Thoracic or Thoracoabdominal Approaches to Endovascular Device Removal and Open Aortic Repair

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Background. Endovascular aortic repair is becoming increasingly common and diverse in its application despite ongoing uncertainty about long-term durability. Recent reports detail late conversion to open surgical repair to treat disease progression and repair failure. We describe our experience with using thoracic or thoracoabdominal approaches to endovascular device removal and open aortic repair after previous endovascular procedures.

Methods. Thirty-five patients underwent open aortic repair through thoracotomy (n = 7) or thoracoabdominal incision (n = 28) 0.5 to 48 months after undergoing endovascular thoracic (n = 27) or abdominal (n = 8) aortic procedures. Indications for open repair included expanding aneurysm (n = 23), device infection (n = 8), fistula (n = 5), pseudoaneurysm (n = 2), aneurysm rupture (n = 2), and restenosis (n = 1). Endovascular devices were completely removed in 26 patients and partially removed in 9. Descending thoracic aortic repair was performed in 10 patients, thoracoabdominal aortic repair in 24, and juxtarenal abdominal aortic repair in 1.

Results. There were 2 in-hospital deaths (6%), both in patients who presented with endovascular device infection. There were 8 late deaths. Overall 1-year survival was 83% ± 7%. Among the patients who presented with infected devices, 3 experienced major late complications, including persistent infection, pseudoaneurysm, and recurrent fistula; 2 of these patients succumbed to late deaths.

Conclusions. Open surgical repair after previous endovascular aortic procedures is successful in the majority of patients, particularly in those without device infections. Achieving definitive aortic repair in patients with infected endovascular devices is particularly challenging.


Endovascular repair of the abdominal aorta and descending thoracic aorta (DTA), which is generally considered to have less early morbidity and mortality than traditional open aortic repair, appeals to both patients and clinicians. Long-term durability after endovascular aortic repair (EAR) can be compromised by disease progression and several modes of repair failure, including endoleak with aneurysm expansion, aortic rupture, and stent-graft infection. Although many secondary interventions after EAR can be performed endovascularly, several recent patient series describe late conversion to open repair [1–11]. The review of such patients could be beneficial in elucidating the circumstances surrounding late conversion and in describing related technical considerations. Here, we describe our experience with 35 patients who underwent late conversion to open aortic repair through a thoracic or thoracoabdominal approach after previous EAR.

Patients and Methods

Study Enrollment and Patient Characteristics
Institutional review board approval was obtained from Baylor College of Medicine, allowing the collection and analysis of clinical data. Informed consent was obtained from all patients enrolled after protocol approval; the institutional review board granted waiver of consent for patients who underwent surgery before protocol approval. Using these data, which were collected from a single clinical practice, we reviewed the techniques and results of open operations comprising endovascular device removal and aortic repair performed through a thoracic approach after previous EAR. We excluded cases in which EAR failures were repaired with endovascular techniques. Further, to focus on cases involving device removal, we included only patients who had at least a partial device extraction; we did not include patients in whom a device was entirely salvaged and incorporated.

Dr Coselli discloses that he has financial relationships with Cook, Inc, Medtronic, Inc, W.L. Gore & Associates, Inc, and Vascutek Terumo.
into secondary open repair (eg, to treat disease progression involving only the adjacent aorta) or patients who underwent open device extraction and aortic repair through an abdominal incision only.

Applying the abovementioned criteria, we identified 35 consecutive patients—22 men (63%) and 13 women (37%)—who underwent open operations between November 1996 and June 2011 for endovascular device removal and aortic repair by means of a thoracotomy or thoracoabdominal incision. Nearly half of the patients (n = 16, 46%) had either a documented or a suspected genetic condition associated with their aortic disease. Eight of these patients (23%) had Marfan syndrome, and 2 (6%) had Loeys-Dietz syndrome; 6 other patients (17%) presented with aortic disease when younger than 50 years of age. More than half of the patients (n = 18) had prior open surgery for aortic repair (Figs 1, 2). In most patients (n = 31, 89%), the primary endovascular procedure (Table 1) was performed outside our institution, including 4 performed in other countries (11%). Whenever possible, reports regarding the primary EAR, subsequent imaging studies, and any secondary or tertiary aortic repairs were obtained and reviewed. Twenty-four patients (69%) had stent-grafts placed in the DTA, 7 (20%) had stent-grafts placed in the abdominal aorta, 3 (9%) had uncovered stents placed in the DTA, and 1 (3%) had an uncovered stent placed in the abdominal aorta. Six patients had undergone hybrid endovascular repairs, including DTA stent-graft placement after elephant trunk arch repair (n = 4; Fig 2), the frozen elephant trunk procedure (n = 1), and aortic arch plus DTA stent-graft placement after arch debranching (n = 1). Sixteen patients (46%) underwent secondary endovascular procedures to treat repair failures before ultimately having open repair; 3 patients (9%) had tertiary endovascular procedures. Ten patients (29%) had four or more devices placed before late open conversion.

