Infected Aortic Grafts in the Descending Thoracic Aorta

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80.1 Introduction

Prosthetic graft or endograft infection is a rare but devastating complication of aortic surgery. The incidence of infected descending and thoracoabdominal prosthetic grafts is reported between 0.5 and 1.7%, including early and late infections with and without aortoesophageal fistulae [1, 2]. The prevalence of infected aortic endografts is 0.25–4% [3–5]. The management of infected descending thoracic or thoracoabdominal aortic grafts or endografts is complex, requiring multiple steps, including initial stabilization, systemic antibiotics, graft or endograft excision, debridement of devitalized tissues, repair of aortobronchial or aortoesophageal fistula when present, revascularization, and pedicled flap coverage [1]. There are reports of non-excisional management, but this should be reserved for exceptional cases [6, 7]. Stent graft deployment to stabilize patients with massive hemoptysis or hematemesis in cases of aortobronchial or aortoesophageal fistulae is considered a suitable emergent treatment. However, this should be considered a bridging procedure in preparation for definitive repair [8–10].

80.2 Diagnostic Testing

Constitutional symptoms of infection, such as fever, sweats, lethargy, and pain often prompt medical attention. However, many cases are nonspecific and subtle [11]. Once there is a suspicion of graft infection, laboratory testing is obtained, including complete blood count, metabolic panel, and blood cultures. Broad-spectrum intravenous antibiotics are begun after cultures are obtained. The test of choice for initial imaging study is computed tomography (CT) scan with aortic-phase intravenous contrast (Fig. 80.1). Signs of graft infection include gas pockets surrounding the graft, new pseudoaneurysm, or tissue stranding [12]. CT has a sensitivity and specificity of 94% and 85%, respectively, in detecting graft infection, but sensitivity decreases significantly to 55% in chronic infection [13, 14]. Magnetic resonance imaging (MRI) is an acceptable alternative and has similar sensitivity and specificity as CT. However, MRI does not differentiate between the signal void created by calcification and air [1, 2]. Labeled white cell scans demonstrate varying sensitivity in detecting graft infection ranging from 60 to 100% [11, 14]. This study is utilized more in subacute and late infections.

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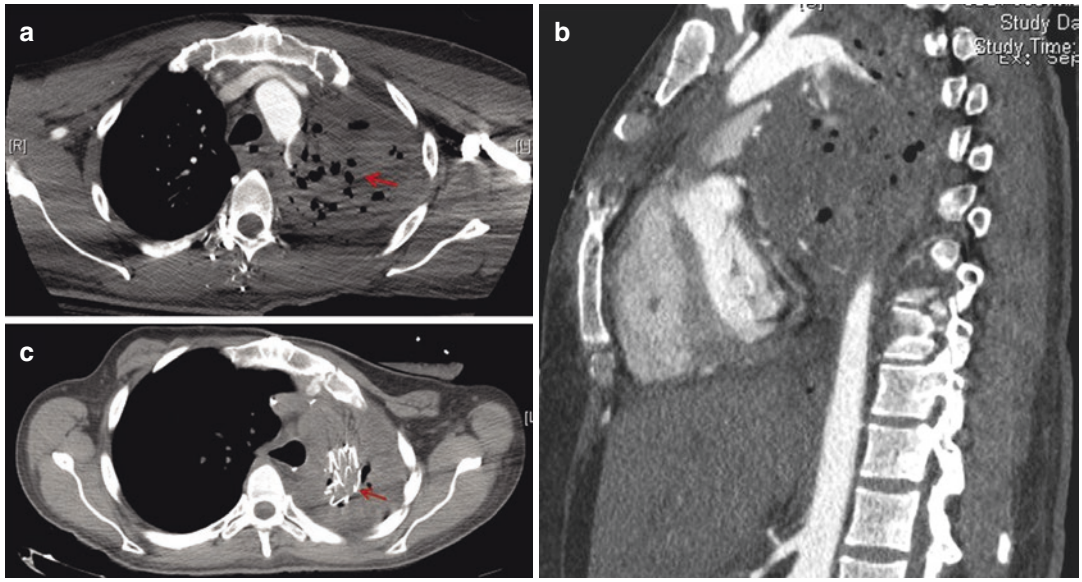

Fig. 80.1 (**a**) Axial view of thoracic CTA of an infected descending thoracic aortic graft demonstrating air pockets in the left hemothorax (arrow). (**b**) Sagittal reconstruction of the same CTA. (**c**) Axial view of thoracic CT of an infected thoracic aortic endograft (arrow)

The inability to define presence or absence of graft involvement in adjacent soft tissue infection is considered one of its limitations [15, 16].

Fluorodeoxyglucose positron-emission tomography (FDG-PET) (Fig. 80.2) with co-registered CT (FDG-PET/CT) combines conventional scintigraphy and CT. FDG-PET and FDG-PET/CT have been shown to have a high sensitivity of 91% and 93% and a specificity of 64% and 88%, respectively [17–19]. However, FDG-PET/CT may lead to false-positive results, since tissue surrounding vascular grafts often displays high accumulation of 18 F-FDG without infection [17, 19–21].

80.3 Treatment

Infections of grafts and endografts of the descending/thoracoabdominal aorta are life threatening and require early diagnosis and appropriate treatment, including surgical intervention and antimicrobial therapy to improve survival. The operative mortality of open surgical repairs in such cases is reported between 25 and 75% [7, 22–24]. The aim of surgical treat-

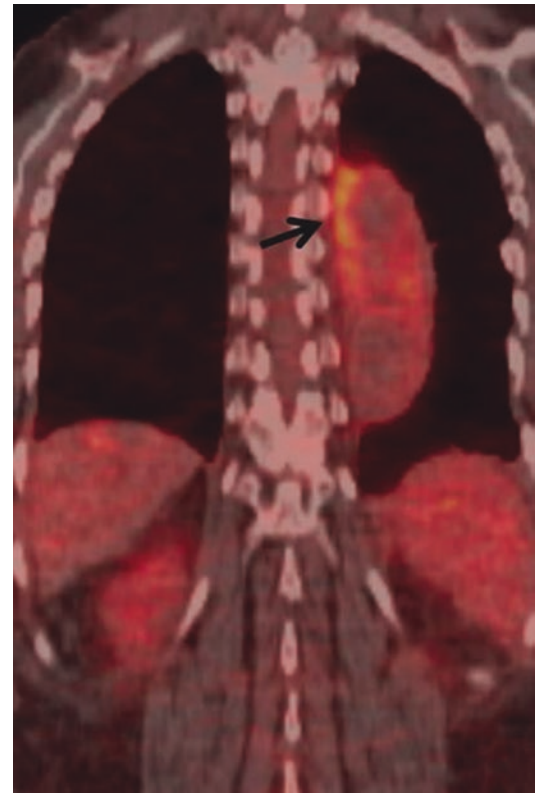

Fig. 80.2 Coronal reconstruction of FDG-PET/CT for and infected thoracic aortic graft

