77 Current Open Treatment of Thoracoabdominal Aortic Aneurysms

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77.1 Procedure

Open surgical repair remains the gold standard operation for thoracoabdominal aortic aneurysms (TAAAs), which involve both the descending thoracic and abdominal aortic segments. These aneurysms can be caused by aortic dissection or by progressive medial degeneration without dissection. Contemporary surgical approaches balance the need to maximize long-term benefit by replacing as much diseased aorta as possible with limiting ischemia-related risk to the spinal cord and other organs. Despite the formidable challenges that extensive aortic replacement entails, early and late outcomes after these operations are excellent. In a recent series of 3309 open TAAA repairs [1], we observed an early mortality rate of 7.5% and low rates of persistent paraplegia or paraparesis (5.4%), stroke (2.2%), and renal failure necessitating permanent dialysis (5.7%). The most extensive operations—Crawford extent II repairs—involve replacing the entire descending thoracic and abdominal aorta. In this chapter, we describe the procedure for performing a Crawford extent II repair in detail, and we mention some alternative scenarios that a surgeon may encounter.

77.2 Indications and Contraindications

Surgical repair of the thoracoabdominal aorta is ideally done electively to prevent a catastrophic event, such as rupture of the aorta (Fig. 77.1). For asymptomatic patients, we generally recommend TAAA repair when the aneurysm diameter exceeds 6.0 cm or has expanded by more than 0.5 cm in 1 year [2]. Patients who develop symptoms related to a TAAA undergo surgical repair regardless of aneurysm diameter. The most common indication for urgent repair of a TAAA is superimposed acute dissection. We recommend earlier intervention at a threshold of 5.5 cm in those with a confirmed genetic etiology of their aortic disease or chronic aortic dissection. Other urgent indications include aortic rupture and any symptom or sign indicating a high risk of rupture: refractory pain, refractory hypertension, or rapid aortic expansion. Acute dissection of the thoracoabdominal aorta may also lead to malperfusion of vital organs and limbs, necessitating restora-

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Fig. 77.1 Contained rupture of the descending thoracic aorta

tion of flow by endovascular or open surgical intervention [3, 4]. Regardless of the indication, urgent or emergent open repair of TAAA is associated with significantly greater risk of morbidity and mortality than elective repair.

Contraindications to open repair must be individualized to the patient and to the surgeon's own experience and outcomes. In general, patients with prohibitive cardiopulmonary risk or limited life expectancy are not candidates for open surgical repair. Other considerations include the increased operative risk in patients with chronic renal insufficiency, chronic obstructive pulmonary disease, heart failure, coronary artery disease, or advanced age [5, 6].

77.3 Special Preoperative Diagnostic or Imaging Tests

In addition to assessing cardiopulmonary risk and acuity of presentation as described above, careful preoperative evaluation of the patient's computed tomographic angiograms is essential. The diameter of the thoracoabdominal aorta throughout the diseased and non-aneurysmal portions is measured. We pay close attention to anatomic variants, such as a retroaortic renal vein, and note the presence and location of particularly large segmental arteries. Potential clamp and cannulation sites are assessed for dissection and mural thrombus. The visceral and renal arteries are evaluated for stenotic origins, their spatial relationships to each other, and whether the true lumen, false lumen, or both supply them in cases of chronic dissection.

77.4 Anesthesia

A right radial arterial catheter is placed to ensure uninterrupted blood pressure monitoring in case the aorta needs to be clamped proximal to the left subclavian artery (LSCA). Large-bore central and peripheral venous lines are placed for central venous pressure monitoring and for fluid and blood replacement. General anesthesia is administered, and single right-lung ventilation is established through a double-lumen endobronchial tube. A temperature probe is positioned in the patient's nasopharynx. A cerebrospinal fluid (CSF) drain is placed for hemodynamically stable patients undergoing Crawford extent II repairs. Cell-saving and rapid infusion devices are set up so that shed blood can be salvaged and volume can be rapidly replaced, respectively. Either transesophageal echocardiography or Swan-Ganz catheter monitoring is routinely used to monitor hemodynamics and cardiac function. Prophylactic broad-spectrum intravenous antibiotics are administered 1 h before skin incision to reduce the risk of graft and surgical wound infection.

77.5 Positioning

The patient is placed on top of a beanbag in a modified right lateral decubitus position, with the shoulders rotated to 60° from horizontal and the hips rotated to 30° from horizontal, which ensures that both groins are accessible (Fig. 77.2a, b). An axillary roll is placed under the patient's right axilla, and the beanbag is suction-deflated and made firm in order to maintain the patient's position. The patient's left arm is placed on top of an elevated arm board and extended at an angle above the shoulders in a freestyle-swimming-stroke position. The patient's left chest and back, abdomen, groins, and upper thighs are prepared and draped in a

Fig. 77.2 Positioning, preparing, and draping. Patient positioned (**a** and **b**) and prepared and draped (**c** and **d**) for open repair of a thoracoabdominal aneurysm. *ASIS* anterior superior iliac spine

sterile fashion (Fig. 77.2c, d). An adhesive antimicrobial drape is placed over all exposed skin.

77.6 Incision

A left thoracotomy is made after single right-lung ventilation is initiated (Fig. 77.3a); the incision is then curved inferiorly and extended across the costal margin and toward the umbilicus. For patients undergoing Crawford extent II repairs, the left thorax is usually entered through the sixth intercostal space, although the fifth interspace is preferable when there is a rupture or large aneurysm involving the proximal descending thoracic aorta. Medial visceral rotation is performed through a transperitoneal approach; electrocautery is used to dissect along the line of Toldt. Although a retroperitoneal approach is equally acceptable, our preference is for a transperitoneal approach, as it allows us to evaluate by direct vision and palpation the bowel and its arterial circulation as well as the spleen after the aortic repair. The diaphragm is divided circumferentially, and a 3- to 4-cm rim of diaphragm is left attached to the lateral and posterior chest wall, with retraction sutures along the edge of the divided diaphragm on the cardiac side (Fig. 77.3b).

77.7 Retractor

A table-mounted retractor is used to maintain stable exposure during the repair (Fig. 77.4). The caudal aspect of the incision is exposed posteriorly and to the left with two bladder blades. The cranial aspect of the incision is exposed with a large Richardson retractor under the upper rib and an upper hand retractor under the scapula, both stabilized by the table-mounted ether screen.

