Fate of the Dissected Thoraco-Abdominal Aorta Distal to TEVAR (Thoracic Endovascular Aortic Repair) for Complicated Acute and Subacute Type B Aortic Dissection

Jowan Nassib, MD1, Kheira Hireche, MD1,2, Baris Ata Ozdemir, FRCS, PhD1,3, Pierre Alric, MD, PhD1,2, and Ludovic Canaud, MD, PhD1,2

Abstract
Purpose: This study assessed morphological changes in the aortic true and false lumens during follow-up of patients undergoing TEVAR (Thoracic Endovascular Aortic Repair) for complicated acute and subacute type B dissection. The study analyzes the effectiveness of TEVAR in preventing distal aneurysmal progression.
Materials and Methods: All patients between 2009 and 2019 undergoing TEVAR for complicated acute and subacute type B dissection at the study institution were retrospectively reviewed. Maximal diameters were measured on the proximal descending aorta right below the left subclavian artery, thoraco-abdominal junction right above the celiac trunk, and infrarenal aortic right above the inferior mesenteric artery, pre-operatively and during follow-up, analyzing either expansion or shrinkage of true and false lumens at these 3 sites.
Results: Forty-one patients were included. Thirty-day incidence of death, stroke, paraplegia, and visceral ischemia was, respectively, 8% (n = 4), 6% (n = 3), 2% (n = 1), and 2% (n = 1). Three patients (6%) died from intervention-related cause. Mortality was 17% (n = 8) during a mean follow-up of 54 months. One patient had aneurysmal dilation of the descending aorta needing additional coverage and only 2 (4%) developed thoraco-abdominal aneurysms requiring re-intervention. In the remaining patients, both significant expansion of the true lumen and shrinkage of false lumen were observed at all 3 sites.
Conclusion: Proximal coverage of the main entry tear appears to prevent aneurysmal progression in most patients (96%). With such promising results, TEVAR should be considered as a first-line treatment in acute and subacute type B dissection.

Keywords
thoracic aorta, thoracic endovascular aortic repair, thoracic aorta dissection, true lumen, false lumen, thoraco-abdominal aortic aneurysm

Introduction
In recent decades, the strategy of treatment for complicated acute and subacute type B aortic dissection has changed. Historically, open repair was the gold standard. As operative complications were high, endovascular therapy is now considered first-line treatment due to both reduced invasiveness and better outcomes.1 The endovascular approach targets closure of the proximal entry tear, using a covered stent graft, thus excluding the false lumen (FL). The aim is to induce aortic remodeling that is defined by FL diameter reduction or thrombosis. In some cases, however, the FL perfusion persists with subsequent aneurysmal progression in the thoraco-abdominal (TA) or abdominal aorta. In a recent systematic review, rates of thoracic aortic growth ranged from 8% to 63%, whereas rates of abdominal growth ranged from 8% to 47% after acute type B dissection.2

1Department of Thoracic and Vascular Surgery, Arnaud de Villeneuve Hospital, Montpellier, France
2PhysMedExp, INSERM, CNRS, University of Montpellier, Montpellier, France
3University of Bristol, Bristol, UK

Corresponding Author:
Jowan Nassib, Department of Thoracic and Vascular Surgery, Arnaud de Villeneuve Hospital, 191 Av. Doyen Gaston Giraud, 34090 Montpellier, France.
Email: jowannassib@hotmail.com
Tsai and colleagues demonstrated that partial thrombosis is prognostically worse than complete FL patency in type B aortic dissection. Complete exclusion of the FL, however, could improve the prognosis of this disease. To promote true lumen (TL) expansion and FL thrombosis, devices with bare metal stents that extend into the TA aorta have been used in an attempt to induce aortic remodeling. The ultimate aim of this approach is to prevent aortic aneurysmal evolution, decrease the number of additional procedures required, and ultimately prevent rupture.

The aim of this study was to evaluate the long-term impact of TEVAR (Thoracic Endovascular Aortic Repair), on aortic aneurysmal progression, by assessing TL and FL diameters, in patients treated for acute and subacute complicated type B aortic dissection.

Materials and Methods

Ethical approval was obtained from the institutional review board, and all patients provided informed consent.

