Aortic Morphologic Findings After Thoracic Endovascular Aortic Repair for Type B Aortic Dissection

Michael M. Sigman, MD; Owen P. Palmer, MD; Sung W. Ham, MD; Mark Cunningham, MD; Fred A. Weaver, MD, MMM

IMPORTANCE Thoracic endovascular aortic repair (TEVAR) is used in the treatment of type B aortic dissections. Information related to aortic morphologic findings and the condition of the abdominal aorta after TEVAR is limited.

OBJECTIVE To analyze aortic morphologic findings after TEVAR for type B aortic dissections.

DESIGN, SETTING, AND PARTICIPANTS After a retrospective database review, the data for 30 patients who underwent TEVAR from January 1, 2007, through December 31, 2013, for type B aortic dissection were analyzed. Imaging software was used to calculate aortic diameters and volumes of the aorta on computed tomography (CT) or magnetic resonance imaging (MRI). Mean follow-up was 14.4 months.

INTERVENTIONS We performed TEVAR to cover proximal thoracic aorta tears in patients who underwent acute or chronic type B aortic dissections.

MAIN OUTCOMES AND MEASURES Aortic morphologic findings of pre-TEVAR CT or MRI were compared with the most recent findings of post-TEVAR CT or MRI. Frequency of thoracic false lumen thrombosis (FLT) and false lumen patency (FLP) was determined and the effect on post-TEVAR aortic morphologic findings analyzed.

RESULTS Mean (SD) TEVAR increased true lumen diameter (19.50 [6.92] mm to 31.19 [5.36] mm, \( P < .001 \)) and volume (77.92 [41.70] mL to 166.95 [69.69] mL, \( P < .001 \)) and decreased false lumen diameter (29.77 [12.55] mm to 21.92 [12.05] mm, \( P = .001 \)) on post-TEVAR CT or MRI when compared with pre-TEVAR scans. Seventy percent of patients experienced thoracic FLT; 30% had FLP. True lumen volume expansion and false lumen volume regression occurred in patients with FLT (82.07 [46.95] mm to 180.55 [77.99] mm, \( P < .001 \) and 161.84 [106.36] mm to 115.76 [140.77] mm, \( P = .002 \), respectively) and FLP (68.23 [21.43] mm to 128.22 [21.46] mm, \( P < .001 \) and 238.64 [174.00] mm to 198.93 [120.46] mm, \( P = .04 \), respectively). Patients with FLT had increased true lumen diameter (15.67 [6.43] mm to 26.13 [7.62] mm, \( P < .001 \)) and volume (54.86 [30.52] mL to 88.08 [41.07] mL, \( P = .001 \)) in the abdominal aorta after TEVAR, with no change in total abdominal aortic volume (161.94 [70.12] mL vs 160.36 [82.11] mL, \( P = .90 \)). Total abdominal aortic volume significantly increased in patients with thoracic FLP (187.24 [89.88] mL to 221.41 [82.64] mL, \( P = .02 \)).

CONCLUSIONS AND RELEVANCE Favorable aortic remodeling of the thoracic aorta occurs after TEVAR for type B aortic dissections in patients with thoracic FLT and FLP. However, failure to achieve thrombosis of the thoracic false lumen negatively influences aortic morphologic findings of the contiguous abdominal aorta.
A type B aortic dissection is a serious condition that may result in short- and long-term cardiovascular complications and death. Acute uncomplicated aortic dissections have traditionally been managed medically with normalization of blood pressure and anti-impulse therapy, with open surgical repair reserved for patients presenting with rupture, malperfusion syndrome, or refractory pain. Long-term management includes β-blockade and lifelong surveillance imaging of the aorta. Despite 1-year survival rates of greater than 80% in patients managed medically, long-term outcomes have been poor. Up to 60% of patients have experienced aneurysmal degeneration of the dissected aorta during their lifetime, with a late survival rate of less than 50%. With the development of endovascular stent grafts, thoracic endovascular aortic repair (TEVAR) has increasingly been used in the management of acute and chronic type B aortic dissections. The governing principle of TEVAR in this setting is coverage of the proximal entry aortic tear, allowing re-establishment of primary true lumen blood flow with exclusion of flow into the false lumen. If successful, false lumen thrombosis (FLT) ensues with the purported potential for favorable late aortic remodeling and a decreased incidence of aneurysm formation.