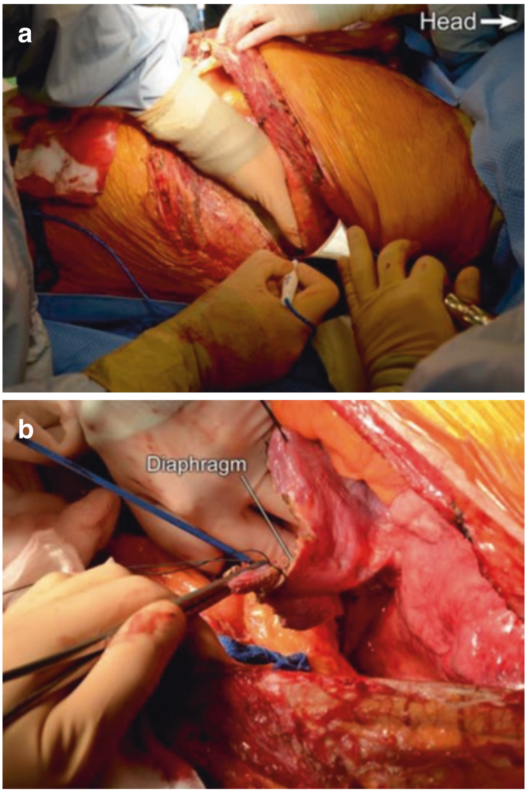

Fig. 77.3 Incision and exposure. (**a**) A left thoracotomy is made and the chest is entered through the sixth intercostal space. The incision is then curved inferiorly and extended across the costal margin and toward the umbilicus. (**b**) The diaphragm is circumferentially divided and retracted with 2-0 silk sutures

77.8 Heparin and Adjuncts

Our strategies for organ protection during TAAA repair have been previously described in detail [7–11]. For spinal cord protection, we use CSF drainage [9], mild passive hypothermia (32–33 °C nasopharyngeal), left heart bypass (LHB) [7], sequential cross-clamping, and selective reimplantation of segmental arteries. To minimize ischemic damage to the kidneys, we administer lactated Ringer's solution at 4 °C with mannitol (12.5 g/L) and methylprednisolone (125 mg/L) to the renal arteries [10, 11]. Finally, to protect the abdominal organs, we perfuse the celiac axis and superior mesenteric artery (SMA) with isothermic blood from the LHB circuit. Table 77.1 summarizes the various adjuncts we use for organ protection during open TAAA repair of various extents as per the Crawford classification.

77.9 Left Heart Bypass

Left heart bypass is typically used for patients undergoing Crawford extent I and II repairs. After moderate systemic heparinization (1 mg/kg), we place a 3-0 pledgeted polypropylene horizontal mattress suture on the left inferior pulmonary vein and cannulate the left atrium with a 24-French

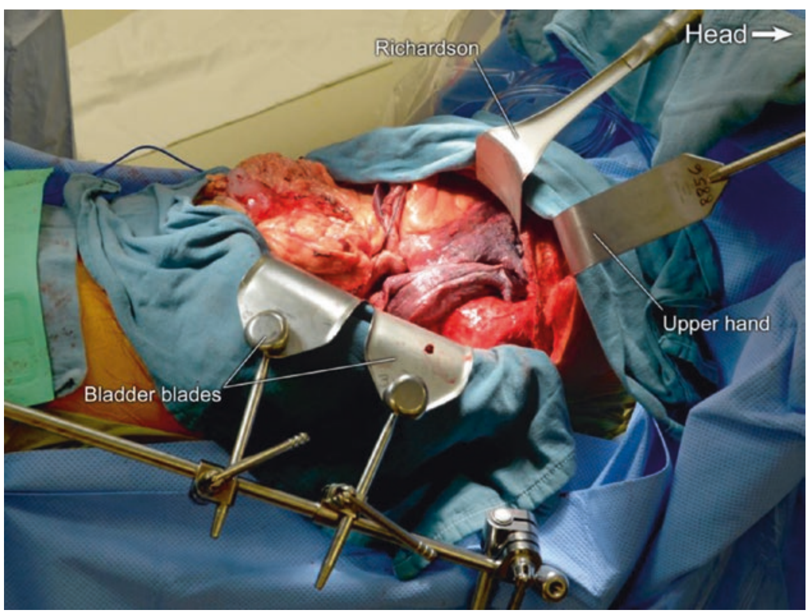

Fig. 77.4 Retraction. A table-mounted retractor is used for stable exposure throughout the procedure. The caudal aspect of the incision is exposed posteriorly and to the left with two bladder blades. The cranial aspect of the incision is exposed with a large Richardson retractor under the upper rib and an upper hand retractor under the scapula, both stabilized by the table-mounted ether screen

Table 77.1 The use of adjuncts for organ protection during open repair of thoracoabdominal aneurysms

Crawford extent	CSF drainage	LHB	Isothermic blood to SMA/ celiac artery	Cold renal perfusion	Reimplantation of segmental arteries
I	+	+	±	±	±
II	+	+	+	+	+
III	±	±	±	+	±
IV	–	–	–	+	–

CSF cerebrospinal fluid, *LHB* left heart bypass, *SMA* superior mesenteric artery
+, generally use; –, generally do not use; ±, may use depending on patient characteristics and intraoperative findings

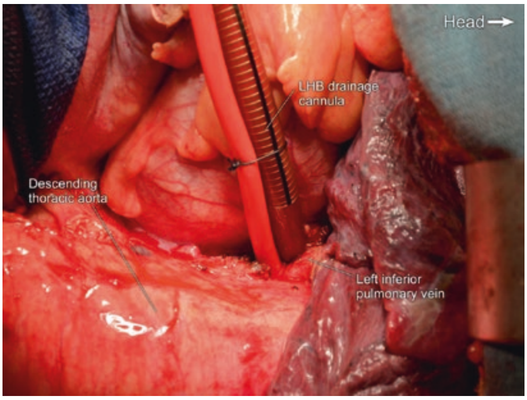

Fig. 77.5 Left heart bypass drainage cannula. A 24-French angled-tip cannula is placed in the left atrium via the left inferior pulmonary vein. *LHB* left heart bypass

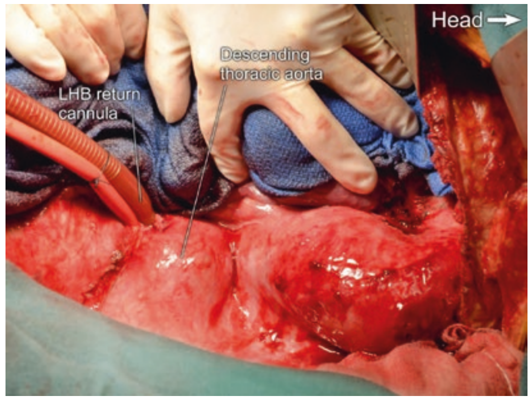

Fig. 77.6 Left heart bypass return cannula. A 24-French angled-tip cannula is placed in the distal aorta, a few cm cranial to the origin of the left renal artery. *LHB* left heart bypass

angled-tip cannula secured with a Rummel tourniquet (Fig. 77.5). The LHB return is through a 24-French angled-tip cannula placed in the distal aorta (generally a few cm proximal to the origin of the left renal artery) and similarly secured (Fig. 77.6).