Preoperative variables included the mode of EAR failure, including endoleak, aortic aneurysm expansion, and suspected infection. In 8 patients (23%), endovascular device infection was suspected preoperatively because of the clinical situation (eg, persistent unexplained fevers, sepsis) and imaging findings (eg, evidence of fistula; Fig 3). Twenty-three patients (66%) had documented expansion of their aortic aneurysm. Aneurysm expansion was extremely rapid (Fig 4) in 5 patients who exhibited changes in aortic diameter that exceeded 0.5 cm within a 1-month period (median, 2.0 cm/month; range, 0.9 to 3.9 cm/month). The youngest patient had an unusually long coarctation involving the entire thoracoabdominal aorta that had been repeatedly treated with balloon angioplasty and stent placement. At the time of referral, his aortic lumen was severely compromised by a hyperendothelialization reaction to the uncovered stents.

Surgical Procedures

The average interval between EAR and device explantation was 18.4 ± 21.7 months (median, 11.0 months; range, 0.5 to 48 months); 19 patients (54%) underwent explantation within the first year, 12 (34%) within 6 months, and 10 (29%) within 3 months. Of the 5 patients identified as having extremely rapid aneurysm expansion, 3 underwent explantation within 1 month of EAR.

Operative techniques used during open aortic repair
are described in Table 2. Typically, exposure was attained in a standard fashion according to the extent of repair, as described elsewhere [12–14]. However, it was not uncommon in these complex repairs to modify our standard incision in an attempt to enhance exposure. For example, we often entered the thorax through the fifth intercostal space (instead of the sixth) when dealing with stent-grafts that involved the aortic arch. Similarly, we liberally used the thoracoabdominal approach to ensure adequate exposure of the upper abdominal aorta adjacent to device landing zones.

We followed our routine multimodal approach to organ protection during aortic repair [12, 14]. For extensive aortic repairs (extent I and II thoracoabdominal aortic repairs), we usually used left heart bypass and cerebrospinal fluid drainage. We occasionally used cerebrospinal fluid drainage in less extensive repairs (eg, when replacing the DTA in patients with previous abdominal aortic repair).

Whenever possible, we selected the location of proximal clamp placement to avoid trapping the endovascular device. Although we do not routinely use hypothermic circulatory arrest for DTA or thoracoabdominal aortic repairs, we used this approach in 5 patients whose proximal aorta could not safely be clamped because of extension of an endovascular device into the aortic arch (4 patients) or enormous aneurysm size (9.9 cm; 1 patient).

Once the diseased aortic segment was opened, the decision whether to remove all or part of the endovascular device was based primarily on whether infection was present. In 9 cases without infection, partial endograft removal was performed because the stent-graft was well adhered to full-thickness vessel wall (Fig 1B). This was most commonly done if the patient had a well-adhered bifurcated abdominal endograft or if a portion of an endograft could not be safely removed from the aortic arch [13]. When the new graft was sewn to the salvaged endograft, sutures were placed through the endograft (regardless of the type of material) and adherent vascular tissue to ensure a hemostatic anastomosis.

In all 8 patients with device infection, we removed the entire device, often using supplemental surgical techniques to reduce the potential for recurrent infection or to repair a fistula [13]. In patients with fistulas, concomitant procedures included esophagectomy (with reconstruction planned for a later stage), debridement of lung tissue, and jejunal repair. Other techniques used in cases of device infection included placing a rifampin-soaked prosthetic graft (n = 3) or a homograft (n = 1), wrapping the replacement graft with pedicled omentum (n = 5), placing perigraft catheters to permit postoperative irrigation with antibiotics (n = 1), and aortic extirpation after extra-anatomic bypass (n = 1).