In this study, we examine the effect of TEVAR for the treatment of type B aortic dissections on midterm aortic morphologic findings. Of special interest is the frequency of FLT, the condition of the aortic true lumen, the diameter and total volume of the dissected aorta, and the morphologic behavior of the dissected abdominal aorta.

Methods

A review of the University of Southern California (USC) aortic database and the Keck Hospital of USC, Society for Vascular Surgery, Vascular Quality Initiative database was conducted to identify all patients undergoing TEVAR at the Keck Medical Center of USC from January 1, 2007, through December 31, 2013. The USC Health Sciences Institutional Review Board approved the database review and analysis. Because this was a retrospective review, no informed consent was required.

The diagnosis of type B aortic dissection was established by computed tomography (CT) or magnetic resonance imaging (MRI) evidence of a thoracic aortic tear distal to or at the left subclavian with the creation of true and false lumens for variable lengths of the thoracic and abdominal aorta. The dissection was considered acute in those patients treated with TEVAR within 14 days of symptom onset; for all other patients, the dissections were considered chronic.

Demographic and perioperative data collected included patient comorbidities, symptoms on admission, extent of dissection, and indication for TEVAR. Operative details, including technique, findings of completion angiography, number of devices used, extent of coverage, intraoperative complications, and technical success, were tabulated.

TEVAR was performed using commercially available endografts with the patients under general anesthesia. The endografts were oversized by 10% to 15% of the proximal and distal landing zone diameter of the true aortic lumen and were deployed to cover the major proximal entry tear with proximal and distal endograft landing zones of at least 2 cm. In selected patients, secondary thoracic tears were also covered at the operating surgeon’s discretion. Intraoperative transesophageal or intravascular ultrasonography was used in all patients. Lumbar spinal drains were placed depending on surgeon preference, history of previous aortic surgery, need for left subclavian artery coverage, and anticipated length of aortic coverage. Drains remained in place, draining 10 mL of cerebrospinal fluid per hour for 24 to 48 hours postoperatively. A 24-hour clamp trial was performed before removal. Left subclavian artery revascularization was routine in all electively treated patients when anticipated to be covered by TEVAR. Left carotid-subclavian artery transposition was preferred over bypass. In the acute care setting, we frequently covered the left subclavian artery because of the friable nature of the tissues, and revascularization was performed postoperatively as needed for upper limb ischemia. Those with an existing coronary artery bypass graft from the left internal mammary artery or a dominant left vertebral artery underwent revascularization before TEVAR.

Imaging Analysis

Three-dimensional imaging software (Vital Images, Inc.) was used to obtain measurements of preoperative and postoperative aortic morphologic findings on CT or MRI. Measures of aortic remodeling included the following: maximum thoracic aortic diameter, maximum abdominal aortic diameter, total aorta volume, aorta true lumen volume, and aorta false lumen volume. In patients with multiple postoperative imaging studies, the most recent image was used for postoperative volume calculations.

Using thin-cut, aortic, 3-dimensional reconstruction images, we measured total aortic volume from distal to the left subclavian artery to the aortic bifurcation. This volume was calculated automatically by the addition of a series of cylinders whose diameter or cross-sectional area was manually outlined and defined at 3-cm increments (Figure). False and true lumen volumes were calculated in a similar manner. Postoperative thoracic FLT was defined as the absence of contrast in the false lumen to the distal extent of the endograft. Thoracic false lumen patency (FLP) was defined as the presence of any contrast in this segment of the thoracic false lumen. Abdominal FLT was defined as the absence of contrast or blush in the abdominal false lumen. Values were calculated as a percentage change from preoperative aortic diameter and volume measurements and as a proportion of the total aorta made up by the true lumen.

Outcomes

The primary outcome measure was the pre-TEVAR and last follow-up post-TEVAR difference in maximum thoracic and abdominal aortic diameter and total aortic volume on CT or MRI. The effect of thoracic FLT or FLP on changes in diameter and volume was also analyzed. Secondary outcomes included mortality and morbidity during hospitalization or within 30 days of surgery, reintervention rate, intervention-
free late survival, and overall survival. The Social Security Death Index was used to determine mortality in patients who were unavailable for follow-up.

**Statistical Analysis**

Continuous variables were summarized as mean (SD) and compared using 2-tailed *t* tests. Categorical variables were expressed as frequency and percentage. Survival was estimated using the life-table method. *P* < .05 was considered statistically significant. Statistical analysis was performed using SPSS statistical software, version 17.0 (SPSS Inc).