77.10 Aortic Exposure

The intra-abdominal aorta is exposed to the aortic bifurcation with electrocautery; care is taken to identify the origin of the left renal artery and to keep the incision posterior to the left ureter and gonadal vein. Next, the initial proximal and distal clamp sites in the thorax are developed. During dissection of the proximal clamp site, the ligamentum arteriosum is often divided, and care is taken to preserve the recurrent laryngeal and phrenic nerves (Fig. 77.7a). If possible, the proximal clamp is placed distal to the left subclavian artery to preserve its contribution to spinal cord flow. If there is a large distal arch aneurysm, however, the proximal clamp may have to be positioned between the left common carotid artery (LCCA) and the LSCA. The distal clamp site is at the junction of the upper and middle thirds of the descending thoracic aorta and is developed anterior to the hemiazygos and intercostal veins, some of which may be clipped for safe positioning of the distal clamp (Fig. 77.7b).

77.11 Proximal Aortic Reconstruction

After LHB is initiated at a flow of 500 mL/min, a straight, padded aortic cross-clamp is applied to the aorta at the previously prepared site. A stiff bulldog clamp is applied to the subclavian artery if the clamp site is between the LCCA and the LSCA. The proximal descending thoracic aorta is compressed manually with a laparotomy pad to displace blood distally; then a Crafoord clamp is applied across the aorta at the distal clamp site. Once the aorta is

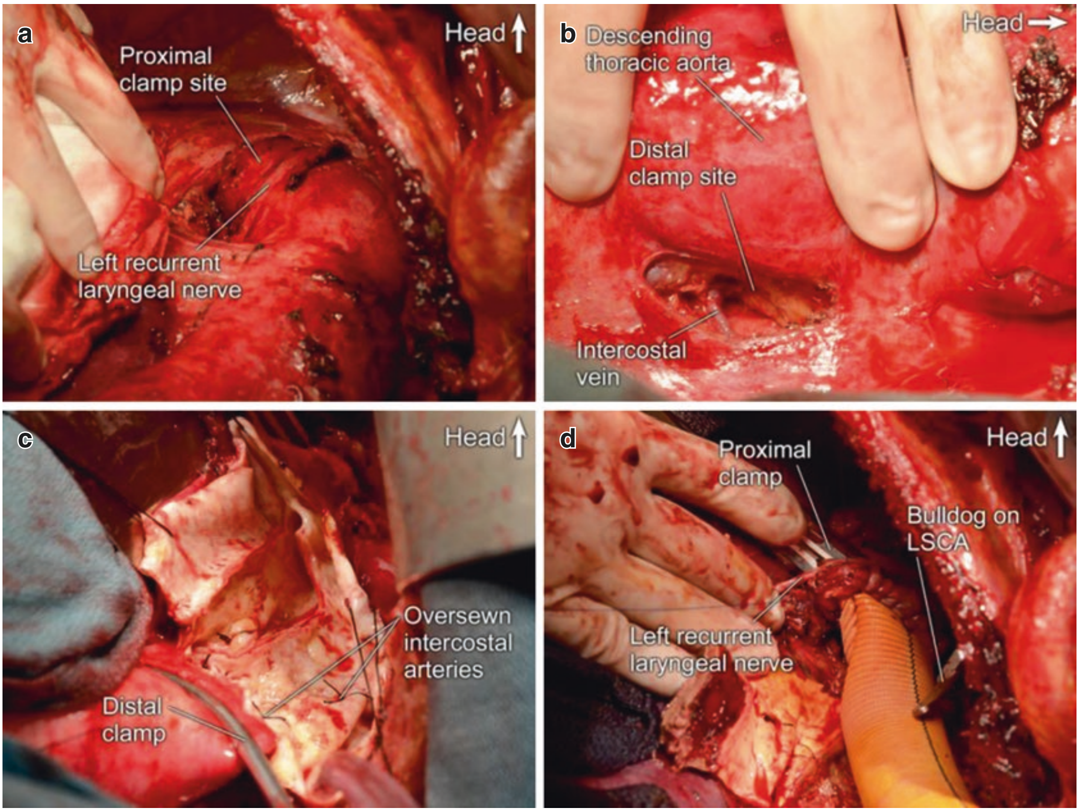

Fig. 77.7 Preparation and construction of the proximal anastomosis. (**a**) The proximal clamp site is prepared, and careful attention is paid to preserving the left recurrent laryngeal nerve. (**b**) The distal clamp site is prepared anterior to the hemiazygos and intercostal veins; the esophagus is avoided. (**c**) The proximal aorta is opened between the two clamps, and all of the intercostal arteries in this segment are oversewn. (**d**) The proximal anastomosis is constructed in an end-to-end fashion with 3-0 or 4-0 polypropylene suture. Note the small, stiff bulldog clamp occluding the left subclavian artery (LSCA)

clamped, the LHB flows are increased to a target of 1.5–2.5 L/min, with a goal mean arterial pressure of 80 mmHg. After it is confirmed that the isolated aortic segment is not pressurized, the segment is opened longitudinally with electrocautery, and the edges are retracted with 0-silk is accurate. All of the intercostal arteries in this segment are ligated with 2-0 silk sutures in a figure-of-eight fashion (Fig. 77.7c). A cuff of proximal descending thoracic aorta is prepared by transecting the aorta at least 2–3 cm distal to the clamp and carefully separating the aortic wall from the underlying esophagus to ensure that it is not incorporated into the anastomosis. An appropriately sized Dacron graft (most often 22 or 24 mm in diameter) is chosen and is sewn end-to-end to the proximal aortic cuff with 3-0 or 4-0 polypropylene sutures (Fig. 77.7d). This suture line is often reinforced circumferentially

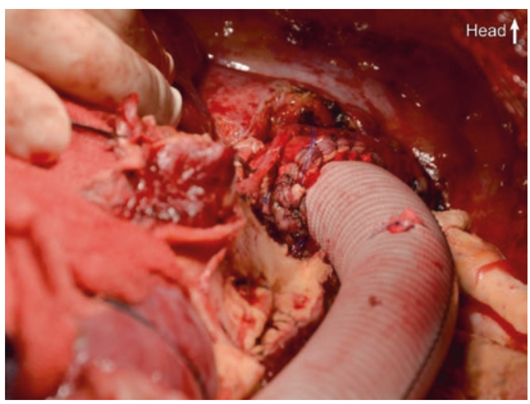

Fig. 77.8 Completed proximal anastomosis

with either a second running layer or a series of interrupted 3-0 or 4-0 pledgeted mattress sutures (Fig. 77.8). At this point, if the proximal clamp was