Outcomes Variables and Follow-Up
Outcome variables were defined in accordance with our previously published reports [14]. Operative mortality was defined as death within 30 days of operation or before hospital discharge. Hospital discharge was defined as a discharge to home, a rehabilitation facility, or a nursing home and did not include hospital-to-hospital
transfer or transfer to a long-term acute care facility. Late deaths were classified as those that occurred after the operative period. Paraplegia and paraparesis were considered permanent if present at hospital discharge. Patients with acute renal failure who remained on hemodialysis at discharge were considered to have permanent renal failure. The length of stay for surviving patients was the number of days between surgery and discharge, including any time spent at another hospital or a long-term acute care facility.

Current clinical follow-up data were available for most patients; for the 2 patients who were lost to follow-up, current vital status was obtained from the Social Security Death Index database. The average length of follow-up was 26 ± 31 months (median, 13 months; range, 1 to 115 months). A Kaplan-Meier survival curve, computed with SAS 9.2 software (SAS Inc, Cary, NC), was used to estimate late survival rates.

Results

Early Outcomes

Early complications of endovascular device extraction and conversion to open repair are presented in Table 3. In general, patients without infected devices (n = 27) did well and had no early death, no renal complications, few cardiac complications (n = 2), and few pulmonary complications (n = 6). Patients with device infection tended to have a complicated postoperative course; both early deaths occurred in this group (Table 4). The overall mean length of stay was 18 ± 17 days (median, 10 days; range, 6 to 72 days). For the patients with device infection, the mean length of stay was 30 ± 26 days (median, 25 days; range, 6 to 72 days). Six patients were discharged to long-term acute care before final discharge home.

Late Outcomes

Among the 33 early survivors, there were 8 late deaths. These deaths resulted from cardiac complications (n = 3), ruptured abdominal aortic aneurysm (n = 1), graft infection with sepsis (n = 1), recurrent aortobronchial fistula (n = 1), new aortobronchial fistula complicated by sepsis (n = 1), and lung cancer (n = 1). Actuarial survival was 83% ± 7% at 1 year and 64% ± 11% at 3 years (Fig 5).

For the 6 early survivors of infected-device removal, late complications were a persistent threat to survival; these cases illustrate the challenge of achieving definitive repair in patients with infected grafts. One patient with an aortobronchopulmonary fistula had recurrent graft infection; the new aortic graft was entirely replaced in a second open DTA repair 3 months after the original procedure. Although the graft was wrapped with omentum and postoperative antibiotic irrigation was delivered, the patient died of recurrent infection and multiple organ failure 3 months later (Table 4, patient 2). Another patient with an aortobronchial fistula died 1.5 months after the procedure because of profuse hemoptysis, probably caused by recurrence of the fistula (Table 4, patient 6). In another patient, a pseudoaneurysm developed at the anastomosis joining the arch elephant trunk and DTA grafts (Table 4, patient 3) 6 weeks after open conversion; because there was no indication of persistent infection, we repaired the pseudoaneurysm endovascularly by placing a stent-graft across the anastomosis. A pseudo-

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Table 1. Preoperative Characteristics of 35 Patients Who Underwent Endovascular Device Removal and Open Aortic Repair

