34 Management of Aortic Infections: Role of Open Surgery and the Value of Multidisciplinary Team Approach

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34.1 Introduction

Aortic graft infection is known to be a very complex and challenging pathology, whether it is a surgical graft or an endograft, and despite of all the recent surgical and medical advances, it still carries a significant risk of morbidity and mortality. Since the first aortic endograft was inserted by Volodos and colleagues in Ukraine, the use of endografts in aortic disease has increased dramatically [1–3]. The majority of early endograft explantations were performed for complications in device insertion and deployment and persistent endoleak causing sac expansion. Stent infection was first reported in 1993 and is now thought to occur in 1–4% of endografts, resulting in major morbidity, mortality and economic cost [4–10]. It is unclear whether or not the incidence of endograft infection is increasing, but the use of endografts in infected fields such as mycotic aneurysms or aorto-enteric fistulae will result in an ongoing case load [6, 11–13]. There are few data available to guide management, and clinical approaches to this complex condition differ widely with variable outcomes, but consensus diagnostic criteria have been defined [14]. Large multicentre retrospective analyses have been performed using the Swedish vascular dataset and in France and the USA [9, 11, 12, 15]. Multicentre prospective data collection is underway by the Management of Aortic Graft Infection Collaboration (www.gsttbrc.com/MAGIC) [14, 16].

No aortic endoprosthesis is designed to ever be removed, and doing so presents several unique challenges to the vascular surgeon. As yet there are no methods for percutaneous endograft removal, and therefore open surgery is mandatory and entails all of the major operative risks that the initial endovascular repair was designed to avoid. This is of particular concern for infection affecting the visceral segment. Whilst some endografts are removed electively or urgently, the patient may also present with haemorrhage through an aorto-enteric, aorto-bronchial or aorto-cutaneous fistula, and disease affecting the visceral segment will frequently involve these a fistula [17]. Proximal and distal control is usually sought beyond the anatomic limits of devices which are often positioned just distal to important arterial branches, for example, the renal,

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subclavian or carotid arteries. Several devices incorporate active fixation with hooks, barbs or anchors to secure the device to the aortic wall preventing migration; these and any bare stent may become incorporated into the wall and make removal difficult. In the setting of infection, it is necessary to remove additional devices such as internal iliac artery embolisation coils if these are within the infected field. Thus complex surgery is required in patients who may have been deemed unfit for open surgical management of their original disease. It is usually not necessary to remove extra-anatomic grafts, for example, those used to de-branch the arch or a femoral-femoral crossover graft, if these are remote from the operating field and well incorporated into the tissues. Once the main device and other infected prosthetic materials have been removed, the arterial circulation must be reconstructed, and in the case of infection, this should not involve placing new prosthetic material in the infected field. Previously this has been by axillobifemoral bypass, but attention has moved towards in situ reconstruction using biological materials [18–25].

34.2 Diagnosis of Aortic Prosthetic Infection

A high index of suspicion is required for diagnosis because the clinical presentation can be varied and occur at any time after graft insertion [10]. A detailed history and examination are essential not just for aortic graft infection (AGI) diagnosis but also determining aetiology and associated features (such as spinal osteomyelitis, visceral fistulae) that must also be managed [26]. Mycotic aneurysms may remain occult for many months. Conversely, because the morbidity and mortality of graft explantation (or even lifelong antimicrobial therapy) are so great, a high degree of certainty is required in AGI diagnosis. Most clinical series on aortic graft infection and mycotic aneurysms have reported their diagnostic criteria as being a combination of 'clinical, radiological and microbiological' features but have always been vague about how these have been applied [15, 27]. Historically, the way in which these three groups of factors should be combined has not been addressed, hindering conglomeration of data and precluding future trial design [5, 28–31]. Consensus diagnostic criteria for the *suspicion* and *diagnosis* of AGI have now been published, allowing consistent diagnosis in future studies and guiding the investigation of suspected AGI (Fig. 34.1) [14]. Aortic graft infection (AGI) is *suspected* in a patient with any isolated major criterion or minor criteria from two of the three categories: clinical/surgical, radiological or laboratory. AGI is *diagnosed* in the presence of a single major criterion, plus any other criterion (major or minor) from another category. Note that where microbiological investigations identify potential 'contaminant' organisms (e.g. coagulase-negative staphylococci, propionibacteria, corynebacteria and other skin commensals), a minimum of (1) two intraoperative specimens, (2) two blood cultures or (3) one intraoperative specimen plus one blood culture must be positive with an indistinguishable organism in each sample based on antibiograms or a recognised typing method, e.g. pulsed-field electrophoresis. These criteria have subsequently been utilised in the diagnosis of mycotic aneurysms [20].