**Results**

TEVARs were performed in 112 patients during the study period. Of these patients, 43 (38%) underwent TEVAR for a type B aortic dissection, and 30 of the 43 (70%) had sufficient pre- and post-TEVAR imaging available for morphologic analysis. In these 30 patients, the mean age was 61 years (range, 31-89 years). Twenty (67%) were men and 27 (90%) had a history of hypertension (Table 1). The aortic dissection involved the thoracic aorta in all patients, with extension of the aortic dissection into the abdominal aorta in 25 patients (83%).

TEVAR was used to treat 15 patients (50%) with an acute type B aortic dissection and 15 (50%) with a chronic type B aortic dissection. The indication for repair in patients with acute type B aortic dissection was aortic rupture in 3 patients, malperfusion in 7, and persistent chest and back pain in 5. Indications for repair in patients with a chronic type B aortic dissection included aneurysmal degeneration in 14 and refractory pain in 1 (eTable 1 in the Supplement). Lumbar spinal drains were placed in 18 patients (60%). Fifteen patients (50%) required complete coverage of the left subclavian artery to obtain adequate seal of the entry tear. All but 1 patient underwent left subclavian revascularization. Additional procedural details are listed in eTable 2 in the Supplement.

Nine patients (30%) experienced 1 or more major complications during hospitalization or within 30 days of surgery. Complications are listed in eTable 3 in the Supplement. Rein-
tervention after TEVAR was not required during hospitalization or within 30 days of surgery. Permanent paraplegia occurred in 1 patient and transient paraplegia with full recovery in another.

Two patients (7%) died. One patient with an acute type B aortic dissection who underwent TEVAR abruptly became hypotensive and died. Aortic rupture was suspected, but the family declined an autopsy. The other death occurred in a patient who presented with renal and limb malperfusion. She underwent TEVAR with resolution of malperfusion and was discharged. She returned to the hospital in septic shock caused by Klebsiella bacteremia and ischemic colitis. She subsequently went into multiorgan system failure and died of a cerebellar herniation.

Mean (SD) follow-up was 14.4 months (range, <1-35 months). During follow-up, 6 interventions were required in 5 patients. Indications for intervention included the following: retrograde aortic dissection (2 patients), aortic expansion and pain with persistent FLP (1 patient), type 1 endoleak (1 patient), and type 2 endoleak from the patent subclavian artery (1 patient). All interventions involved the placement of an endograft proximal or distal to the existing TEVAR: in

<table>
<thead>
<tr>
<th>Variable</th>
<th>TEVAR, Mean (SD) Measurements</th>
<th>Change</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum aortic diameter, mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thoracic</td>
<td>45.28 (11.06)</td>
<td>45.16 (12.83)</td>
<td>−0.12</td>
</tr>
<tr>
<td>Abdominal</td>
<td>37.30 (10.08)</td>
<td>37.39 (10.41)</td>
<td>0.09</td>
</tr>
<tr>
<td>Maximum diameter, mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>True lumen</td>
<td>19.50 (6.92)</td>
<td>31.19 (5.36)</td>
<td>11.69</td>
</tr>
<tr>
<td>False lumen</td>
<td>29.77 (12.55)</td>
<td>21.92 (12.05)</td>
<td>−7.85</td>
</tr>
<tr>
<td>Total aortic volume, mL</td>
<td>422.66 (190.99)</td>
<td>449.24 (209.55)</td>
<td>26.58</td>
</tr>
<tr>
<td>Volume, mL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>True lumen</td>
<td>77.92 (41.70)</td>
<td>166.95 (69.69)</td>
<td>89.03</td>
</tr>
<tr>
<td>False lumen</td>
<td>184.85 (133.32)</td>
<td>90.41 (121.42)</td>
<td>94.44</td>
</tr>
<tr>
<td>Total aortic volume occupied by true lumen, %</td>
<td>20.31 (11.37)</td>
<td>40.05 (15.31)</td>
<td>19.74</td>
</tr>
</tbody>
</table>

Abbreviation: TEVAR, thoracic endovascular aortic repair.