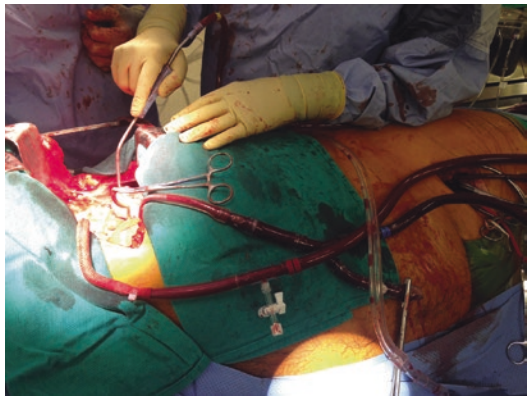

Fig. 80.3 Establishment of cardiopulmonary bypass in preparation for deep hypothermic circulatory arrest in descending aortic repair

ment is debridement of devitalized tissue, removal of grossly infected material, and revascularization of the distal aorta and branches.

80.4 Anatomy

The previous graft/endograft position is important in planning the second surgery. In some cases, access to the aortic arch may be required for proximal clamp placement. Many thoracic endografts are positioned at or near the origin of the left subclavian artery. Some have bare metal struts extending proximally into the aortic arch. In such cases, consideration should be given to performing the procedure with cardiopulmonary bypass and deep hypothermic circulatory arrest. (Fig. 80.3).

In other cases, a thoracoabdominal aortic exposure is required for distal aortic clamping, for example, when fenestrated or branched endografts were used or when a thoracic endograft with distal uncovered struts extends into the thoracoabdominal aorta, e.g., Cook TX2 distal extensions.

80.5 Graft Excision and Extra-anatomic Bypass

Graft excision without revascularization is not possible in the descending thoracic/thoracoabdominal aorta. Although revascularization with extra-anatomic bypass is often utilized in the abdominal aortic graft infections, this is frequently not possible in the descending thoracic/thoracoabdominal aorta without compromising renal and visceral arteries [25].

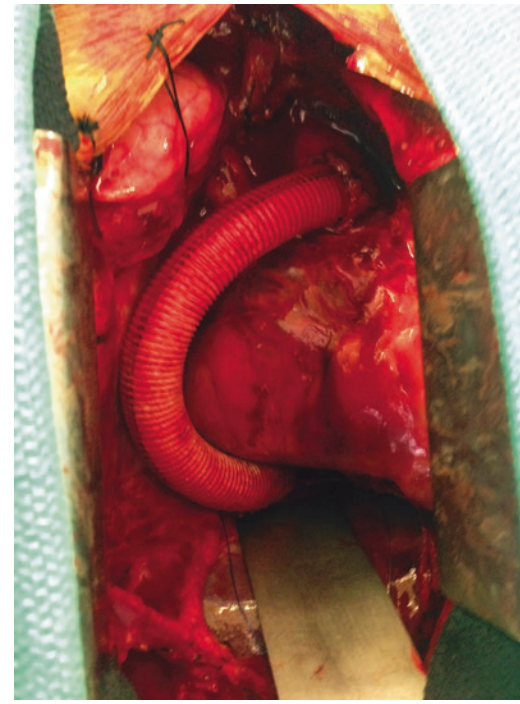

Fig. 80.4 A prosthetic graft bypass from the ascending aorta via median sternotomy to the abdominal aorta

The most appropriate extra-anatomic bypass described for the descending thoracic aorta is a prosthetic graft bypass from the ascending aorta via median sternotomy or right thoracotomy to the abdominal aorta [26–28] (Fig. 80.4). The main advantage of this bypass is that it is routed through a non-infected tract and at a safe distance from the contaminated previous graft. There are some disadvantages and contraindications for such bypass, including the need to reattach intercostal arteries for spinal cord blood supply and visceral arteries or massive hemorrhage that requires immediate control of the aorta. In some centers, an endovascular stent graft repair is a reasonable option for emergency control of hemorrhage as a bridge to more definite treatment [8, 9].

80.6 Graft Excision with In Situ Bypass

80.6.1 Cadaveric Allografts

The use of arterial allografts was described over a decade ago in animal experiments [29, 30]. In the years to follow, case reports using fresh allografts have been described [31, 32]. However, when fresh allografts were used in replacement of infected infrarenal aortic grafts, 9% of the patients required reoperation after 1 year due to pathological changes of the allografts, such as aneurysmal degeneration [33].

Using cryopreserved homografts requires special preparation and thawing prior to usage. When large vascular segments are involved in the infection (such as the thoracoabdominal aorta), several allografts are needed to achieve adequate reconstruction, and allografts may be more expensive than conventional prosthetic grafts. In a retrospective review, Vogt et al. compared conventional techniques using prosthetic grafts with allograft surgery for infrarenal aortic graft infections, and the results in the allograft group were superior to the conventional group. In the earlier series, they reported allograft-related technical complications in 20% of the cases, including friability of the grafts and graft-enteric fistulae developing between tied side branches and the bowel [34–39]. In our previous experience, we also had difficulty with fracture of the intercostal branches that were tied using polypropylene suture that led us to resecure all intercostal side branches with silk sutures. Other publications have described the use of allograft in descending and thoracoabdominal aortic graft infections, with particular benefit in the presence of aorto-esophageal and aortobronchial fistula [35, 40, 41]. The major disadvantages of cadaveric allografts are availability and cost. Many patients with thoracic graft infection present as an emergency and cannot wait for appropriate allograft procurement [38]. One solution to this is on-site storage. At our institution, we keep a selection of grafts on hand, but this is expensive. The US cryopreserved aortic allograft registry reviewed 31 institutions' experience with cryopreserved aortic allograft placement. The mean follow-up period was 5.3 months, and overall mortality rate was 25%. They failed to prove superiority and justify the preferential use of allografts over conventional prosthetic grafts for primary graft infection, mycotic aneurysm, or aortic graft-enteric fistula [42]. Nevertheless, homograft replacement of infected grafts remains a useful option.

80.6.2 Other Biological Alternatives to Allografts

The use of autologous femoral or iliac veins in reconstructing the aorta has been described in the infrarenal abdominal aorta [43–46]. It has a limited role in the treatment of descending thoracic aortic graft infections due to diameter discrepancy and the need for extended vein length. However, it has been described in several cases where the infection was limited to a short segment of the descending aorta [47, 48].