<table>
<thead>
<tr>
<th>Variable</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial endovascular procedures</td>
<td></td>
</tr>
<tr>
<td>Age at time of endovascular repair (y)</td>
<td>51.9 ± 16.0 (9–78)</td>
</tr>
<tr>
<td>Aortic disease</td>
<td></td>
</tr>
<tr>
<td>Aneurysm without dissection</td>
<td>10 (29%)</td>
</tr>
<tr>
<td>Acute dissection</td>
<td>9 (26%)</td>
</tr>
<tr>
<td>Chronic dissection</td>
<td>12 (34%)</td>
</tr>
<tr>
<td>Pseudoaneurysm with infection</td>
<td></td>
</tr>
<tr>
<td>(after open aortic repair)</td>
<td>2 (6%)</td>
</tr>
<tr>
<td>Fistula (after open aortic repair)</td>
<td>1 (3%)</td>
</tr>
<tr>
<td>Severe thoracoabdominal aortic coarctation</td>
<td>1 (3%)</td>
</tr>
<tr>
<td>Patient characteristics at time of open intervention</td>
<td></td>
</tr>
<tr>
<td>Age at time of surgery (y)</td>
<td>53.6 ± 16.4 (12–82)</td>
</tr>
<tr>
<td>Endoleak</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>14 (40%)</td>
</tr>
<tr>
<td>Type I*</td>
<td>18 (51%)</td>
</tr>
<tr>
<td>Type II*</td>
<td>4 (11%)</td>
</tr>
<tr>
<td>Type III</td>
<td>2 (6%)</td>
</tr>
<tr>
<td>Expanding aneurysm</td>
<td>23 (66%)</td>
</tr>
<tr>
<td>Device infection</td>
<td>8 (23%)</td>
</tr>
<tr>
<td>Fistula</td>
<td>5 (14%)</td>
</tr>
<tr>
<td>Pseudoaneurysm</td>
<td>2 (6%)</td>
</tr>
<tr>
<td>Aneurysm rupture</td>
<td>2 (6%)</td>
</tr>
<tr>
<td>Recurrent thoracoabdominal aortic stenosis</td>
<td>1 (3%)</td>
</tr>
</tbody>
</table>

* Three patients had both type I and type II endoleaks.
Aneurysm involving the visceral patch was then identified and primarily repaired during an open operation. This patient was in good health at 1-year follow-up.

In contrast, aortic repairs remained intact in all but 1 of the 27 patients without endograft infection. One patient with Loeys-Dietz syndrome experienced sepsis and an aortobronchial fistula and died of massive hemoptysis 4 months after undergoing thoracic endograft removal and extent I thoracoabdominal aortic replacement. Two patients with Marfan syndrome had aortic complications related to disease progression. One patient died of a ruptured abdominal aortic aneurysm 31 months after undergoing thoracic endograft removal and DTA replacement. Another patient presented with acute ascending aortic dissection 3 years after undergoing thoracic endograft removal and DTA replacement; she underwent successful emergent surgical repair of the aortic root, ascending aorta, and aortic arch.

**Comment**

Although the frequency of open conversion is difficult to determine because of the lack of large series with long-term follow-up, emerging reports and trends observed in our own tertiary referral center suggest that these procedures have become more frequent in recent years. Pivotal trial data supporting thoracic EAR indicated that open conversion after failed EAR was rare, occurring in only 7 of 497 patients (1.4%) [15–17]. In recent reports, rates of late open conversion after EAR range from 2.2% to 6.2% for thoracic procedures [2, 4, 6, 18] and 0.9% to 2.1% for abdominal procedures [1, 7, 8, 11].

Factors associated with late open conversion include connective tissue disorder, dissection, aneurysm size, hybrid aortic repairs, using three or more stent-grafts, procedural complications during EAR, disease progression, late endoleaks, late retrograde aortic dissection, device migration, and infection [4, 5, 19]. It is notable that several of these factors reflect off-label applications of EAR and that 71% of the patients in our series had undergone off-label EAR procedures. For example, 60%...
of patients who underwent EAR had acute or chronic aortic dissection (Figs 1, 2). Many of these patients eventually presented with disease progression and aneurysm expansion as the false lumen continued to receive retrograde blood flow from distal reentry sites. Additionally, 29% of our patients had connective tissue disorders. Failures after EAR are not surprising in such patients because their inherently weak aortic tissue is poorly suited for maintaining secure seals at the landing zones. Indeed, in an analysis of 422 patients who underwent thoracic EAR, Ehrlich and colleagues [4] found that Marfan syndrome was the second best independent predictor of late conversion. Whether similar problems with long-term durability will manifest in patients with nonsyndromic, genetically triggered aortic disease remains to be seen. The use of stent-grafts to cover fistulas or pseudoaneurysms associated with infection is another off-label EAR scenario we encountered. Emergent EAR can be lifesaving in patients who present with severe hemorrhage from such lesions. Patients successfully treated in this manner invariably need subsequent open conversion to achieve definitive repair [5].