Aortic Morphologic Findings
The CT and MRI scans taken before and after TEVAR at a mean of 14.4 months (range, <1-35 months) were analyzed. The post-TEVAR mean maximum thoracic aortic diameter was unchanged compared with preoperative values (45.16 [12.83] mm vs 45.28 [11.06] mm, \( P = .48 \)) (Table 2). A significant increase in the thoracic maximum true lumen diameter was documented when comparing pre- and post-TEVAR values (19.50 [6.92] mm to 31.19 [5.36] mm, \( P < .001 \)). This finding was associated with a decrease in the maximum false lumen diameter (29.77 [12.55] mm to 21.92 [12.05] mm, \( P = .001 \)).

Post-TEVAR total aortic volume increased from 422.66 (190.99) mL to 449.24 (209.55) mL (\( P = .01 \)). A significant increase in true lumen volume after TEVAR was documented (77.92 [41.70] mL to 166.95 [69.69] mL, \( P < .001 \)). This finding was associated with a significant decrease in false lumen volume (184.85 [133.32] mL to 90.41 [121.42] mL, \( P = .004 \)). The percentage of aortic volume occupied by the true lumen increased from 20.31% (11.37%) to 40.05% (15.31%) (\( P < .001 \)).

Two patients (7%) experienced thoracic FLT and 9 (30%) had FLP. Ten of 25 patients (40%) had abdominal FLT. No patients had documented abdominal FLT without also having thoracic FLT. For both patient groups, maximum aortic diameter was unchanged and associated with significant increases in true lumen diameter and decreases in false lu-
men diameter after TEVAR (Table 3). The FLT and FLP groups had numerically increased total aortic volumes after TEVAR (FLT group: 429.95 [197.51] mL to 448.93 [212.24] mL, P = .06; FLP group: 409.48 [193.93] mL to 446.85 [215.76] mL, P = .047). True lumen volume expansion and false lumen volume regression occurred in patients with FLT and FLP but was of greater statistical significance in patients with FLT (P < .001 for FLT vs P = .01 for FLP).

Patients with thoracic FLT had statistically significant increases in true lumen diameter (P < .001) and volume (P = .001)
in the abdominal aorta after TEVAR (Table 4). Mean abdominal aorta false lumen diameters ($P = .001$) and volumes ($P = .003$) significantly decreased postoperatively in the thoracic FLT group. Total volume of the abdominal aorta was unchanged.

In patients with thoracic FLP, no significant change was found in true lumen ($P = .19$) and false lumen ($P = .47$) diameters in the abdominal aorta. Although there was a significant increase in true lumen volume ($P = .045$) after TEVAR, there was no significant regression of the false lumen volume ($P = .64$) in patients with thoracic FLP. Abdominal aortic volume significantly increased in patients with FLP ($P = .02$) (Table 4).

**Discussion**

The indications for TEVAR in patients with type B aortic dissection have been the subject of controversy and investigation. Previous studies have documented favorable remodeling in the short term with the implication that late aneurysmal degeneration will be less common. However, the timing of TEVAR continues to be a subject of debate. Proponents of early TEVAR cite a higher likelihood of achieving favorable aortic remodeling while the dissection flap is mobile, the aorta is not yet aneurysmal, and the false lumen is small, thereby decreasing the risk of incomplete FLT. Others have cautioned that TEVAR should only be performed for difficult dissections to minimize the potential complications, which, although infrequent, may result in death. Our series contains only patients with traditional indications for intervention, namely, malperfusion, refractory pain, or late aneurysmal degeneration. In this cohort of patients, TEVAR was effective in increasing true lumen diameter and volume with stabilization or regression of false lumen diameter and volume. This finding is consistent with previous studies that have reported true lumen volume expansion with false lumen volume regression. However, despite stabilization of aortic diameter in the thorax and abdomen and favorable true lumen and false lumen remodeling, total aortic volume increased. Steingruber et al suggested one possibility for this finding in a study of 35 patients with an acute type B aortic dissection treated by TEVAR. Despite favorable remodeling of the stented portion of the thoracic aorta in this cohort, the segment distal to the endograft continued to expand, although the true lumen volume increased. Longer lengths of aortic coverage by the endograft decreased the degree of aortic expansion. Another possible explanation is expansion of the dissected abdominal aorta as suggested by Andacheh et al.