80.6.2.1 Tissue-Engineered Vascular Grafts

Tissue-engineered vascular graft (TEVG) was first reported in 1986 by Weinberg and Bell [49]. The goal of tissue engineering is to produce a biological tissue that can replace a damaged human tissue/organ and restore its function. The concept of tissue engineering requires three components: the extracellular matrix (ECM), the cells, and the signaling system for remodeling [50]. Over the last two decades, multiple publications have demonstrated the clinical application of tissue engineering, starting in animal models and continuing to human trials [50–53].

CorMatrix is a Food and Drug Administration-approved ECM for use in cardiovascular surgery. It is a decellularized ECM from porcine small intestinal submucosa, which has been reported as an alternative to synthetic grafts/patches in cardiovascular surgery [54–59]. TEVG have the potential to become a promising alternative in the future for allografts and prosthetic grafts in

cardiovascular surgery. However, better understanding of the remodeling process and the neotissue formation is required prior to a broader use of TEVG.

80.6.3 Prosthetic Grafts

Excision and replacement of the infected graft/endograft are the most common and expedient conduit. In situ replacement with a new prosthetic graft, along with wide infected tissue debridement and graft coverage with rotated muscle or omental flap, is the most commonly used treatment method [25, 60, 61].

"Stump blowout" is our primary concern with extra-anatomic bypass for the descending thoracic aorta, such as the ascending aorta to the abdominal aorta bypass. Therefore, we prefer in situ revascularization after infected thoracic graft/endograft resection for replacing the thoracic and thoracoabdominal aorta. For the most part, we use the spinal protective adjuncts of distal aortic perfusion and moderate passive hypothermia. We use deep hypothermic circulatory arrest when a proximal aortic cross-clamp cannot be placed safely.

80.7 Management

80.7.1 Anesthesia and Monitoring Lines

After induction of general endotracheal anesthesia, a double-lumen endotracheal tube is placed. Arterial monitoring (usually right radial) and central venous lines with a pulmonary artery catheter are placed. The patient is placed in the right lateral decubitus position. In general, we avoid placement of a cerebrospinal fluid (CSF) drainage catheter in infected cases due to the potential concern of seeding the cerebrospinal space, leading to meningitis. We use motor- and somatosensory-evoked potential neuromonitoring (MEP and SSEP) to guide our repair (Fig. 80.5).

80.7.2 Surgical Technique

The left femoral artery is exposed and encircled through an oblique groin incision. A left thoracotomy incision is made over the sixth rib followed by deflation of the left lung by anesthesia. The chest is entered via the fifth intercostal space, and the costal margin is cut (a modified thoracoabdominal incision). This allows us to have complete exposure of the entire thoracic aorta. Adhesions from previous procedures or inflammation from the infection are often encountered. The lung is carefully dissected off of the parietal pleura and aortic graft. If by preoperative radiographic evaluation a pseudoaneurysm contained by the lung parenchyma is suspected, no further mobilization of the lung is performed. When distal transverse arch can be mobilized safely, we use distal aortic perfusion, avoiding the need for deep hypothermic circulatory arrest through femoral arterial and venous cannulation [62, 63].

80.7.3 Infected Graft Resection

Distal aortic perfusion is initiated, followed by a sharp and blunt dissection, exposing the junction between the infected graft and native aorta. The left vagus and recurrent laryngeal nerve are protected. We dissect native aorta circumferentially and clamp either proximal or distal to the left subclavian artery. The distal clamp is applied to the native aorta distal to the infected graft. When the proximal aortic clamp is placed proximal to the subclavian artery, a separate clamp is placed on the left subclavian artery. The infected graft is completely excised, and all suture materials are resected. The infected tissue in the aortic bed is debrided, until we get healthy margins proximally and distally.

80.7.4 Graft Reconstruction

We generally use gelatin- or collagen-impregnated woven Dacron grafts. Once the appropriate-sized graft is selected, it is soaked in

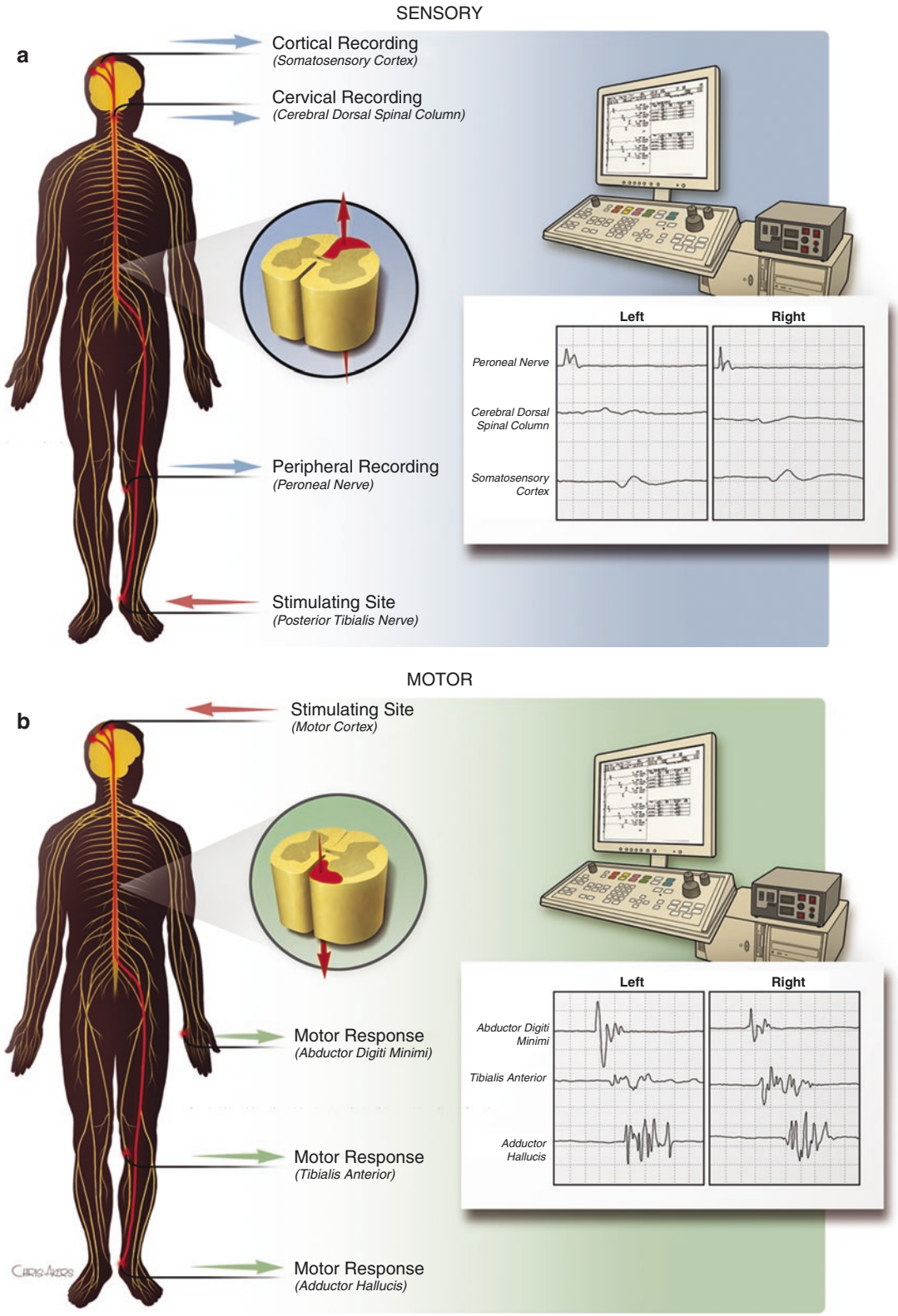

Fig. 80.5 (**a**) Sensory-evoked potential monitoring procedure. (**b**) Motor-evoked potential monitoring procedure