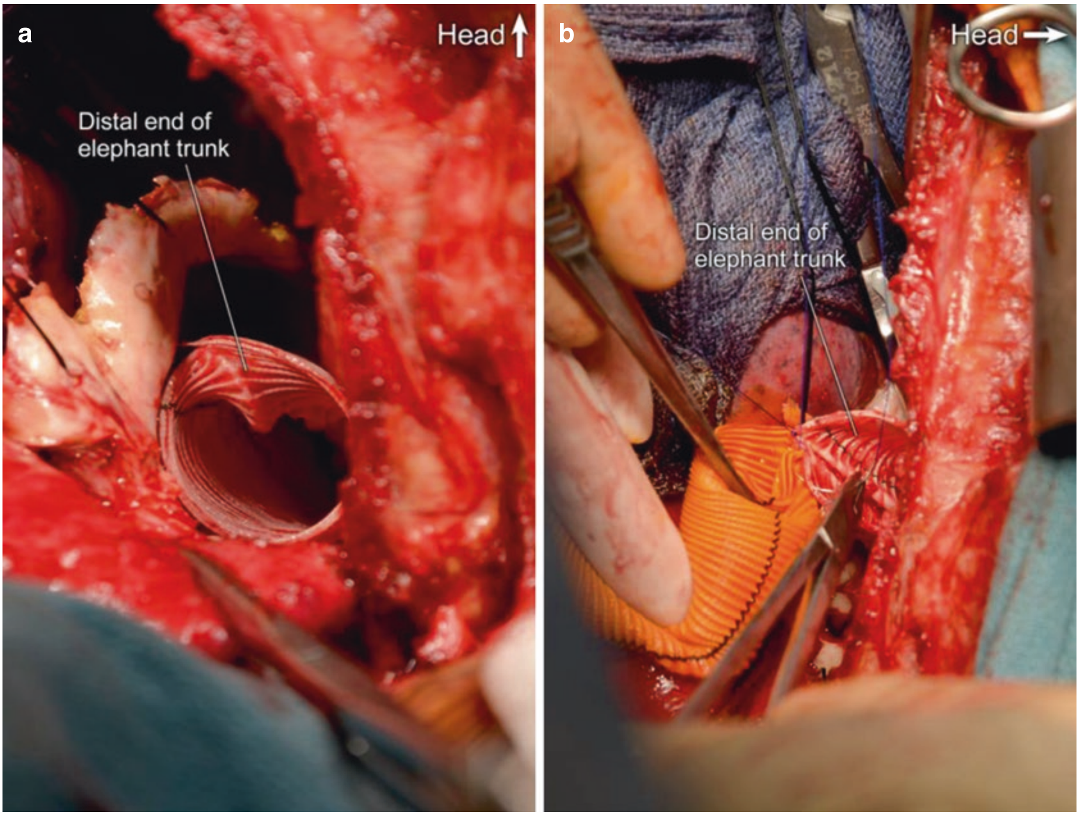

Fig. 77.9 Proximal anastomosis with previous elephant trunk. (**a**) Distal end of prior elephant trunk graft. (**b**) Proximal anastomosis of aortic graft to previous elephant trunk

placed between the LCCA and LSCA, the clamp is moved onto the graft and the LSCA bulldog clamp is removed, thereby restoring LSCA and left vertebral perfusion.

77.11.1 Elephant Trunk Technique

If the patient had a previous total arch replacement with an elephant trunk (ET) [12], the aorta is generally clamped distal to the LSCA, and the distal end of the ET is identified within the isolated aortic segment (Fig. 77.9a). An appropriately sized Dacron graft is chosen and is sewn end-to-end to the distal ET with 2-0 or 3-0 polypropylene sutures (Fig. 77.9b). Conversely, if the patient has an unrepaired aneurysm of the transverse aortic arch, the reverse ET technique is used to facilitate subsequent repair [13].

77.12 Distal Aortic Reconstruction

After the proximal anastomosis is complete, the LHB is weaned and discontinued. The distal aortic clamp is removed (Fig. 77.10a), and the thoracoabdominal aorta is opened longitudinally with electrocautery down to the aortic bifurcation (Fig. 77.10b). Shed blood is collected by a cell-saver system and rapidly autotransfused back into the patient. The distal aortic segment is prepared, any large pieces of thrombus are removed (Fig. 77.10c), and the dissecting membrane is excised in patients with chronic dissection (Fig. 77.10d). Attention is next turned to protecting the abdominal organs with isothermic blood from the LHB outflow line to the celiac artery and SMA and with cold crystalloid perfusion to the left and right renal arteries, delivered through four 9-French Pruitt catheters (Fig. 77.11).

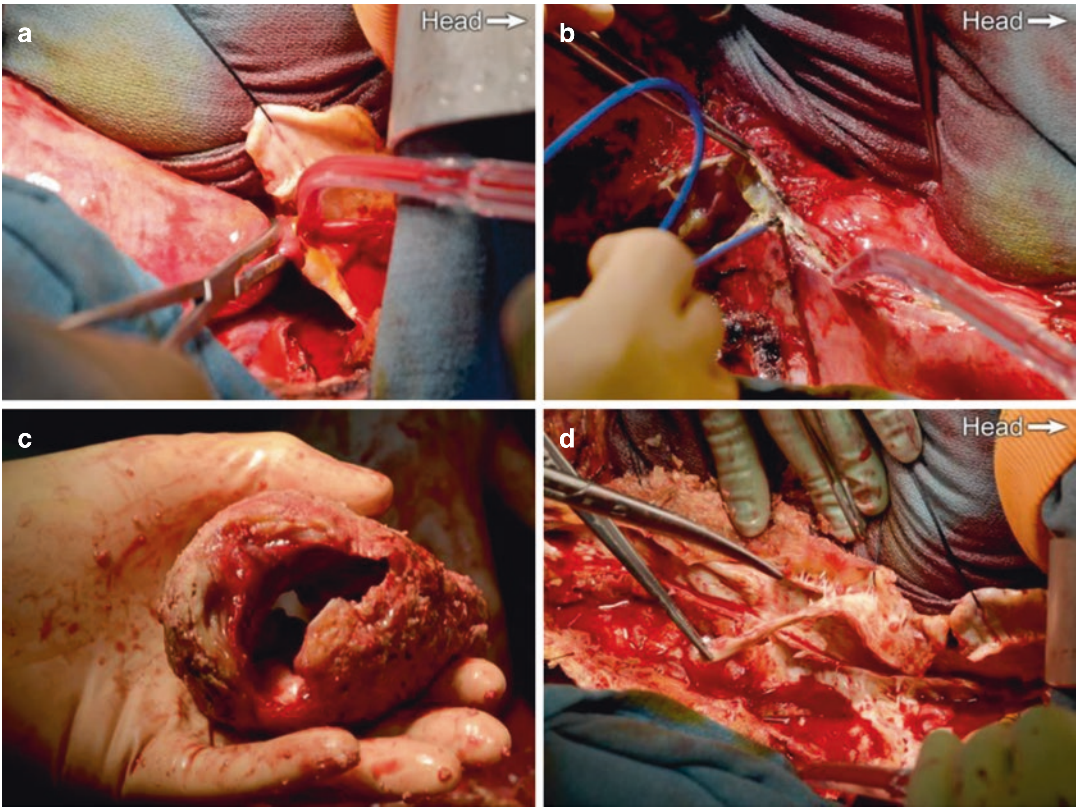

Fig. 77.10 Preparation of the distal aorta. (**a**) After left heart bypass is discontinued, the distal aortic clamp is removed, and shed blood is salvaged and returned to the patient via a rapid infuser. (**b**) The thoracoabdominal aorta is opened longitudinally with electrocautery to the bifurcation. (**c**) A large piece of thrombus is removed from the abdominal aorta. (**d**) The dissecting membrane is excised in a patient with a chronic dissection