We identified a subset of our patients as having extremely rapid aneurysm expansion (ie, >5 mm/month; Fig 4). Aortic aneurysm expansion generally progresses slowly, even for survivors of acute dissection [20], and ranges from 1 mm to 4 mm per year depending on anatomic location. After EAR, aortic diameter usually shrinks or remains stable despite the radial pressure exerted by the endograft itself [21]. However, evidence from pivotal trials suggests that a small proportion of patients (7% to 19%) have post-EAR aortic expansion that exceeds 5 mm; in many of these patients, the aortic expansion does not appear to be associated with an endoleak [15–17, 22]. In our series, patients with rapid aortic expansion tended to be young and have aortic dissection. Further studies elucidating the characteristics of patients prone to rapid aneurysm expansion after EAR would be beneficial.

Patients with infected endovascular devices are particularly challenging to treat. In such patients, open aortic repairs are associated with an early mortality rate up to 25% [10, 23]. Many of these patients have associated fistulas, which further complicate repair procedures [24]. Fistula has been described as an infrequent complication of EAR; however, it may be more prevalent than previously thought. A single-center German study identified aortoesophageal fistula in 6 of 268 thoracic EAR patients (2.2%), which was fatal in all cases [25]. Likewise, an Italian national survey determined that aortoesophageal or aortobronchial fistula occurred in 19 of 1,113 thoracic EAR patients (1.7%); all but 3 of these patients died shortly after fistula discovery [26]. Although a broad range of techniques were used to remove infected devices and repair the involved aorta in our series, several patients had fatal complications, including recurrent infection or fistulization.

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Age (y)</th>
<th>Fistula Type</th>
<th>Postoperative Status</th>
<th>Cause of Death</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>66</td>
<td>Aortoesophageal</td>
<td>In-hospital death</td>
<td>Pneumonia, sepsis, multiple organ failure</td>
</tr>
<tr>
<td>2</td>
<td>61</td>
<td>Aortobronchopulmonary</td>
<td>Reoperation for graft infection; late death at 6.5 months postoperatively</td>
<td>Recurrent infection, multiple organ failure</td>
</tr>
<tr>
<td>3</td>
<td>56</td>
<td>None</td>
<td>Reoperation for pseudoaneurysm; alive at 51.5 months</td>
<td>N/A</td>
</tr>
<tr>
<td>4</td>
<td>39</td>
<td>None</td>
<td>In-hospital death</td>
<td>Rupture of homograft, multiple organ failure</td>
</tr>
<tr>
<td>5</td>
<td>65</td>
<td>None</td>
<td>Alive at 23 months</td>
<td>N/A</td>
</tr>
<tr>
<td>6</td>
<td>61</td>
<td>Aortobronchial</td>
<td>Late death at 1.5 months postoperatively</td>
<td>Hemothoysis from apparent recurrent fistula</td>
</tr>
<tr>
<td>7</td>
<td>69</td>
<td>Aortoesophageal</td>
<td>Alive at 3 months</td>
<td>N/A</td>
</tr>
<tr>
<td>8</td>
<td>66</td>
<td>Aortoenteric</td>
<td>Alive at 1.5 months</td>
<td>N/A</td>
</tr>
</tbody>
</table>

N/A = not applicable.
This retrospective study has several limitations. Because most of our patients were referred from other sites, we could not make any inferences about the frequency of open conversion after EAR. Also, our study was hindered by the limited availability of detailed preoperative data because we relied on medical records and imaging obtained elsewhere. Specific details about the types of endografts removed were often not available. Additionally, because the overall sample size was small, we could not perform any analysis to identify predictors of open conversion or to determine whether any particular device was better suited for partial extraction. Finally, our late survival estimate was hampered by the fact that many of the patients were treated fairly recently.

Despite these limitations, our review shows that patients who need late open conversion and device removal after EAR are likely to survive, provided that they do not have an infected device. Unfortunately, patients with device infection, particularly when associated with fistulae, have a poor prognosis. Future studies that identify specific factors that predict the need for secondary procedures after EAR will be extremely helpful. Such insight will improve surgeons’ ability to select the best initial treatment approach and, when EAR is performed, to appropriately tailor postrepair surveillance strategies.