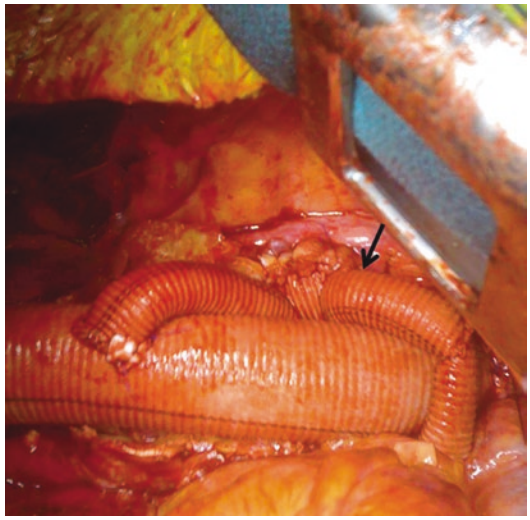

Fig. 80.6 Dacron loop graft (arrow), for reimplantation of patent distal intercostal arteries

rifampin saline solution (1 mg rifampin per mL saline) for at least 15 min [64–66]. End-to-end proximal anastomosis is performed using running 3-0 polypropylene suture. If the aorta is thinned, such as after stent graft removal, we prefer to use 4-0 polypropylene suture. We then use interrupted 4-0 pledgeted polypropylene sutures to buttress the anastomosis.

For the distal anastomosis, the graft is stretched and transected to the appropriate length. Occasionally, we bevel the graft to allow reincorporation of patent distal intercostal arteries, especially T8–T12. More frequently, we reattach them using a 14 mm woven Dacron looped graft (Fig. 80.6) or as a patch to the main graft. If there are no changes on intraoperative spinal cord monitoring with MEP and SSEP, some intercostal arteries can be ligated without reattachment. When the repair is complete, distal aortic perfusion is stopped, and the clamps are slowly released.

During the procedure, we allow the patient's body temperature to passively cool to 32 °C. Once the repair is complete, the patient is rewarmed to 36 °C nasopharyngeally and weaned from distal aortic perfusion. We then remove the arterial and venous cannulas. Heparin is reversed by slowly infusing intravenous protamine at 1 mg per 1 mg heparin. We avoid applying topical hemostatic agents on the anastomoses.

80.7.5 Omental Flap

The omentum is known for its vascularity and lymphatic supply and the ability to induce neovascularity. Multiple publications have demonstrated its use in treatment of aortic graft infections [60, 67–72]. An extension of the thoracotomy incision over the abdomen or a separate supraumbilical minilaparotomy is made. The omentum is divided off of the transverse colon while preserving the epigastric arteries to assure blood supply to the flap (Fig. 80.7). The colon is placed back in the abdomen, and the omental flap is tunneled through a diaphragmatic window (Fig. 80.8). The omental flap should reach the distal aortic arch if constructed properly. It is circumferentially wrapped around the graft and secured in position with interrupted sutures.

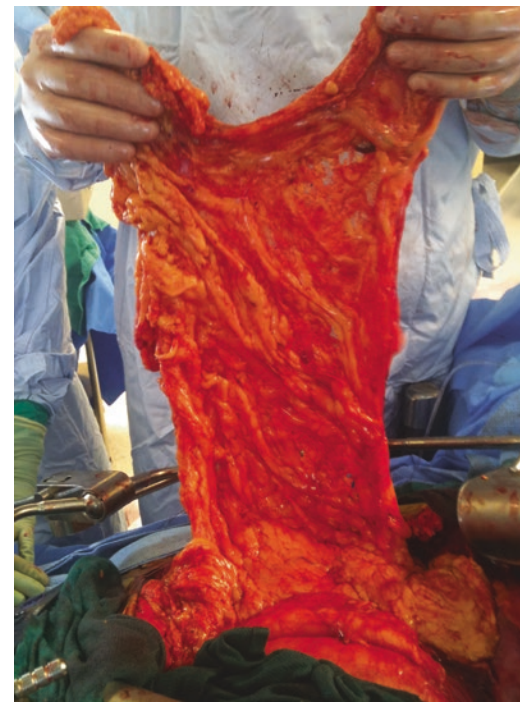

Fig. 80.7 The omentum divided off of the transverse colon while preserving the epigastric arteries to assure blood supply to the flap

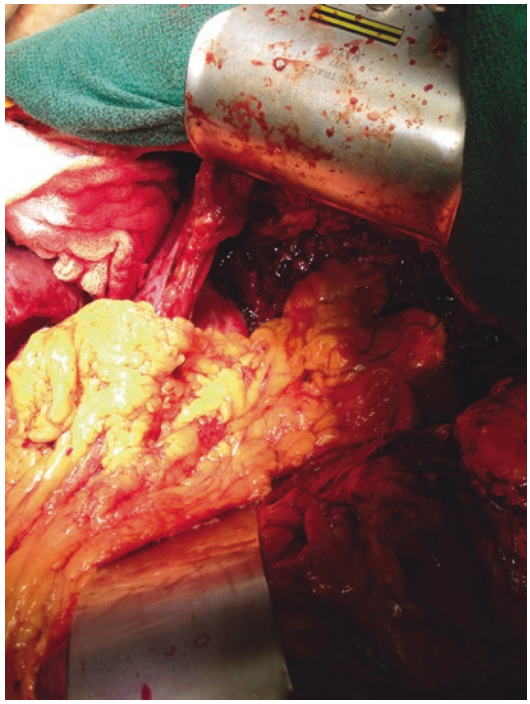

Fig. 80.8 Omental flap tunneled through into the thoracic cavity

80.7.6 Latissimus Dorsi Muscle Flap

In some patients, especially after previous abdominal surgeries, it is easier to utilize the latissimus dorsi muscle (LDM) than the omentum. The LDM flap has been described in the past in cardiomyoplasty procedures where the left LDM pedicle is wrapped around the heart through the left pleural cavity [73]. The preparation of the LDM flap is performed at the beginning of the procedure. After making the skin incision for the thoracotomy, the LDM is identified under the subcutaneous tissue. The muscle is dissected, starting with its surface, afterward dissecting it free from all attachments (thoracic, lumbar, sacral vertebrae, supraspinal ligament, and iliac crest attachments) and preserving the superior neurovascular pedicle [74] (Fig. 80.9). After replacing the infected graft, we make an incision in a superior intercostal space (usually third) and pass the LDM flap through it into the pleural cavity and wrap it around the new graft in the left chest (Fig. 80.10).