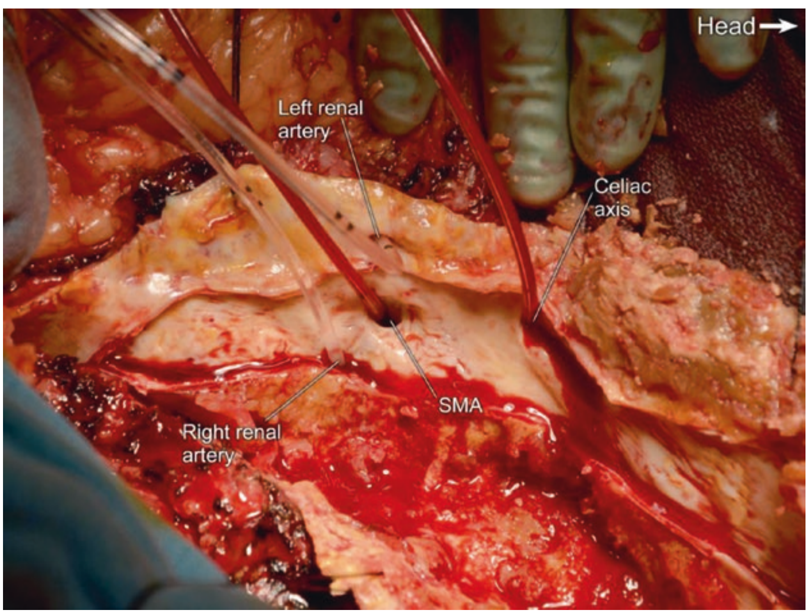

Fig. 77.11 Visceral perfusion. Isothermic blood is delivered from the return line of the left heart bypass circuit through two 9-French Pruitt catheters to the celiac artery and the superior mesenteric artery (SMA) at a rate of about 200 mL/min. Cold crystalloid solution is delivered intermittently in 200–300 mL increments through two 9-French Pruitt catheters to the left and right renal arteries. The amount of cold crystalloid delivered is adjusted as needed to avoid excessive systemic hypothermia and fluid overload

77.12.1 Intercostal Artery Reattachment

Patent segmental arteries, particularly those between T7 and L1, are carefully inspected; any that are large and have little back-bleeding are chosen for reimplantation provided that the adjacent aortic tissue is suitable for an anastomosis. Reimplantation may be done as a patch, in which case an opening is made in the graft and a side-to-side anastomosis is constructed with 3-0 or 4-0 polypropylene suture (Fig. 77.12a–c). If possible, the proximal aortic clamp is then moved immediately distal to the intercostal patch, thus reperfusing that segment of the spinal cord (Fig. 77.12d). Alternatively, reimplantation of segmental arteries may be done with a separate 8- or 10-mm graft off the main body of the graft after the rest of the aortic repair is completed.

77.12.2 Visceral Artery Reimplantation

The configuration of visceral artery reimplantation depends on multiple factors, including the age of the patient, the presence of connective tissue disease, and the distance between the origins of the arteries. In older patients with degenerative aortic disease whose four vessels are in close proximity with one another, all four arteries may be reattached in one patch (Fig. 77.13). A common variation is to reimplant the right renal, superior mesenteric, and celiac arteries together and the left renal artery separately—either directly or with an 8-mm graft. In a younger patient with connective tissue disease or a patient whose arterial origins are significantly displaced as in Fig. 77.14, we use a graft with four pre-sewn branches to reim-

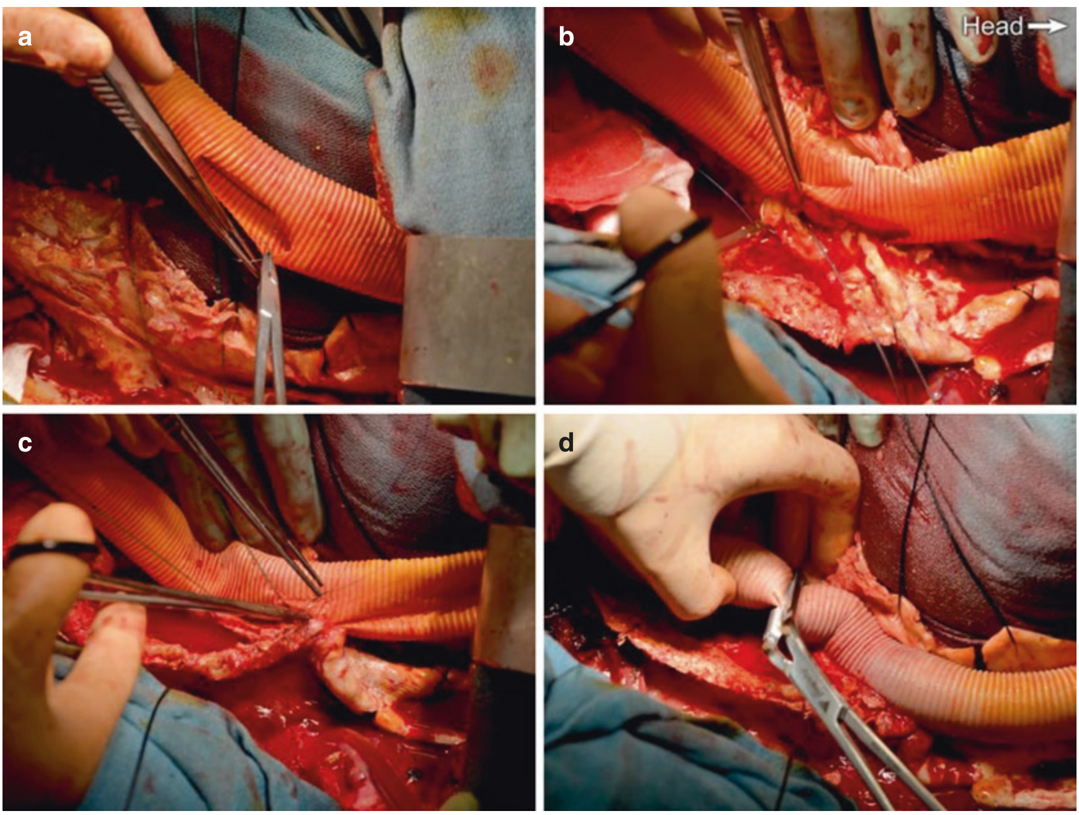

Fig. 77.12 Intercostal artery reattachment. (**a**) After a pair of intercostal arteries is selected, the graft is trimmed appropriately, and a side-to-side anastomosis is begun. (**b**) The anastomosis is constructed with green (3-French) balloon occlusion catheters placed in the intercostal arteries to limit back-bleeding. (**c**) The intercostal patch anastomosis is completed. (**d**) The proximal clamp is reapplied just distal to the intercostal patch anastomosis