34.3 The Role of 18F-FDG PET/CT and Labelled Leucocytes

Most AGI is suspected based on CT angiography [14, 32]. Both 18F-FDG PET/CT and SPECT-CT allow accurate localisation of sites of inflammation, and these investigations are invaluable in the diagnostic workup of AGI, both in the confirmation of AGI (as part of the diagnostic criteria) and in their ability to identify occult non-aortic infection or other causes of inflammation (e.g. vasculitis), thereby preventing unnecessary surgery [33–47]. MRI may have a very limited role [48, 49].

The 18F-FDG uptake in both normal aorta and in aneurysmal (untreated) aorta has been well defined in a large number of patients, with an upper limit of SUV_{max} of 3.8 [14]. Others have suggested a high degree of sensitivity and specificity in the diagnosis of aortic graft infection using SUV_{max} cutoffs between 3.8 and 8, and further work is required in this area. The positive predictive value of PET/CT may be improved by

	CLINICAL / SURGICAL	RADIOLOGY	LABORATORY
MAJOR CRITERIA	• Pus (confirmed by microscopy) around graft or in aneurysm sac at surgery • Open wound with exposed graft or communicating sinus • Fistula development e.g. aorto-enteric or aorto-bronchial • Graft insertion in an infected site e.g. fistula, mycotic aneurysm or infected pseudoaneurysm	• Peri-graft fluid on CT scan ≥ 3 months after insertion • Peri-graft gas on CT scan ≥ 7 weeks after insertion • Increase in peri-graft gas volume demonstrated on serial imaging	• Organisms recovered from an explanted graft • Organisms recovered from an intra-operative specimen • Organisms recovered from a percutaneous, radiologically-guided aspirate of peri-graft fluid
MINOR CRITERIA	• Localized clinical features of AGI e.g. erythema, warmth, swelling, purulent discharge, pain • Fever ≥38°C with AGI as most likely cause	• Other e.g. suspicious peri-graft gas/fluid/soft tissue inflammation; aneurysm expansion; pseudoaneurysm formation; focal bowel wall thickening; discitis/osteomyelitis; suspicious metabolic activity on FDG PET/CT; radiolabelled leukocyte uptake	• Blood culture(s) positive and no apparent source expect AGI • Abnormally elevated infalmmatory markers with AGI as most likely cause e.g. ESR, CRP, white cell count

Fig. 34.1 Diagnostic criteria for aortic graft infection. Aortic graft infection (AGI) is *suspected* in a patient with any isolated major criterion or minor criteria from two of the three categories: clinical/surgical, radiological or laboratory. AGI is *diagnosed* in the presence of a single major criterion, plus any other criterion (major or minor) from another category. *CT*, computed tomography; *FDG*, fluorodeoxyglucose; *PET*, positron emission tomography; *ESR*, erythrocyte sedimentation rate; *CRP*, C-reactive protein. Reproduced from Lyons et al., Eur J Vasc Endovasc Surg (2016) 52, 758–763

combining a SUV_{max} cutoff with visual scoring of the uptake pattern [50]. The normal limits of 18F-FDG uptake in the early period after endograft deployment or open surgical repair have not been clearly defined, and this remains a limitation to the use of 18F-FDG [51]. Several attempts to develop infection-specific PET tracers are underway [52]. All these diagnostic imaging techniques require further validation in a prospective study enrolling patients diagnosed according to standardised criteria. 18F-FDG PET/CT may continue to play an important role in monitoring the response to antimicrobial therapy once AGI has been diagnosed.