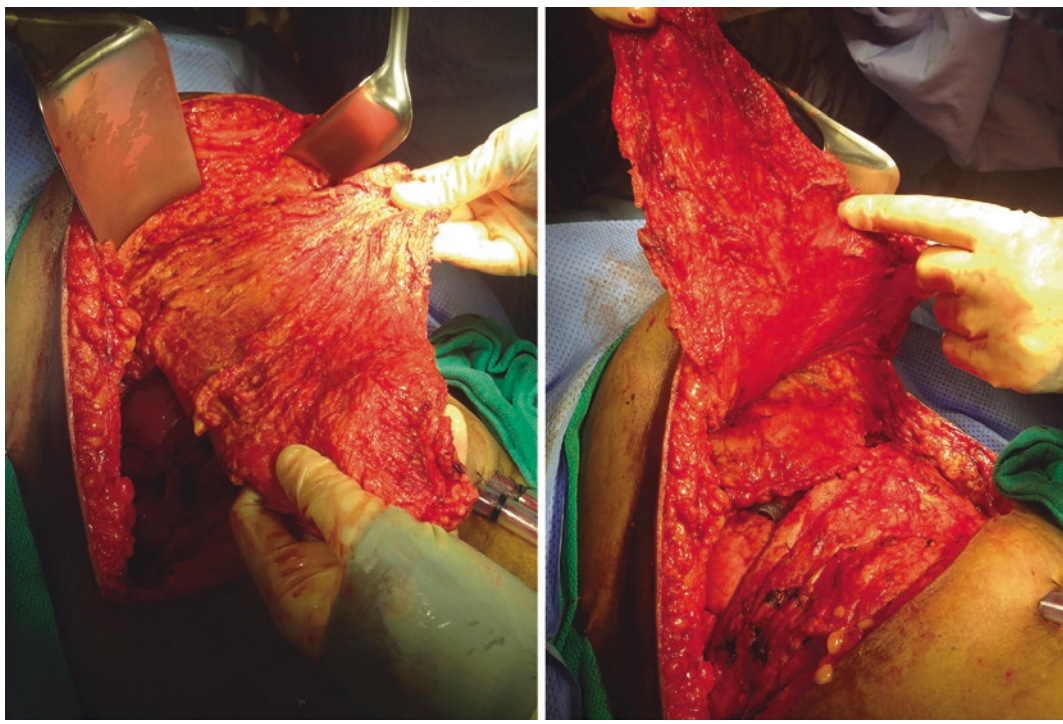

Fig. 80.9 Latissimus dorsi muscle (LDM) pedicle

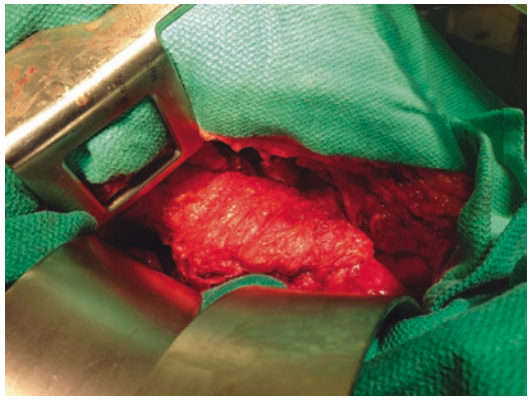

Fig. 80.10 Latissimus dorsi muscle pedicle wrapped around a descending aortic graft

80.7.7 Closure

The chest wall is closed in layers after placement of two #32 French chest tubes. When coagulopathy or hemodynamic instability is present at the end of the case, we perform temporary abbreviated closure with negative pressure dressing. Delayed primary closure can be performed in 1–2 days, once the patient is stabilized and coagulopathy is resolved.

80.8 Endovascular Treatment

In the last decade, various publications have described acceptable short- and mid-term results of endovascular treatment for infected aortic aneurysms. However, the long-term results are still poor, with the need for additional procedures, such as debridement, sac irrigations, late explantation, and open reconstructive surgery. The endovascular approach may be considered in very high-risk patients and, mostly, as a bridging procedure [8, 75–78].

80.9 In Situ Debridement with Graft Preservation Therapy

The high mortality and morbidity rates in surgeries for infected aortic grafts have forced surgeons, even in the earlier series, to treat some patients who were at high risk for surgery with only debridement, graft preservation, and lifelong antibiotic treatment. Recently, multiple studies have described conservative treatment in selected patients with infected thoracic and abdominal aortic grafts/endografts with low early mortality [79–84]. There are certain cases in which this conservative approach is preferable. They include patients with comorbidities and high risk for surgery, those with high-risk anatomy, in which graft excision will result in organ malperfusion, such as the aortic arch or thoracoabdominal aorta, infection with indolent Gram-positive organisms, and infection involving only the body of the graft [85].

80.10 Antibiotic Treatment

The strategy for the treatment of aortic graft infections consists of antibiotic treatment as a necessary adjunct. An empiric, broad-spectrum antibiotic should be started with diagnosis of graft infection. Later in the course of treatment, this should be altered based on culture growth. An intravenous antibiotic should be administrated for a minimum of 2 weeks and up to 6 weeks, followed by long-term oral antibiotic treatment. The duration of the oral antibiotic treatment varies in the literature, from 6 weeks to 6 months, and some report the need for lifelong treatment [8, 86, 87].

80.11 Antibiotic-Loaded Beads

The use of antibiotic polymethyl methacrylate (PMMA) cement beads has been previously described as an adjunct in the treatment of orthopedic prosthesis and ventricular assist devices [88, 89]. Recently, its use has been implemented in vascular infections as well, mostly extracavitary and abdominal aortic graft infections. During surgery, the infected tissue is debrided, and the antibiotic-loaded beads are made in the operating room. They are then wrapped around the graft with temporary wound closure, usually using a negative pressure dressing. The beads are removed before pedicled flap placement and final closure [90, 91].

80.12 Follow-Up and Surveillance

Once microbiologic data becomes available from preoperative blood cultures and intraoperative samples, the systemic antibiotics are tailored to the infecting organism. Prior to discharge, patients are switched to oral antibiotics. The length of treatment differs in the literature. Most publications describe at least 2 weeks of IV antibiotic followed by 6–8 weeks of oral treatment, and others advocate 6 months or lifelong treatment [87, 92, 93]. Close follow-up is recommended, but there is a lack of standardization regarding follow-up protocols. Our group suggests obtaining surveillance chest CT scans at 1, 6, and 12 months and then annually thereafter [87].