The diagnosis of dissection was based on contrast-enhanced computed tomography (CT) with scanning from the ascending aorta to the common femoral arteries. Acute type B dissection was defined according to symptom onset, with acute less than 14 days and subacute from 15 days to 3 months since symptom onset. Only complicated acute and subacute type B dissections underwent endovascular repair. Complicated dissection was defined as presence of branch vessel malperfusion (visceral, renal, and lower limbs) due to complete or incomplete obstruction of the vessel on CT scan associated with clinical symptoms and or signs. Presence of periaortic hematoma, resistant hypertension (despite maximum pharmacologic treatment), persistent pain (despite maximum pharmacologic treatment), or rapid aortic diameter expansion (5 mm growth on center luminal reconstruction) was also defined as complicated. Rupture was defined by the presence of hemothorax or hemo mediastinum on the CT scan whether the patient was or was not hemodynamically stable.

Data were collected by reviewing the medical record and imaging studies for each patient. Procedural data included number of stent graft(s) implanted, length of aorta covered by stent grafts, and adjunct procedures. Postoperative complications and re-interventions were also recorded.

The principal aim of each intervention was coverage of all proximal entry tears by TEVAR with a standard covered stent graft. For zones 0, 1, and 2, entry tears either supraaortic debranching or surgeon modified fenestrated endografts were used to maintain the patency of the supra-aortic trunks as described in previous publications by the study institution. For patients with entry tear located in zone 1, this meant either left subclavian and common carotid artery debranching or a the use of a double-fenestrated surgeon-modified stent graft. The stent graft diameters were oversized by 0% up to 10% using the largest diameter of the proximal landing zone as reference.

All implantations were performed by 4 senior vascular surgeons in a regional tertiary aortic unit in this single center study. Remodeling of the dissected aorta was assessed by measuring the changes in the FL, TL, and total lumen at their largest point, as well as patency status of the FL pre- and postprocedure at discharge, 1 month then annually. The most up-to-date follow-up measurement was included in the analysis. Contrast-enhanced arterial and venous phase CTs with a slice thickness of ≤3 mm scan were acquired. All computed tomography angiographies were analyzed on a dedicated workstation with automatic 3-dimensional sizing software (Endosize; Therenva, Rennes, France) by 2 vascular surgeons experienced in endograft planning (J.N., L.C.). Measurements of 3 selected aortic segments were made at the maximal diameters just distal to the left subclavian artery (LSA), above the celiac artery level, and at the inferior mesenteric artery (IMA) level. Consecutive patients with acute and subacute complicated type B aortic dissection between 2009 and 2019 were included. No patients were treated with open repair.

Statistics

Statistical analysis was performed using R (R Core Team, R Foundation for Statistical Computing, Vienna, Austria). The threshold of statistical significance was set at \( p < 0.05 \). Differences between subgroups were assessed using mean comparison tests (Student or Wilcoxon as a function of the distribution tested for using the Shapiro-Wilk test). Results are expressed as means or medians for continuous, and frequency and percentages for categorical variables.

Results

The medical records of 47 patients undergoing TEVAR for acute (\( n = 40 \)) and subacute (\( n = 7 \)) complicated type B aortic dissection at the study institution between 2009 and 2019 were analyzed. Comorbidities are summarized in Table 1. Patient’s mean age was 68 years ±9.8 (45–88).

Indications for TEVAR were rapid aortic expansion on early planned inpatient CT scan (usually on day 7 after the onset of the symptoms) in 27.2%, persistent pain despite optimal medical management in 26.2% of patients, rupture in 21.2%, bowel ischemia in 12.7%, lower limb ischemia in 8.5%, spinal cord ischemia and renal hypoperfusion in 4.2%.