34.4 Decision-Making

In 2016 the AHA published guidelines on the management of vascular graft infections, mycotic aneurysms and endovascular infections [10]. In general these recommendations are based on a low level of evidence and are not specific to the aorta. The evidence base for the advice to make management decisions based on microbial growth, and for the duration of antimicrobial therapy, is particularly lacking. Little guidance is given on the complexities of managing the visceral segment (Fig. 34.2).

34.5 Medical Management

Detailed investigation and antimicrobial therapy will not be discussed here [53]. Multidisciplinary management involving interventional radiology, infectious diseases/microbiology and nuclear medicine (all with an interest in AGI management) is essential to guide appropriate investigation and ongoing antimicrobial therapy in all patients. We discuss all patients with suspected or confirmed AGI in a vascular infection

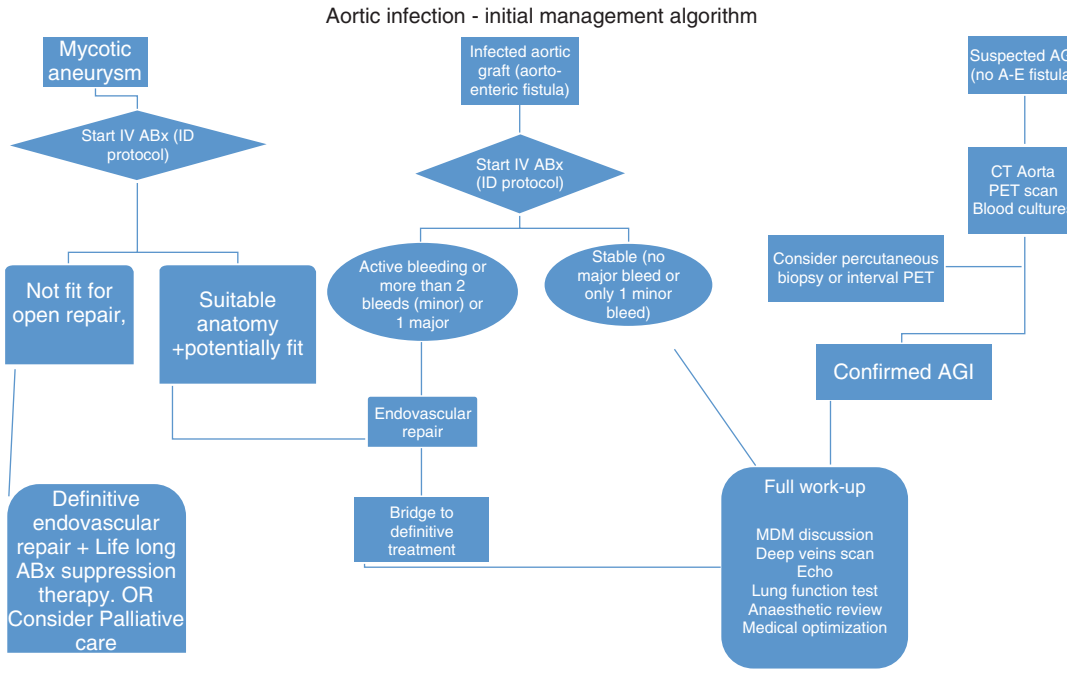

Fig. 34.2 Aortic infection initial management algorithm

multidisciplinary team meeting. Rifampicin-soaking implanted grafts may reduce infection rates in preclinical models [54]. We recommend trying to send at least three separate peripheral blood cultures before the start of antimicrobial therapy if an aortic infection is suspected. Unfortunately the diagnosis of prosthetic infection is often delayed, and many patients presenting to us have received antimicrobial therapy without adequate cultures. Further blood cultures should still be obtained. Broad-spectrum cover is almost always mandated at this stage unless a certain organism has been confirmed. We add antifungal therapy for all suspected and confirmed enteric fistula, due to the inevitable fungal contamination from the gastrointestinal tract. Once a source and an organism have been identified, the protocol should be targeted accordingly in order to minimise harm from antimicrobial therapy. There is low-quality evidence for the route and duration of antimicrobial therapy, but it is important to note the persistence of deaths with sepsis following the endovascular treatment of mycotic aneurysms and deaths from haemorrhage (local sepsis, disease extension) when infected endografts are not explanted [11, 19].

34.6 Endograft Bridging in Aorto-enteric Fistulae

In our experience of using endografts for haemorrhage control in the setting of AGI, infection persisted despite ongoing antimicrobial therapy, and all patients had died of their aortic disease within 2 years of follow-up [19]. We now therefore proceed to explantation of infected grafts wherever the patient's condition allows. We frequently use an endograft as a bridging tool, mainly to stabilise patients who present with bleeding from an aorto-enteric/aorto-bronchial fistula or rapidly expanding mycotic aneurysm. The main aim is to 'separate bleeding from sepsis' giving a chance to prepare and optimise the patient for a major operation as well as allow sufficient time for planning further management strategies.