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References

DISCUSSION

DR TOMAS D. MARTIN (Gainesville, FL): Doctor Kim, you said you had 21 endoleaks and 1 coarctation. Do you know what type of endoleaks those were, and were there any attempts to fix those endoleaks endovascularly?

DR KIM: During the interim period, 19 endovascular reinterventions were tried in 16 patients.

DR MARTIN: Do you know if they were type I or type II endoleaks?

DR KIM: Fifteen had a type I endoleak, 1 had a type II endoleak, 3 had a type 1 and II combined leak, and 2 had a type III endoleak.

DR MARTIN: Do you know what the cause of the coarctation was?

DR KIM: The patient was congenital, coarctation of aorta patient. Actually, he just was included in this study, but he didn't have any aneurysm on his aorta. But he had an endovascular stent anyway, so we included the patient.

DR SAQIB MASROOR (Milwaukee, WI): Excellent presentation. Thank you for this work. Some groups have talked about using the stent-grafting for aortoesophageal fistulas and other fistulas, which are obviously infected. Looking at these data, do you recommend endografting in such cases, which have a significantly high risk of infection?

And the second question was type II endoleaks: how do you follow them, when do you decide to operate on them?

DR KIM: Did you ask about how to treat the infection?

DR MASROOR: What do you think about using endografting for aortoesophageal fistulas, which have been reported? People have suggested using them in cases where there is obviously infection such as these.

DR KIM: Thanks for your question. In patients with aortoesophageal fistula, actually just stenting is not a permanent treatment for the patient. It can be used as just a bridging treatment for the later open surgery when the patient's condition is better. In that case, stenting would be not a good option for that case.

DR MASROOR: And when do you operate on type II endoleaks?

DR KIM: Mostly, type II endoleak is not an indication for open repair. In most of the cases, the type II endoleak will disappear and doesn't cause any problem. We check the diameter of the aneurysm, and then if it dilates during the follow-up, we repair the aneurysm.

DR MASROOR: I just had 1 patient who died from a rupture with no enlargement in size but had a persistent endoleak, and actually, the graft size had gone from 6 cm to about 5.8. But he ruptured at an outside hospital. We were transferring him over, and during that time he just crashed and died.

DR ERIC ROSELLI (Cleveland, OH): Congratulations on a fine presentation. I think it is important that you and Dr Coselli present this work because, as we see, it highlights the important need for cardiovascular surgeons to be involved with stent-grafting, because we will need to take care of these patients afterward, and the better you understand the devices, the better you will be able to take care of the complications as well. That is a comment. I do have a question.

I noticed that 80% of the patients had their stent-graft removed. We have also operated on many of these patients for late complications, and I think in a greater proportion of them, we have opted to leave the stent-graft in place so as not to extend the operation into a very proximal portion of the aorta. How is the decision made to remove the stent-graft, and why did you think that that was necessary? Can you give us some insight, please?

DR KIM: Our strategy for the patient who had a stent-graft inside is total removal of the stent-graft; especially it is important for a patient who presented with an infection. In this study, in 9 patients we left the stent-graft in place. Some patients had EVAR [endovascular abdominal aortic repair], and the iliac limb was very hard to pull out. So we either just used it as a tunnel for the limb, or when we didn't need to go down to the iliac arteries, we just sewed the distal suture line above the bifurcation of the aorta.

DR ACCOLA: Joe, would you like to comment on that?

DR COSELLI: The work does raise the issue that when infection is involved, the results of this generally have been rather poor. But specifically on his question of leaving some of it behind: number one, if infection was involved, we opted to take out all the stent-graft and clean out the whole area, but in patients who had bifurcation grafts and the iliac arteries were well healed to the stent-graft, we would leave that behind. And even in the descending thoracic aorta or the lower portion of an EVAR, if the outer wall of the aneurysm was adherent to and adjacent to the stent-graft, we might leave that behind. But if the stent-graft, for instance, was lying in the true lumen of a dissection and the outer wall was at some distance from it, in most cases we chose not to suture directly only to the stent-graft. But if we couldn't incorporate the outer wall, we would move up to a level where we could, and, as a result, in about four cases we left portions of stent-grafts behind where there wasn't infection.