Technical success was 100%. In total, 81% (\( n = 38 \)) of patients had 1 stent graft and 19% (\( n = 9 \)) had 2 stent grafts. The median length of aortic coverage was 185 mm (range 150–300mm). The mean diameter of the stent grafts was 34
mm (range 26–42). Twenty-four patients (51%) underwent standard TEVAR. Seven patients (15%) had TEVAR with left subclavian to left common carotid artery transposition due to an entry tear in zone 2. Two patients (4%) had left subclavian and common carotid artery debranching in association with TEVAR due to a zone 1 entry tear. Eleven (23%) had TEVAR with a surgeon-modified single-fragmented stent graft to maintain flow in the LSA (zone 2 entry tears) and 3 (6%) had surgeon-modified dual-fragmented stent grafts preserving blood flow in all supra-aortic arteries (zone 1 entry tears). Aortic dissections reported according to the 2020 STS/SVS classification were as follows: 4 entry tears were located in zone 1 and 3 dissections were classified type B1, 1 and type B1, 10; 18 entry tears were located in zone 2: 10 dissections were type B2, 9; 5 were type B2, 8 and 3 type B2, 10; 25 entry tears located in zone 3: 11 dissections were type B3, 9; 6 were type B3, 8; 1 was type B3, 6, and 7 were B3, 5.

30-Day Outcomes

Early death occurred in 4 patients (8.5%). One patient with a ruptured aorta underwent urgent repair but died during intervention. One patient suffered a lethal stroke. One patient died 22 days after intervention due to massive pulmonary embolism and another patient died at day 14 from massive bleeding from a gastro-duodenal ulcer. Six percent (n = 3) of patients had strokes from which they fully recovered. Two type Ia endoleaks were observed leading in one case to subclavian debranching and proximal extension of the stents. In the second case, additional proximal coverage was performed. One case of early oesophageo-aortic fistula was observed and treated by total oesophagectomy in association with epiploic coverage of the graft. One case of secondary bowel ischemia due to compression of the TL, diagnosed because of persistent abdominal pain, was managed by distal stent graft extension. The total early reintervention rate was 8%. Postoperative paraplegia (complete neurological impairment of the lower extremities) occurred in 1 patient immediately after TEVAR and was permanent despite therapeutic cerebrospinal fluid drainage. The total rate of major complications was 17% (4 deaths, 1 spinal cord ischemia, 3 strokes, and 1 bowel ischemia).

The 30-day outcomes are listed in Table 2.

### Table 2. 30-Day Outcomes

<table>
<thead>
<tr>
<th>Outcome</th>
<th>No.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-day outcomes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Death</td>
<td>4</td>
<td>8.5</td>
</tr>
<tr>
<td>Re-intervention</td>
<td>4</td>
<td>8.5</td>
</tr>
<tr>
<td>Stroke</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Endoleak</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Paraplegia</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Bowel ischemia</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

COPD = chronic obstructive pulmonary disease.

During Follow-Up

The mean follow-up duration was 54 months.

The preoperative widest median diameter of the whole lumen right after the LSA was 40 mm, at the celiac artery (CA) 33 mm, and at the IMA 22 mm. After TEVAR and during follow-up, the medians were 34 mm (p<0.001), 31 mm (p=0.793), and 22 mm (p=0.130), respectively. Boxplots of total aortic diameter are depicted in Figure 1.

The preoperative widest median diameter of the largest TL right after the LSA was 25 mm, CA segment 20 mm, and IMA segment 18 mm. After TEVAR and during follow-up, the medians were 33 mm (p<0.001), 26 mm (p<0.001), and 19 mm (p=0.001), respectively.

The preoperative widest median diameter of the FL right after the LSA was 17 mm, CA segment 14 mm, and IMA segment 5 mm. After TEVAR and during follow-up, the medians were 0 mm (p<0.001), 0 mm (p=0.021), and 0 mm (p=0.026), respectively.

Lumen measurements are summarized in Table 3.

Complete FL thrombosis in all 3 levels occurred in 27 patients (57%).

In all, 93% of patients had complete thrombosis of the FL of the descending thoracic aorta, 67% of the TA junction, and 48% of the abdominal aorta.

During follow-up, 1 (2%) patient had aneurysmal dilatation of the descending thoracic aorta that required endovascular coverage down to the celiac trunk 2 years after their initial TEVAR.

Two patients (4%) developed a type 2 TA aneurysms (Crawford classification). One patient had open surgical repair 6 years after initial TEVAR and the second had hybrid surgery 10 years after initial TEVAR.