80.13 Outcomes

Despite the advancements in surgical techniques and adjuncts, the mid-term mortality rate remains high and ranges from 25 to 80% [1, 27, 60, 93]. Yamanaka et al. recently reported a series of 70 patients with aortic-related infections. The in-hospital mortality was 17.1%, mean follow-up of 26.7 ± 26 months, and an overall 3-year survival of 60.1 ± 6.7%. In this report, there was a trend of improved infection-related deaths since 2008. They attribute this improvement to better maximal debridement of surrounding tissue in the later years [86]. There are limited data in the literature regarding long-term outcomes and reinfection rates following treatment of infected thoracic aortic grafts. We recently published our data of 25% reinfection rate following resection and revascularization of infected abdominal aortic grafts [87].

80.14 Conclusions

Prosthetic graft/endograft infection after descending thoracic/thoracoabdominal aortic aneurysm repair remains a challenge. Improvements in surgical techniques, endovascular therapies as bridging procedures, and perioperative care have led to improved in-hospital survival. Replacement of the infected graft with pedicled flap coverage leads to reasonable long-term results. Additional studies are needed before widespread adoption of graft preservation techniques.

References

1. Svensson LG, Crawford ES, Hess KR, Coselli JS, Safi HJ. Experience with 1509 patients undergoing thoracoabdominal aortic operations. J Vasc Surg. 1993;17:357–68.
2. Svensson LG, Crawford ES, Hess KR, Coselli JS, Safi HJ. Variables predictive of outcome in 832 patients undergoing repairs of the descending thoracic aorta. Chest. 1993;104:1248–53.
3. Herdrich BJ, Fairman RM. How to manage infected aortic endografts. J Cardiovasc Surg. 2013;54:595–604.
4. Ducasse E, Calisti A, Speziale F, Rizzo L, Misuraca M, Fiorani P. Aortoiliac stent graft infection: current problems and management. Ann Vasc Surg. 2004;18:521–6.
5. Heyer KS, Modi P, Morasch MD, et al. Secondary infections of thoracic and abdominal aortic endografts. J Vasc Interv Radiol. 2009;20:173–9.
6. Bandyk DF, Berni GA, Thiele BL, Towne JB. Aortofemoral graft infection due to Staphylococcus epidermidis. Arch Surg. 1984;119:102–8.
7. Lorentzen JE, Nielsen OM, Arendrup H, et al. Vascular graft infection: an analysis of sixty-two graft infections in 2411 consecutively implanted synthetic vascular grafts. Surgery. 1985;98:81–6.
8. Kan CD, Lee HL, Yang YJ. Outcome after endovascular stent graft treatment for mycotic aortic aneurysm: a systematic review. J Vasc Surg. 2007;46:906–12.
9. Kakkos SK, Antoniadis PN, Klonaris CN, et al. Open or endovascular repair of aortoenteric fistulas? A multicentre comparative study. Eur J Vasc Endovasc Surg. 2011;41:625–34.
10. Swain TW 3rd, Calligaro KD, Dougherty MD. Management of infected aortic prosthetic grafts. Vasc Endovasc Surg. 2004;38:75–82.
11. Orton DF, LeVeen RF, Saigh JA, et al. Aortic prosthetic graft infections: radiologic manifestations and implications for management. Radiographics. 2000;20:977–93.
12. Legout L, D'Elia PV, Sarraz-Bournet B, et al. Diagnosis and management of prosthetic vascular graft infections. Med Mal Infect. 2012;42:102–9.
13. Low RN, Wall SD, Jeffrey RB Jr, Sollitto RA, Reilly LM, Tierney LM Jr. Aortoenteric fistula and perigraft infection: evaluation with CT. Radiology. 1990;175:157–62.
14. Fiorani P, Speziale F, Rizzo L, et al. Detection of aortic graft infection with leukocytes labeled with technetium 99m-hexametazime. J Vasc Surg. 1993;17:87–95.

