless-steel spirals were mechanically fixated to the stents to provide additional longitudinal support.

In 2 patients the proximal end of the stent-graft was sutured to the aortic wall during a combined open and endovascular procedure. In another patient a polyester band was placed immediately below the left subclavian artery to constrict the aorta to create a suitable neck. Proximal neck measurements on these 3 patients were excluded from the analysis.

Statistics

All statistical analyses were performed with StatView 5.0 software (Abacus Concepts, Berkeley, Calif). Normal distribution was not assumed. Values are given as medians with interquartile

*Gore-Tex suture, registered trademark of W. L. Gore & Associates, Inc, Flagstaff, Ariz.

TABLE 1. Stent-graft migration and aneurysm neck dilatation

	Neck dilatation	
Graft migration	**No**	**Yes**
Proximal neck aneurysm (n = 20)		
No	15 (75%)	2 (10%)
Yes	1 (5%)	2 (10%)
Distal neck aneurysm (n = 23)		
No	15 (65%)	1 (5%)
Yes	3 (13%)	4 (17%)

Stent-graft migration is defined as 5 mm or greater cranial or caudal dislocation of the stent-graft. Neck dilatation is defined as 3 mm or greater increase in neck diameter. Three patients had surgical fixation of the proximal end of the stent-graft and are not included in the measurements of the proximal neck. Three patients displayed both cranial and caudal stent-graft migration. Four patients displayed both proximal and distal neck dilatation. There was a positive relationship between neck dilatation and stent-graft migration at both the proximal and distal necks (P = .03 and P = .02, respectively, χ^2 test).

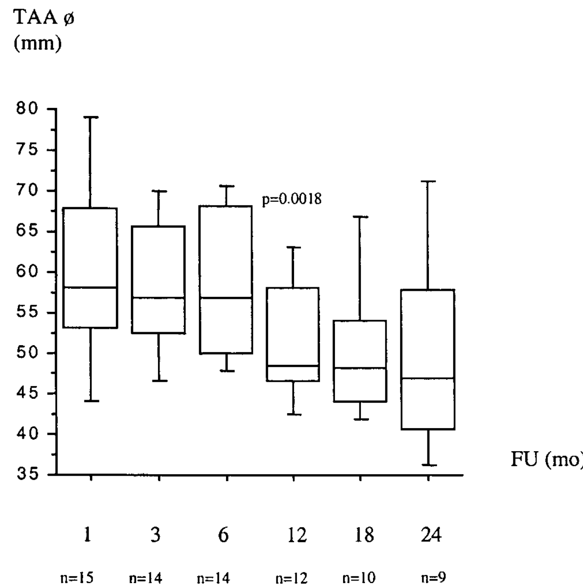

Figure 1. Change in maximum TAA diameter during follow-up. *Horizontal lines* in *box plots* represent 10th, 25th, 50th, 75th, and 90th percentiles.

ranges (IQRs) in parentheses if not otherwise indicated. The Mann-Whitney U test was used for nonpaired comparisons, and the Wilcoxon rank sum test was used for paired comparisons. Correlations were performed according to the Spearman coefficient and given with confidence intervals (CIs) within parentheses. The χ^2 test was used to compare proportions.

This study was approved by the institutional review board, and informed consent was obtained from each patient regarding procedures and radiologic follow-up.

Results

Maximum TAA Diameter

The maximum preoperative TAA diameter was 57 mm (51-67 mm).

In 19 patients with completely excluded TAAs, there was a 4-mm (0.5-10 mm) cumulative decrease of the TAA diameter at 12-month follow-up (P = .0018). This time was chosen as representative because it contained the largest number of patients. The decrease was progressive over time (Figure 1).

Four patients displayed early graft-related endoleaks, all of which were distal. These patients all showed an increase in aneurysm diameter before subsequent percutaneous intervention was performed (stent-graft extension, n = 3; coil embolization, n = 1). Subsequently, the aneurysms decreased in diameter. No proximal perigraft leaks were seen.

One patient displayed collateral perfusion through an intercostal artery at follow-up. No change in the aneurysm diameter was seen. The patient died of unrelated causes.