One-, five-, and ten-year survival was 85% (95% confidence interval = 75%–96%), 76% (67%–91%), and 65% (50%–86%), respectively (Figure 2). The patient who developed an oesophageo-aortic fistula died 4 months after TEVAR.
Figure 1. Box and whisker plot of total aortic diameter just distal to the left subclavian artery, celiac artery, and inferior mesenteric artery before intervention and on latest follow-up imaging. Diameter in millimeters.

Table 3. Median Lumen Measurements (mm) and Interquartile Range Before and After TEVAR.a

<table>
<thead>
<tr>
<th>Aortic segment</th>
<th>Before TEVAR</th>
<th>After TEVAR</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LSA</td>
<td>CA</td>
<td>IMA</td>
</tr>
<tr>
<td>True lumen</td>
<td>25 (13)</td>
<td>20 (11)</td>
<td>18 (8)</td>
</tr>
<tr>
<td>False lumen</td>
<td>17 (9)</td>
<td>14 (12)</td>
<td>5 (11)</td>
</tr>
<tr>
<td>Whole lumen</td>
<td>40 (10)</td>
<td>33 (6)</td>
<td>22 (6)</td>
</tr>
</tbody>
</table>

Abbreviations: CA, celiac artery; IMA, inferior mesenteric artery; LSA, left subclavian artery; TEVAR, thoracic endovascular aortic repair.

aMost recent measurement available.

Figure 2. Kaplan-Meier survival curve and risk table for patients undergoing TEVAR for complicated acute and subacute complicated type B dissection. TEVAR, thoracic endovascular aortic repair.

TEVAR. The patient operated for a type 2 TA aneurysm died after surgery. Three patients died from unknown cause, respectively, 1, 2, and 6 years after TEVAR. Three other patients died 2 years after TEVAR, 1 from type A aortic dissection, 1 from respiratory tract infection, and 1 from prostate cancer. Kaplan-Meier time-to-event analysis for re-interventions is depicted in Figure 3.

Discussion

In this study, after a mean follow-up of 54 months, a 4% risk of aneurysmal evolution of the TA aorta after coverage of the proximal entry tear is reported. After closure of the proximal entry tear during the acute and subacute phase, FL flow may persist in the lower thoracic and abdominal aorta due to re-entry tears but, by stopping the antegrade flow, shrinkage of the FL at all aortic levels and increase of the
TL was obtained. In 41 (95%) patients, TEVAR alone was sufficient to prevent aneurysmal evolution of the TA aorta after a mean follow-up of 54 months.

These results suggest that the risk of aneurysm degeneration after proximal TEVAR for acute and subacute type B aortic dissections is low (4%). These results are similar to other studies. Rodriguez et al did not observe aortic diameter expansion in segments distal to the stented region when they analyzed aortic diameters in 106 patients during follow-up after TEVAR for acute or chronic type B dissection.10

Debate exists regarding the need for extensive coverage of the descending thoracic and abdominal aorta at an early stage to obtain expansion of the TL and eliminate retrograde flow and allow remodeling. To promote TL expansion and FL thrombosis, some authors have proposed the use of bare metal stents in the distal TA aorta. The PETTICOAT (or Provisional Ex-Tension To Induce Complete ATtachment) technique was first reported in 2005 by Mossop and colleagues11 and in 2006 a series of 12 cases was reported.12 This technique eliminates the entry tear and increases the TL diameter in the distal aorta through a combination of stent grafting and bare metal stenting of the visceral and infrarenal segments.

As previously demonstrated in a meta-analysis, the combination of proximal stent grafting with distal bare stenting for the management of aortic dissection clearly improved TL perfusion and diameter; however, it failed to suppress FL patency completely.13 At 1 year, FL patency was still present in 29.6% of the patients at the thoracic level and in 86.5% of the patients at the abdominal level. Data on patients for whom complete imaging was available beyond this period were limited. Yang and colleagues14 studied aortic remodeling after TEVAR for acute and chronic dissection, and they reported a comparable rate of FL patency of 19.4% at the thoracic level at 1 year. Extensive coverage carried nontrivial risks of severe complications such as retrograde extension of the dissection into the ascending aorta, neurological complications, and aortic ruptures (3.7% vs 1.8%, 5.5% vs 3.1%, and 3.7% vs 1.8%).