15. McKeown PP, Miller DC, Jamieson SW, et al. Diagnosis of arterial prosthetic graft infection by indium-111 oxine white blood cell scans. Circulation. 1982;66:I130–4.
16. Love C, Palestro CJ. Radionuclide imaging of infection. J Nucl Med Technol. 2004;32:47–57.
17. Fukuchi K, Ishida Y, Higashi M, et al. Detection of aortic graft infection by fluorodeoxyglucose positron emission tomography: comparison with computed tomographic findings. J Vasc Surg. 2005;42:919–25.
18. Keidar Z, Engel A, Hoffman A, Israel O, Nitecki S. Prosthetic vascular graft infection: the role of 18F-FDG PET/CT. J Nucl Med. 2007;48:1230–6.
19. Tokuda Y, Oshima H, Araki Y, et al. Detection of thoracic aortic prosthetic graft infection with 18F-fluorodeoxyglucose positron emission tomography/computed tomography. Eur J Cardiothorac Surg. 2013;43:1183–7.
20. Wasselius J, Malmstedt J, Kalin B, et al. High 18F-FDG uptake in synthetic aortic vascular grafts on PET/CT in symptomatic and asymptomatic patients. J Nucl Med. 2008;49:1601–5.
21. Keidar Z, Nitecki S. FDG-PET for the detection of infected vascular grafts. Q J Nucl Med Mol Imaging. 2009;53:35–40.
22. Calligaro KD, Veith FJ. Diagnosis and management of infected prosthetic aortic grafts. Surgery. 1991;110:805–13.
23. Hsu RB, Lin FY. Infected aneurysm of the thoracic aorta. J Vasc Surg. 2008;47:270–6.
24. Weis-Muller BT, Rascanu C, Sagban A, Grabitz K, Godehardt E, Sandmann W. Single-center experience with open surgical treatment of 36 infected aneurysms of the thoracic, thoracoabdominal, and abdominal aorta. Ann Vasc Surg. 2011;25:1020–5.
25. Chan FY, Crawford ES, Coselli JS, Safi HJ, Williams TW Jr. In situ prosthetic graft replacement for mycotic aneurysm of the aorta. Ann Thorac Surg. 1989;47:193–203.
26. Crawford ES, Reardon MJ, Williams TW Jr. Surgical considerations of infection following operations involving the descending thoracic aorta. World J Surg. 1980;4:669–77.
27. Hargrove WC 3rd, Edmunds LH Jr. Management of infected thoracic aortic prosthetic grafts. Ann Thorac Surg. 1984;37:72–7.
28. Barnard SP, Dark JH, Jones NA. Prosthetic graft infection in the descending thoracic aorta treated by extra-anatomic rerouting. Cardiovasc Surg. 1995;3:703–5.
29. Watts SH. VIII. The suture of blood vessels. Implantation and transplantation of vessels and organs. An historical and experimental study. Ann Surg. 1907;46:373–404.
30. Carrel A. Landmark article, Nov 14, 1908: results of the transplantation of blood vessels, organs and limbs. By Alexis Carrel. JAMA. 1983;250:944–53.
31. Dubost C, Allary M, Oeconomos N. Resection of an aneurysm of the abdominal aorta: reestablishment of the continuity by a preserved human arterial graft, with result after five months. AMA Arch Surg. 1952;64:405–8.
32. Nuboer JF. Treatment of certain coarctations with homologous grafts, fixed in 4% formalin. Arch Chir Neerl. 1954;6:123–42.
33. Kieffer E, Gomes D, Chiche L, Fleron MH, Koskas F, Bahnini A. Allograft replacement for infrarenal aortic graft infection: early and late results in 179 patients. J Vasc Surg. 2004;39:1009–17.
34. Vogt PR, von Segesser LK, Goffin Y, et al. Eradication of aortic infections with the use of cryopreserved arterial homografts. Ann Thorac Surg. 1996;62:640–5.
35. Vogt PR, Pfammatter T, Schlumpf R, et al. In situ repair of aortobronchial, aortoesophageal, and aorto-enteric fistulae with cryopreserved aortic homografts. J Vasc Surg. 1997;26:11–7.
36. Vogt PR, Brunner-La Rocca HP, Carrel T, et al. Cryopreserved arterial allografts in the treatment of major vascular infection: a comparison with conventional surgical techniques. J Thorac Cardiovasc Surg. 1998;116:965–72.
37. Vogt PR, Turina MI. Management of infected aortic grafts: development of less invasive surgery using cryopreserved homografts. Ann Thorac Surg. 1999;67:1986–9.
38. Vogt PR. Arterial allografts in treating aortic graft infections: something old, something new. Semin Vasc Surg. 2011;24:227–33.
39. Vogt PR, Brunner-LaRocca HP, Lachat M, Ruef C, Turina MI. Technical details with the use of cryopreserved arterial allografts for aortic infection: influence on early and midterm mortality. J Vasc Surg. 2002;35:80–6.
40. von Segesser LK, Tkebuchava T, Niederhauser U, et al. Aortobronchial and aortoesophageal fistulae as risk factors in surgery of descending thoracic aortic aneurysms. Eur J Cardiothorac Surg. 1997;12:195–201.
41. Kieffer E, Sabatier J, Plissonnier D, Knosalla C. Prosthetic graft infection after descending thoracic/thoracoabdominal aortic aneurysmectomy: management with in situ arterial allografts. J Vasc Surg. 2001;33:671–8.
42. Noel AA, Gloviczki P, Cherry KJ Jr, et al. Abdominal aortic reconstruction in infected fields: early results of the United States cryopreserved aortic allograft registry. J Vasc Surg. 2002;35:847–52.
43. Clagett GP, Bowers BL, Lopez-Viego MA, et al. Creation of a neo-aortoiliac system from lower extremity deep and superficial veins. Ann Surg. 1993;218:239–48.
44. Nevelsteen A, Lacroix H, Suy R. Autogenous reconstruction with the lower extremity deep veins: an alternative treatment of prosthetic infection after reconstructive surgery for aortoiliac disease. J Vasc Surg. 1995;22:129–34.
45. Ali AT, Modrall JG, Hocking J, et al. Long-term results of the treatment of aortic graft infection by in situ replacement with femoral popliteal vein grafts. J Vasc Surg. 2009;50:30–9.
46. Chung J, Clagett GP. Neoaortoiliac System (NAIS) procedure for the treatment of the infected aortic graft. Semin Vasc Surg. 2011;24:220–6.