Aneurysm Necks

The preoperative proximal aneurysm neck was 30 mm (28-32 mm) in diameter and 64 mm (41-115 mm) in length. The distal neck was 29 mm (26-32 mm) in diameter and 60 mm (40-118 mm) in length. Four (20%) patients displayed dilatation of both the proximal and distal necks of 3 mm or greater (mean, 8.5 mm [range, 7-10 mm; SE, 0.75] and 7.5 mm [range, 6-10 mm; SE, 0.9], respectively). Another patient displayed dilatation of the distal aneurysm neck only (6 mm). No correlation was found between neck dilation and preoperative neck diameter (proximal neck: r = 0.2 [95% CI, –0.4 to 0.7; P = .5]; distal neck: r = 0.5 [95% CI, –0.8 to 0.02; P = .06]). No correlation was found between neck dilation and preoperative neck length (proximal neck: r = –0.4 [95% CI, –0.8 to 0.2; P = .2]; distal neck: r = 0.3 [95% CI, –0.3 to 0.7; P = .3]).

Stent-Graft Migration

In 7 (30%) patients there was proximal migration of the distal end of the stent-graft. Three (13%) patients displayed both distal migration of the proximal end of the stent-graft and proximal migration of the distal end of the stent-graft (Table 1). There was a positive relationship between neck dilatation and stent-graft migration at both the proximal and distal necks (P = .03 and P = .02, respectively, χ^2 test). In no case did the migration lead to the appearance of an endoleak before intervention was performed.

Eight (32%) patients displayed stent-graft kinking during follow-up (Figure 2). There was a significant correlation

Figure 2. Plain chest radiograph performed on postoperative day 1 *(left)* showing good stent-graft configuration and alignment within the descending thoracic aorta. At 14 months postoperatively, an angiogram was performed *(right)* that showed severe kinking of the stent-graft.

between stent-graft kinking and the appearance of proximal or distal stent-graft migration (P = .005 and P = .0007, respectively).

Discussion

Changes in aneurysm morphologic characteristics and stent-graft configuration after endovascular repair of descending TAAs are not yet clearly established. It is possible that, in resemblance to endovascular repair of abdominal aortic aneurysm (AAAs), these factors might become determinants for successful midterm and long-term outcome.

Successful TAA exclusion leads to thrombosis of the aneurysm sac in most cases, but changes in the aneurysm diameter are unknown. It has been stated that the aneurysm increases in size in 26% of patients, remains stable in 26% of patients, and decreases in 48% of patients over the first 1.1 years after the initial procedure.[8] Our results show that when primary or secondary TAA exclusion is achieved, the aneurysm reduces in size in a way similar to that found with AAAs.[13-15] The presence of an endoleak seems to prevent aneurysm size decrease. Thus, when a TAA fails to decrease in size after technically successful endovascular TAA exclusion, further investigations should be performed to rule out endoleaks. Collateral perfusion of the excluded aneurysm sac after AAA repair has been reported in 5% to 25% of cases.[16] It seems to be a less common event after TAA repair, as shown by us and others. Its implications for changes in aneurysm morphologic characteristics are hard to determine because of its infrequent occurrence. It may have an effect equal to that found after AAA repair (ie, preventing a decrease in aneurysm size but not promoting aneurysm growth). The single case of collateral perfusion in this series was left untreated, and percutaneous coil embolization was not considered because of the stability in aneurysm diameter. Whether collateral perfusions should only be treated in the presence of TAA growth is unclear, and further studies are needed.

The fate of the aneurysm neck after endovascular TAA repair remains uncertain. Our results suggest that there might be an association between neck dilatation and stent-graft migration, with analysis reaching statistical significance. However, the presence of neck dilatation without migration was also seen (Table 1). In the current study we did not measure the length of the stent-graft extension into the fixation sites prospectively. Because this type of measurement cannot be made retrospectively in an accurate fashion, we have not been able to study what effect, if any, this has had on the development of neck dilation and stent-graft migration, respectively. This might very well be of importance for the outcome. In the AAA endografting arena there is an ongoing debate on infrarenal neck changes. Although some state that neck dilation occurs and is responsible for distal stent-graft migrations,[17,18] others argue that aneurysm neck morphologic characteristics do not change after AAA stent grafting.[19,20] Neck dilatation after endovascular TAA repair has previously been recognized in 2 patients by a group at Stanford University.[6] In our series 5 patients displayed neck dilatation, and 4 of these patients displayed dilatation at both fixation sites. This might suggest the presence of a subgroup of patients prone to aneurysm neck dilatation. We could not, however, identify such a group by radiologic means.