In a recent meta-analysis, Bertoglio et al15 studied all articles comparing TEVAR + distal bar stenting versus TEVAR alone and showed that the combination of both techniques improves TL expansion of the distal TA aorta possibly improving end-organ perfusion. However, there is no evidence of improved short- or mid-term positive remodeling of the FL in the distal aorta, when compared with a simple proximal stent grafting.

Sobocinski et al reported an aortic volume analysis of patients receiving TEVAR alone compared with those treated with the STABLE (Staged Thoraco-Abdominal and Branch vessel Endoluminal repair) technique for the treatment of acute type B dissection.16 Significant remodeling in both TL and FL was seen with both strategies. In the thoracic aorta, both groups showed significant TL expansion and FL reduction. Although a total increase of thoracic aortic diameter was in favor of STABLE, the proportions of patients who experienced >10% changes were not significantly in this group. Furthermore, the total diameter is greater in the STABLE group due to a possible greater oversizing of the stent grafts in comparison with the TEVAR group. Also, the initial FL diameter in the STABLE group was significantly higher. In the abdominal aorta, FL decrease was significant in the STABLE group but no significant difference between total diameters was seen between the 2 groups and the total abdominal aortic size increased similarly in both groups.

Recently, a series of 41 patients treated according to the STABILISE technique (Stent Assisted Balloon Induced Intimal Disruption and Relamination in Aortic Dissection Repair) showed that total aortic remodeling in the non-stented area occurred in only 39% of patients, leading to aortic diameter growth in 5% of patients during a mean follow-up of 12 months. Furthermore, a re-intervention rate of 20% was observed due to iliac thrombosis, endoleaks, and visceral stent graft thrombosis. Primary visceral patency rate was 93%.

Aneurysmal risk factors after TEVAR should be considered in the choice of a more extensive coverage strategy. Pre-operative thoracic false lumen branches (TFLB) are associated with more aneurysmal degeneration. Yan et al conducted a retrospective study on 67 patients with DeBakey III b dissections initially treated with TEVAR with a median imaging follow-up of 12.2 months and reported a significantly higher proportion of aneurysmal evolution in patients with 8 or more TFLB.18 Furthermore, patients who had less than 8 TFLB experienced a significant shrinkage in the distal aorta due to more frequent complete FL thrombosis. Conversely, patients with 8 or more TFLB had an increased risk of FL evolution.
TFLB had frequent partial FL thrombosis, which was associated with a higher risk of aneurysmal degeneration.

Another risk factor to keep in mind is the presence of distal entry tears. Chenmou et al compared aortic remodeling between 2 groups of patients treated by TEVAR, one group without distal entry tears (group A) and another with distal entry tears (group B). During a median follow-up of 29 months, group A had a higher rate of complete thrombosis in the thoracic aorta than group B. The diameter reduction of the thoracic aorta was more in group A than in group B. At the abdominal level, maximum aortic diameter in group A decreased; however, it continued to expand in group B. In summary, distal entry tears increase the occurrence of late aortic events and inhibit aortic remodeling with acute type B aortic dissection patients after TEVAR. The authors reported that distal entry tears had bidirectional blood flow, inducing increased FL pressure and wall shear stress and inhibiting progression of FL thrombosis.19

Our study has several limitations due to its small sample size. Retrospective data collection is subject to bias. Finally, it is a single center study that reflects only an isolated experience among others and larger studies are necessary to confirm our promising results.

**Conclusion**

This study suggests that TEVAR, despite the non-negligible rate of complication in this challenging subgroup of patients, is an efficient procedure in treatment of complicated acute and subacute type B dissection. TEVAR helps to prevent aneurysmal progression, allowing growth in the TL while shrinking the FL diameters. The low rate of re-intervention for distal aneurysmal progression suggests that proximal entry tear coverage should be considered the first-line strategy for managing complicated acute and subacute dissections. Adjunctive distal coverage can be considered in cases of persistent distal malperfusion syndrome after careful evaluation of the immediate results of primary entry tear closure.20

**Declaration of Conflicting Interests**

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

**Funding**

The author(s) received no financial support for the research, authorship, and/or publication of this article.

**References**