The importance of thoracic FLT on aortic remodeling and late outcomes was confirmed by the Investigation of Stent Grafts in Aortic Dissection With Extended Length of Follow-up (INSTEAD-XL) trial. The authors of this multicenter, randomized, prospective trial of TEVAR for uncomplicated dissection found that aorta-specific and all-cause mortality was decreased in patients randomized to TEVAR when compared with optimal medical therapy alone. False lumen thrombosis occurred in 90% of patients treated with TEVAR compared with only 22% in patients treated with optimal medical therapy at a minimum of 5 years of follow-up. False lumen thrombosis was associated with stabilization of aortic diameters and ultimately fewer cardiovascular events and less aneurysm expansion. Although these authors analyzed FLT status and aortic diameters, remodeling effects of TEVAR with respect to aortic volumes were not evaluated in the INSTEAD-XL trial. In addition, data on the fate of the abdominal aorta were not part of the analysis.

Our analysis concerning the effect of FLT on aortic remodeling indicates that true lumen, false lumen, and total aortic volume are stabilized by TEVAR as would be expected by the INSTEAD-XL results. Because we only achieved FLT in 70% of patients, the effect of FLP after TEVAR could be evaluated. Despite FLP, true lumen volume expanded with regression of the false lumen, although not as markedly as in the FLT group. Thus, TEVAR can promote favorable remodeling despite the presence of FLP. Some investigators have suggested that secondary procedures are indicated in all patients in which FLT is not achieved. Our volumetric analysis suggests that, in certain situations, expectant management may be acceptable and preferable, especially in patients with diameter stabilization or in whom extensive aortic coverage is believed necessary to achieve FLT.

To our knowledge, the current literature provides little information regarding the fate of the abdominal aorta after TEVAR for type B aortic dissections. Andacheh et al observed expansion of the infrarenal aorta after TEVAR in patients who presented with a dissection that extended into the abdominal aorta. They observed expansion of the infrarenal false lumen diameter and overall abdominal aortic volume but did not comment specifically on the abdominal false or true lumen volumes. Kim et al observed abdominal aortic expansion after TEVAR in the presence of endoleak, and Steingruber et al found that stent grafts reliably prevented aneurysm expansion only in the segment that was stented but observed expansion from the distal end of the stent graft to the celiac artery.

When we examined the changes in the abdominal aorta after TEVAR, we saw an increase in abdominal aortic volume but only in those patients who had FLP. Maximum abdominal aortic diameter remained unchanged in the FLP and FLT groups, and favorable remodeling with true lumen expansion was observed in both groups as well. However, as would be expected, aortic remodeling was much more robust in the FLT group, and false lumen regression only occurred in the FLT group. Although at odds with the study by Steingruber et al, these findings suggest that FLT is critical in the stabilization of the abdominal aorta. Our analysis and the INSTEAD-XL study findings of lower late cardiovascular events with thoracic FLT suggest that thoracic FLT should also lower late cardiovascular events related to the abdominal aorta. Furthermore, these findings suggest that procedures such as those used in the PETTICOAT (Provisional Extension to Induce Complete Attachment) procedure may not be necessary in patients with thoracic FLP after TEVAR.
Conclusions

TEVAR appears to be advantageous for the treatment of acute and chronic type B aortic dissections. Successful TEVAR provides favorable aortic remodeling and is associated with acceptable morbidity and mortality. Our data also suggest that aortic remodeling is most robust in those patients with complete thoracic FLT, but a degree of favorable aortic remodeling is also seen in patients with FLP. However, failure to achieve FLT of the thoracic false lumen appears to negatively influence aortic remodeling of a contiguous abdominal aortic dissection. Further study is required to define the association between the condition of the thoracic false lumen and late complications specifically related to the abdominal aorta after TEVAR.

ARTICLE INFORMATION

Accepted for Publication: May 7, 2014.
Published Online: July 30, 2014.

Author Contributions: Dr Weaver had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Sigman, Ham, Weaver.

Acquisition, analysis, or interpretation of data: All authors.

Drafting of the manuscript: Sigman, Palmer, Ham, Weaver.

Critical revision of the manuscript for important intellectual content: Sigman, Ham, Cunningham, Weaver.

Statistical analysis: Sigman, Ham.

Administrative, technical, or material support: Ham, Cunningham, Weaver.

Study supervision: Ham, Weaver.

Conflict of Interest Disclosures: None reported.

Previous Presentation: This study was presented at the 85th Annual Pacific Coast Surgical Association; February 15, 2014; Dana Point, California.

REFERENCES