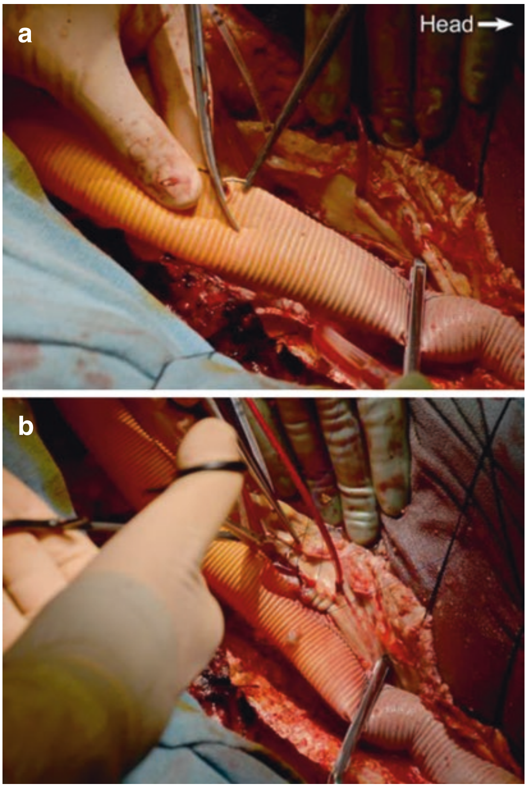

Fig. 77.13 Visceral patch anastomosis. (**a**) The graft is trimmed, and (**b**) the side-to-side visceral patch anastomosis is constructed with the visceral perfusion catheters in place

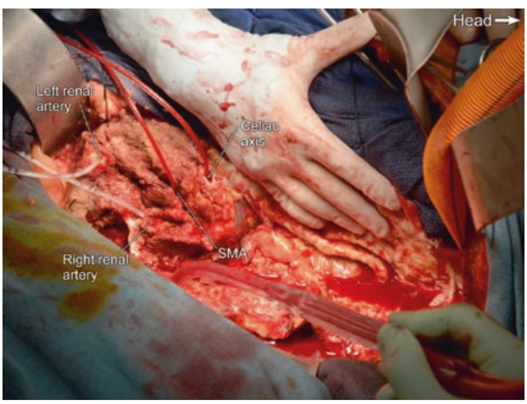

Fig. 77.14 Open distal aorta with visceral perfusion catheters in place. Note the large distance between the origins of the celiac artery, superior mesenteric artery (SMA), and left and right renal arteries

Fig. 77.15 Graft-to-graft anastomosis. A graft-to-graft anastomosis is constructed between the multi-branched graft and the previous descending thoracic graft

plant each vessel separately [14–16]. The multi-branched graft is anastomosed to either the native proximal aorta or, as is shown in Fig. 77.15, a previous descending thoracic graft. When using a multi-branched graft, we generally perform the distal aortic anastomosis (described below) before reattaching the visceral branches; this enables restoration of blood flow to the iliac arteries and their branches that provide collateral perfusion to the spinal cord. Then, each of the branches of the graft is trimmed and anastomosed to its corresponding artery in an end-to-side fashion with 4-0 or 5-0 polypropylene suture (Fig. 77.16). The order of the anastomoses depends on the patient's anatomy and baseline renal function, but it is typically as follows: right renal artery, SMA, celiac artery, and left renal artery.

The origins of each of these vessels are carefully inspected for stenosis, calcification, or dissection. The dissecting membrane is often excised in cases of chronic dissection. Alternatively, the false channel may be obliterated during the end-to-end anastomosis or with circumferential interrupted fine polypropylene sutures. Stenotic visceral arteries may need endarterectomy, stenting, or both [17]. As shown in Fig. 77.17, we often use balloon-expandable stents, generally 6 or 7 mm in diameter and 14 or 15 mm in length, for stenotic arteries.

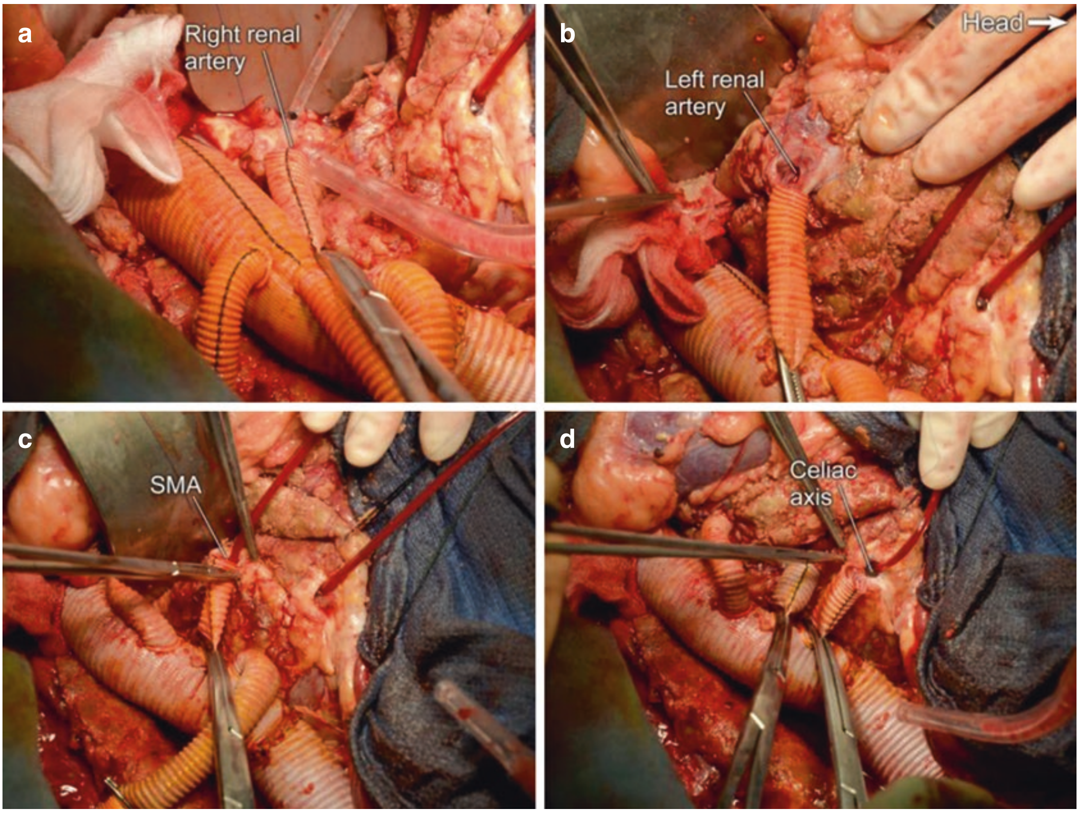

Fig. 77.16 Visceral branch anastomoses. Each branch of the multi-branched graft is anastomosed to its appropriate artery. (**a**) The right renal artery is generally reattached first via the right-sided 8-mm branch in an end-to-end fashion with 5-0 polypropylene. (**b**) The left renal artery is reattached via the left-sided 8-mm branch. (**c**) The superior mesenteric artery (SMA) is reattached via the more inferior 10-mm branch. (**d**) Finally, the celiac artery is reattached via the more superior 10-mm branch. The graft to the superior mesenteric artery remains clamped to avoid celiac back-bleeding during the anastomosis