47. Gibbons CP, Ferguson CJ, Fligelstone LJ, Edwards K. Experience with femoro-popliteal vein as a conduit for vascular reconstruction in infected fields. Eur J Vasc Endovasc Surg. 2003;25:424–31.
48. Okamoto H, Tamenishi A, Matsumura Y, Niimi T. Composite vein graft reconstruction for infected descending aortic prosthesis. Ann Thorac Surg. 2012;93:2061–3.
49. Weinberg CB, Bell E. A blood vessel model constructed from collagen and cultured vascular cells. Science. 1986;231:397–400.
50. Naito Y, Rocco K, Kurobe H, Maxfield M, Breuer C, Shinoka T. Tissue engineering in the vasculature. Anat Rec. 2014;297:83–97.
51. Shin'oka T, Imai Y, Ikada Y. Transplantation of a tissue-engineered pulmonary artery. N Engl J Med. 2001;344:532–3.
52. Shin'oka T, Matsumura G, Hibino N, et al. Midterm clinical result of tissue-engineered vascular autografts seeded with autologous bone marrow cells. J Thorac Cardiovasc Surg. 2005;129:1330–8.
53. Hibino N, McGillicuddy E, Matsumura G, et al. Late-term results of tissue-engineered vascular grafts in humans. J Thorac Cardiovasc Surg. 2010;139:431–6.
54. DuBose JJ, Azizzadeh A. Utilization of a tubularized CorMatrix extracellular matrix for repair of an arteriovenous fistula aneurysm. Ann Vasc Surg. 2015;29:366.
55. Rosario-Quinones F, Magid MS, Yau J, Pawale A, Nguyen K. Tissue reaction to porcine intestinal submucosa (CorMatrix) implants in pediatric cardiac patients: a single-center experience. Ann Thorac Surg. 2015;99:1373–7.
56. Deorsola L, Pace Napoleone C, Abbruzzese PA. Repair of an unusual aortic coarctation using an extracellular matrix patch. Ann Thorac Surg. 2014;97:1059–61.
57. Fallon A, Goodchild T, Wang R, Matheny RG. Remodeling of extracellular matrix patch used for carotid artery repair. J Surg Res. 2012;175:25–34.
58. Sundermann SH, Rodriguez Cetina Biefer H, Emmert MY, Falk V. Use of extracellular matrix materials in patients with endocarditis. Thorac Cardiovasc Surg. 2014;62:76–9.
59. Piterina AV, Cloonan AJ, Meaney CL, et al. ECM-based materials in cardiovascular applications: inherent healing potential and augmentation of native regenerative processes. Int J Mol Sci. 2009;10:4375–417.
60. Coselli JS, Crawford ES, Williams TW, et al. Treatment of postoperative infection of ascending aorta and transverse aortic arch, including use of viable omentum and muscle flaps. Ann Thorac Surg. 1990;50:868–81.
61. Quinones-Baldrich WJ, Nene SM, Gelabert HA, Moore WS. Rupture of the perivisceral aorta: atherosclerotic versus mycotic aneurysm. Ann Vasc Surg. 1997;11:331–41.
62. Safi HJ. How I do it: thoracoabdominal aortic aneurysm graft replacement. Cardiovasc Surg. 1999;7:607–13.
63. Miller CC 3rd, Villa MA, Sutton J, et al. Serum myoglobin and renal morbidity and mortality following thoracic and thoraco-abdominal aortic repair: does rhabdomyolysis play a role? Eur J Vasc Endovasc Surg. 2009;37:388–94.
64. Avramovic J, Fletcher JP. Prevention of prosthetic vascular graft infection by rifampicin impregnation of a protein-sealed Dacron graft in combination with parenteral cephalosporin. J Cardiovasc Surg. 1992;33:70–4.
65. Goeau-Brissonniere O, Mercier F, Nicolas MH, et al. Treatment of vascular graft infection by in situ replacement with a rifampin-bonded gelatin-sealed Dacron graft. J Vasc Surg. 1994;19:739–41.
66. Coggia M, Goeau-Brissonniere O, Leflon V, Nicolas MH, Pechere JC. Experimental treatment of vascular graft infection due to Staphylococcus epidermidis by in situ replacement with a rifampin-bonded polyester graft. Ann Vasc Surg. 2001;15:421–9.
67. Seguin JR, Loisance DY. Omental transposition for closure of median sternotomy following severe mediastinal and vascular infection. Chest. 1985;88:684–6.
68. Miller DW Jr, Johnson DD. Omental pedicle graft in the management of infected ascending aortic prostheses. Ann Thorac Surg. 1987;44:614–7.
69. Nakajima N, Masuda M, Ichinose M, Ando M. A new method for the treatment of graft infection in the thoracic aorta: in situ preservation. Ann Thorac Surg. 1999;67:1994–6.
70. Soyer R, Bessou JP, Bouchart F, Redonnet M, Mouton-Schleifer D, Arrignon J. Surgical treatment of infected composite graft after replacement of ascending aorta. Ann Thorac Surg. 1994;58:425–8.
71. Cartier R, Brunette I, Hashimoto K, Bourne WM, Schaff HV. Angiogenic factor: a possible mechanism for neovascularization produced by omental pedicles. J Thoracic Cardiovasc Surg. 1990;99:264–8.
72. Lee AB Jr, Schimert G, Shaktin S, Seigel JH. Total excision of the sternum and thoracic pedicle transposition of the greater omentum; useful strategems in managing severe mediastinal infection following open heart surgery. Surgery. 1976;80:433–6.
73. Chachques JC, Grandjean PA, Carpentier A. Latissimus dorsi dynamic cardiomyoplasty. Ann Thorac Surg. 1989;47:600–4.
74. Taguchi S, Mori A, Suzuki R, Ishida O. Technique for using pedicled latissimus dorsi muscle flaps to wrap prosthetic grafts in an infected thoracic aorta. Ann Vasc Surg. 2013;27:1223–7.
75. Sedivy P, Spacek M, El Samman K, et al. Endovascular treatment of infected aortic aneurysms. Eur J Vasc Endovasc Surg. 2012;44:385–94.
76. Semba CP, Sakai T, Slonim SM, et al. Mycotic aneurysms of the thoracic aorta: repair with use of endovascular stent-grafts. J Vasc Interv Radiol. 1998;9:33–40.

77. Chen YX, Liu CW, Li YJ, et al. Endovascular repair of descending aortic pseudoaneurysms. Zhonghua wai ke za zhi [Chinese J Surg]. 2011;49:897–902.
78. Ting AC, Cheng SW, Ho P, Poon JT. Endovascular stent graft repair for infected thoracic aortic pseudoaneurysms—a durable option? J Vasc Surg. 2006;44:701–5.
79. Moulakakis KG, Sfyroeras GS, Mylonas SN, et al. Outcome after preservation of infected abdominal aortic endografts. J Endovasc Ther. 2014;21:448–55.
80. Maze MJ, Laws P, Buckenham T, et al. Outcomes of infected abdominal aortic grafts managed with antimicrobial therapy and graft retention in an unselected cohort. Eur J Vasc Endovasc Surg. 2013;45:373–80.
81. Tossios P, Karatzopoulos A, Tsagakis K, et al. Successful surgical in situ treatment of prosthetic graft infection by staged procedure after Bentall operation and total aortic arch replacement. Springerplus. 2014;3:172.
82. Takano T, Terasaki T, Wada Y, Seto T, Fukui D, Amano J. Treatment of prosthetic graft infection after thoracic aorta replacement. Ann Thorac Cardiovasc Surg. 2014;20:304–9.
83. Tossios P, Karatzopoulos A, Tsagakis K, et al. Treatment of infected thoracic aortic prosthetic grafts with the in situ preservation strategy: a review of its history, surgical technique, and results. Heart Lung Circ. 2014;23:24–31.
84. Suzuki T, Kawamoto S, Motoyoshi N, et al. Contemporary outcome of the surgical management of prosthetic graft infection after a thoracic aortic replacement: is there a room to consider vacuum-assisted wound closure as an alternative? Gen Thorac Cardiovasc Surg. 2015;63:86–92.
85. Lawrence PF. Conservative treatment of aortic graft infection. Semin Vasc Surg. 2011;24:199–204.
86. Yamanaka K, Omura A, Nomura Y, et al. Surgical strategy for aorta-related infection. Eur J Cardiothorac Surg. 2014;46:974–80.
87. Charlton-Ouw KM, Sandhu HK, Huang G, et al. Reinfection after resection and revascularization of infected infrarenal abdominal aortic grafts. J Vasc Surg. 2014;59:684–92.
88. Buchholz HW, Engelbrecht H. Depot effects of various antibiotics mixed with Palacos resins. Chirurg. 1970;41:511–5.
89. Kretlow JD, Brown RH, Wolfswinkel EM, et al. Salvage of infected left ventricular assist device with antibiotic beads. Plast Reconstr Surg. 2014;133:28–38.
90. Stone PA, Armstrong PA, Bandyk DF, et al. Use of antibiotic-loaded polymethylmethacrylate beads for the treatment of extracavitary prosthetic vascular graft infections. J Vasc Surg. 2006;44:757–61.
91. Charlton-Ouw KM, Kubrusly F, Sandhu HK, et al. In vitro efficacy of antibiotic beads in treating abdominal vascular graft infections. J Vasc Surg. 2015;62:1048–53.
92. Inafuku H, Senaha S, Morishima Y, et al. Infected thoracoabdominal aortic aneurysms including the major abdominal branches in 4 cases. Ann Thorac Cardiovasc Surg. 2008;14:196–9.
93. Coselli JS, Koksoy C, LeMaire SA. Management of thoracic aortic graft infections. Ann Thorac Surg. 1999;67:1990–3.