The incidence of neck dilatation was similar in the proximal and distal fixation sites. However, stent-graft migration was almost twice as frequent at the distal fixation site. Thus some mechanism in addition to neck dilatation seems to promote stent-graft migration. The association between upward migration of the distal end of the stent-graft and subsequent kinking suggests that there are forces acting on the stent-graft to cause a pull-up. The action of vector forces in stent-grafts has been described for the abdominal aorta,[21] and the often severe tortuosity in the thoracic aorta might induce even stronger vector forces after TAA repair. The reinforced proximal stent provides a stronger attachment than the plain distal stent that is held in place only by the expansile force of the stent. As a result, vector forces may result in a selective pull-up on the distal end of the stent-graft, with the proximal end as the fixation point. When stent-graft migration is associated with kinking, the vector forces may be further accentuated, leading to further migration. In our opinion, this is an area where further developments in stent-graft design with improved distal stent-graft fixation might improve the midterm and long-term results. The measurement of a significant migration, which we have chosen to define as greater than 5 mm, is cumbersome when using axial CT reconstructions, as we have done. This is especially true with regard to the curved portion of the aorta. We are, however, confident in our findings. The addition of multiplanar reconstructions and plain chest radiographs in follow-up gives good appreciation of tortuosity. We have also had only one physician make the measurements. This allows for reproducible results. In addition, the finding of progressive displacement of the stent-graft on serial examinations strengthens the finding of migrations.

When considering the findings in this study, it must be remembered that the endovascular device used is a first-generation device. The problems with stent-graft kinking and migration may be entirely specific for this type of device and not transferable to newer, more flexible conforming designs. However, the concept of vector forces acting on stent-grafts will apply to all devices and must be considered when designing and evaluating endovascular devices for TAA repair. We believe that the use of interconnecting wires in the stent-graft, as done in our last 11 cases in this series, might be a possible way of lessening the problem of kinking and migration.

When encountering cases of stent-graft migration and kinking, we use stent-graft extensions or giant Palmaz stents for correction. However, if the aneurysm is well excluded without sign of endoleak and no flow problem is encountered, we sometimes choose not to intervene but continue to monitor the patient closely on the basis of the patient's condition and suitability for additional intervention.

In conclusion, our results show that endovascularly excluded TAAs decrease in size on midterm follow-up. Stent-grafts have a significant risk of migration, possibly caused by a combination of aneurysm neck dilatation and vector forces acting on the stent-graft in the tortuous descending thoracic aorta. Close follow-up is warranted, and at present, the procedure must still be considered experimental. Further system development and careful patient selection is needed to improve midterm and long-term results.

We thank Jan-Åke Nilsson, Consultant Statistician, Lund University, for help with the statistical analysis.