77.12.3 Distal Aortic and Limb Anastomoses

The location of the distal anastomosis depends on the degree of aneurysmal dilation of the distal aorta and the iliac and femoral vessels. If the aorta is of adequate quality and caliber proximal to the bifurcation, an end-to-end anastomosis is made at this level (Fig. 77.18a). If the vessels beyond the bifurcation are involved, we sew an end-to-end anastomosis to a bifurcated abdominal aortic graft with 4-0 polypropylene suture as shown in Fig. 77.18b. The limbs of this graft are anastomosed to the common iliac (Fig. 77.19a), external iliac, or common femoral arteries (Fig. 77.19b), targeting on each side the most proximal level where distal arteries of sufficient quality and caliber are encountered; flow into the internal iliac arteries is preserved whenever possible. As noted above, one of the advantages of the multi-branched graft is that the distal aortic anastomosis may be performed before the four visceral branches are reattached.

77.13 Closure

Several examples of completed aortic repairs are shown in Figs. 77.20 and 77.21. After the aortic replacement is completed, intravenous protamine and indigo carmine are administered to reverse the effect of heparin and assess the adequacy of renal perfusion, respectively. Each anastomosis is inspected for bleeding and repaired as necessary by using reinforcing sutures with felt strips or

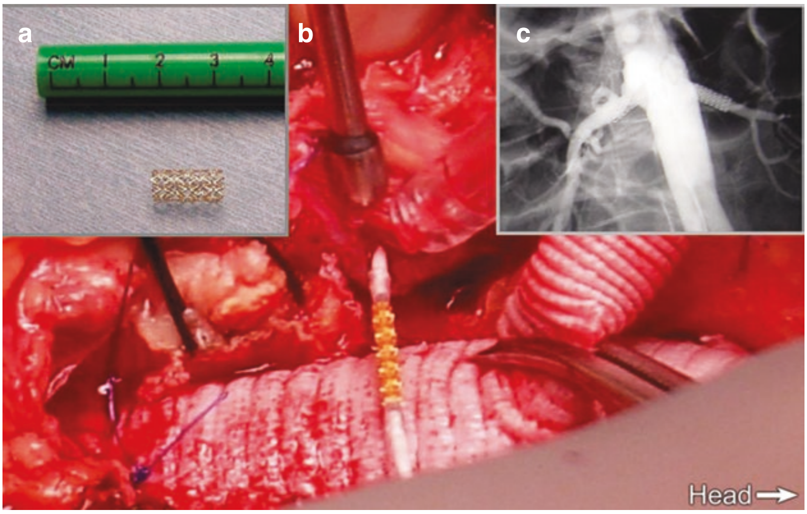

Fig. 77.17 Left renal artery stent insertion. (**a**) Balloon-expandable stent. (**b**) Insertion of balloon-expandable stent into the left renal artery. (**c**) Abdominal angiogram showing stents in both renal arteries. Reproduced with permission from [17]. Copyright European Association for Cardio-Thoracic Surgery

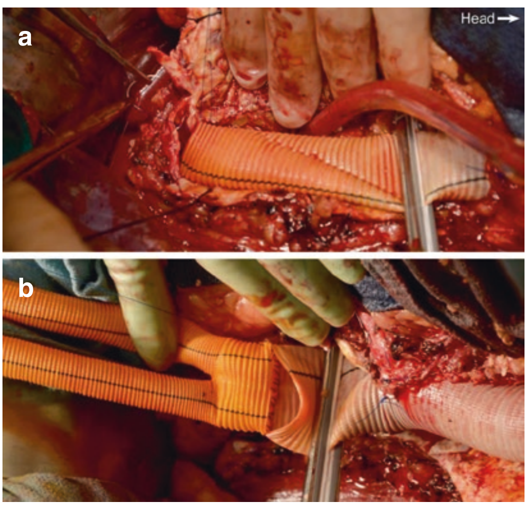

Fig. 77.18 Options for distal aortic anastomosis. (**a**) End-to-end anastomosis to the distal abdominal aorta, a few cm proximal to the aortic bifurcation. (**b**) End-to-end anastomosis to a bifurcated abdominal graft

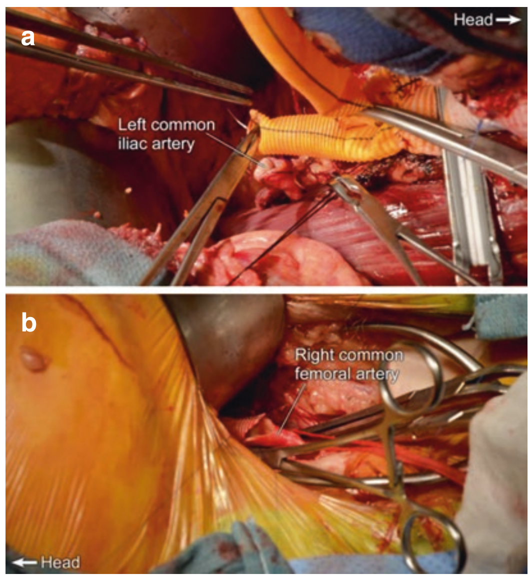

Fig. 77.19 Distal limb anastomoses. (**a**) End-to-end anastomosis to the left common iliac artery. (**b**) End-to-side anastomosis to the right common femoral artery

pledgets. The left atrial cannula is removed, and the venotomy is repaired. The field is irrigated with warm water, and blood products are administered as necessary. Satisfactory perfusion to the abdominal organs and the iliac and femoral arteries is confirmed. The spleen is assessed to ensure there are no capsular tears or subcapsular hematomas. A 19-French closed-suction abdominal drain is placed in the upper left retroperitoneal space (Fig. 77.22a). The diaphragm is reapproximated with a continuous #1 polypropylene suture