ACD

References

1. Kouchoukos NT, Dougenis D. Surgery of the thoracic aorta. *N Engl J Med.* 1997;336:1876-88.
2. Moreno-Cabral CE, Miller DC, Mitchell RS, Stinson EB, Oyer PE, Jamieson SW, et al. Degenerative and atherosclerotic aneurysms of the thoracic aorta: determinants of early and late surgical outcome. *J Thorac Cardiovasc Surg.* 1984;88:1020-32.
3. Pressler V, McNamara JJ. Aneurysm of the thoracic aorta: review of 260 cases. *J Thorac Cardiovasc Surg.* 1985;89:50-4.
4. Mitchell RS, Dake MD, Sembra CP, Fogarty TJ, Zarins CK, Liddel RP, et al. Endovascular stent-graft repair of thoracic aortic aneurysms. *J Thorac Cardiovasc Surg.* 1996;111:1054-62.
5. Dake MD, Miller DC, Semba CP, Mitchell RS, Walker PJ, Liddell RP. Transluminal placement of endovascular stent-grafts for the treatment of descending thoracic aortic aneurysms. *N Engl J Med.* 1994; 331:1729-34.
6. Mitchell RS. Endovascular stent graft repair of thoracic aortic aneurysms. *Semin Thorac Cardiovasc Surg.* 1997;9:257-68.
7. Semba CP, Mitchell RS, Miller DC, Kato N, Kee ST, Chen JT, et al. Thoracic aortic aneurysm repair with endovascular stent-grafts. *Vasc Med.* 1997;2:98-103.
8. Dake MD, Miller DC, Mitchell RS, Semba CP, Moore KA, Sakai T. The "first generation" of endovascular stent-grafts for patients with aneurysms of the descending thoracic aorta. *J Thorac Cardiovasc Surg.* 1998;116:689-704.
9. Dake MD, Kato N, Mitchell RS, Semba CP, Razavi MK, Shimono T, et al. Endovascular stent-graft placement for the treatment of acute aortic dissection. *N Engl J Med.* 1999;340:1546-52.
10. Nienaber CA, Fattori R, Lund G, Dieckmann C, Wolf W, von Kodolitsch Y, et al. Nonsurgical reconstruction of thoracic aortic dissection by stent-graft placement. *N Engl J Med.* 1999;340:1539-45.
11. Fann JI, Miller DC. Endovascular treatment of descending thoracic aortic aneurysms and dissections. *Surg Clin North Am.* 1999;79:551-74.
12. White G, May J, Waugh R, Chaufour X, Yu W. Toward a complete definition of blood flow in the sac after endoluminal AAA repair. *J Endovasc Surg.* 1998;5:305-9.
13. Resch T, Ivancev K, Brunkwall J, Nirhov N, Malina M, Lindblad B. Mid-term changes in aortic aneurysm morphology after endovascular repair. *J Endovasc Surg Ther.* 2000;7:279-85.
14. Matsumura J, Pearce W, McCarthy W, Yao J. Reduction in aortic aneurysm size: early results after endovascular graft placement. *J Vasc Surg.* 1997;25:113-23.
15. May J, White G, Yu W, Waugh R, Stephen M, Harris J. A prospective study of anatomico-pathological changes in abdominal aortic aneurysms following endoluminal repair: Is the aneurysmal process reversed? *Eur J Vasc Endovasc Surg.* 1996;12:11-7.

16. Schurink GW, Aarts NJ, van Bockel JH. Endoleak after stent-graft treatment of abdominal aortic aneurysm: a meta-analysis of clinical studies. *Br J Surg.* 1999;86:581-7.
17. Resch T, Ivancev K, Brunkwall J, Nyman U, Malina M, Lindblad B. Distal migration of stent-grafts after endovascular repair of abdominal aortic aneurysms. *J Vasc Intervent Radiol.* 1999;10:257-64.
18. Matsumura J, Chaikof E. Continued expansion of aortic necks after endovascular repair of abdominal aortic aneurysms. *J Vasc Surg.* 1998;28:422-31.
19. Walker SR, Macierewicz J, Elmarasy NM, Gregson RH, Whitaker SC, Hopkinson BR. A prospective study to assess changes in proximal aortic neck dimensions after endovascular repair of abdominal aortic aneurysms. *J Vasc Surg.* 1999;29:625-30.
20. Broeders I, Blankensteijn J, Gvakharia A, May J, Bell PR, Swedenborg J, et al. The efficacy of transfemoral endovascular aneurysm management: a study on size changes of the abdominal aorta during midterm follow-up. *Eur J Vasc Endovasc Surg.* 1997;14:84-90.
21. Lawrence-Brown M, Semmens J, Hartley D. How is durability related to patient selection and graft design with endoluminal grafting for abdominal aortic aneurysm? In: Greenhalgh R, editor. The durability of vascular and endovascular surgery. London: WB Saunders; 1999. p. 375-85.