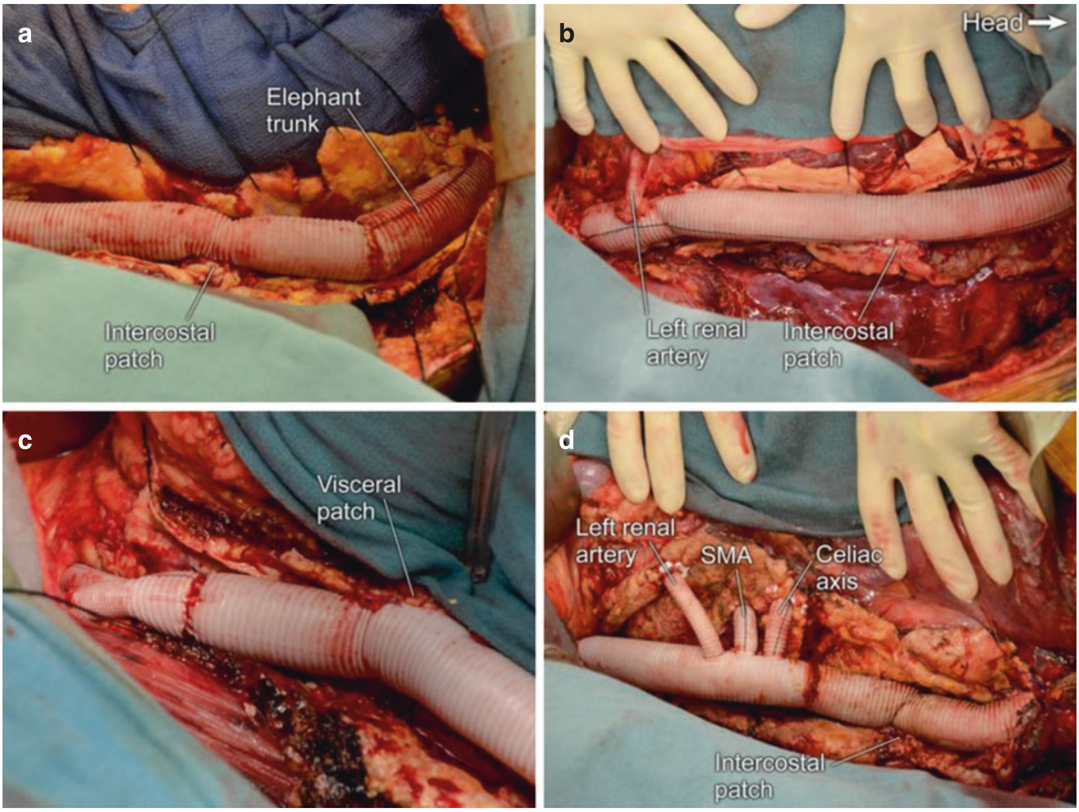

Fig. 77.20 Completed repairs. (**a**) Tube graft sewn to previous elephant trunk graft. (**b**) Tube graft with direct reimplantation of left renal artery. (**c**) Bifurcated abdominal graft. (**d**) Multi-branched thoracoabdominal graft. *SMA* superior mesenteric artery

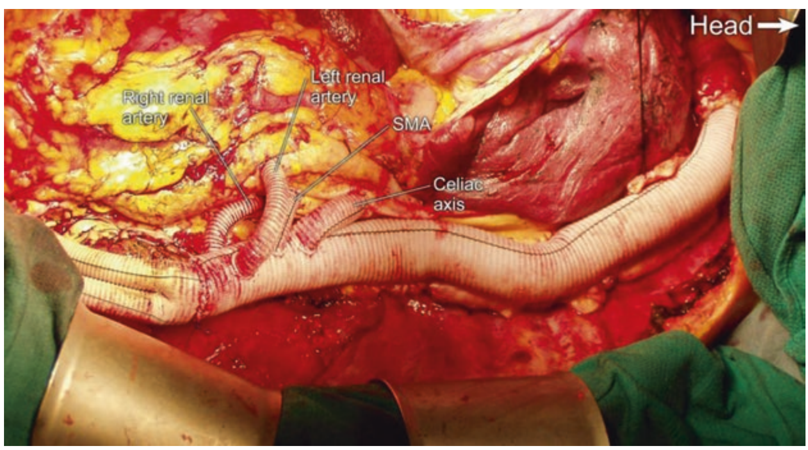

Fig. 77.21 Completed extent II thoracoabdominal repair with multi-branched graft and bifurcated distal aortic graft. *SMA* superior mesenteric artery

(Fig. 77.22b, c). Two straight 36-French chest tubes are placed in an anteroapical and posterobasal position within the left chest cavity. The chest is closed with pericostal sutures and two surgical steel wires (Fig. 77.22d). Two pericostal analgesia catheters are placed along the thoracotomy incision. The abdominal fascia, serratus anterior, and latissimus dorsi are each closed with separate continuous #1 polypropylene suture.

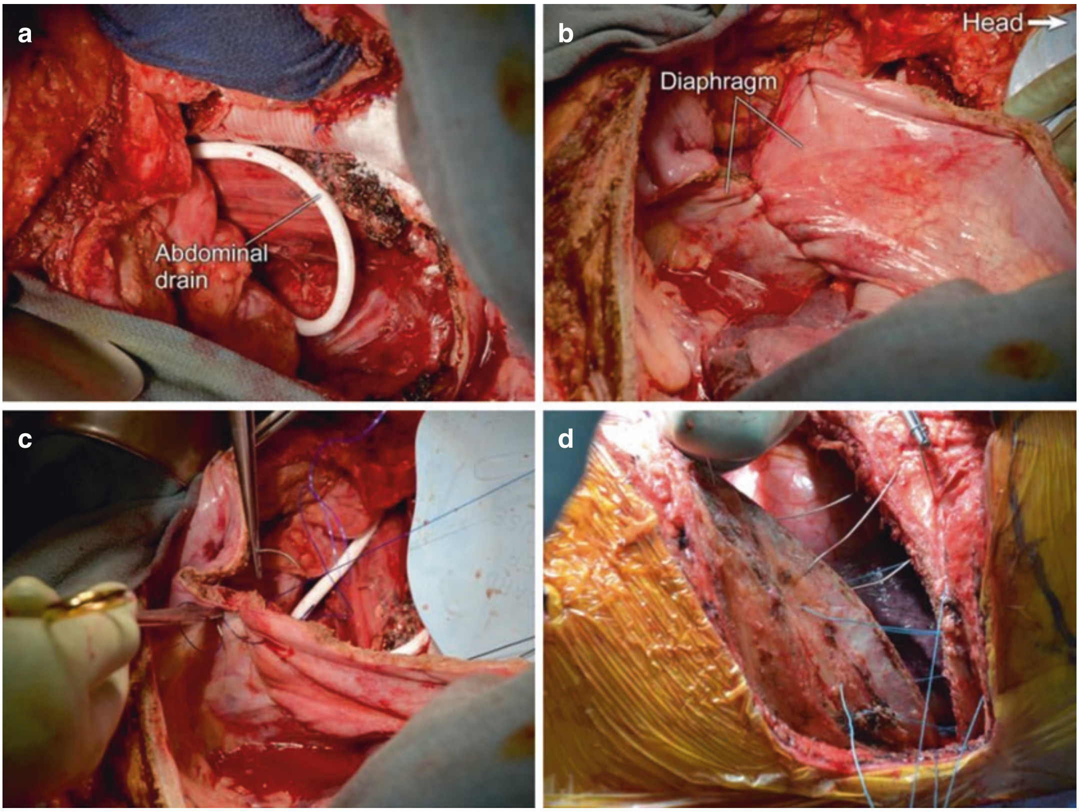

Fig. 77.22 Closure. (**a**) A 19-French closed-suction abdominal drain is placed over the psoas muscle in the left retroperitoneum. (**b**, **c**) The diaphragm is reapproximated with a continuous #1 polypropylene suture. (**d**) The thorax is closed with braided #2 pericostal sutures and two #7 surgical steel wires

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