34.7 The Role of Percutaneous Drainage and Irrigation

Aspiration may be performed for diagnostic purposes, but a *drain* should not be placed unless AGI has been confirmed [14, 55]. When time allows, drainage of collections can lead to resolution of overt sepsis (but not cure of infection) and may improve the outcome of subsequent surgery [56]. Management of AGI without explantation likely carries a far higher mortality than with explantation in the medium term. In series with longer follow-up, the mortality from leaving infected prostheses in situ can approach 100% [9, 19]. In selected patients who are deemed unfit for explantation, conservative measures such as antibiotic therapy and percutaneous drainage of pus and irrigation of the aneurysm sac may be appropriate [57–61]. Irrigation of the native aneurysm sac (in the proven absence of endoleak) or an abscess cavity with povidone-iodine or antimicrobials has been described [62–64].

34.8 Open Surgery for Visceral Segment Infection

34.8.1 Aim of Treatment

Primary aortic infection (termed a mycotic aneurysm) is associated with aortic dilatation and early rupture, whilst aortic graft infection carries a grave prognosis in the medium term [19, 65]. The main goal of treatment is to prevent death from haemorrhage. We define ‘cure’ as persistent eradication of infection with no need for lifelong suppressive antibiotic therapy.

Our current protocol for aortic infections considers radical surgery in the form of complete graft explantation and in situ anatomical reconstruction with a biological graft as the treatment of choice for any patient deemed to be fit enough for this operation (Fig. 34.3). The components of operative management should include:

- Excision of all infected artery and synthetic material
- Debridement of infected/necrotic tissue (source control, e.g. aorto-enteric fistula) and drainage of related collections
- Tissue sampling for microbial culture and/or PCR
- Arterial reconstruction (ideally anatomical and autologous)
- Source control (aorto-enteric fistula)

Achieving all of the above can be very challenging and certainly involves significant physiological insult with an associated inflammatory response from surgical trauma. If tolerated by the patient, the control of sepsis is achieved faster, and cure (without the need for long-term antimicrobial therapy) is feasible.

With the increased complexity of surgery resulting from infections involving the visceral segment, these aims may frequently be unachievable. The only viable option may be to temporise with an endovascular graft and lifelong suppressive antimicrobial therapy.

34.8.2 Treatment Options

- Open surgery
- Endovascular
- Lifelong antimicrobial suppressive therapy
- Short-term palliative care

34.8.3 Open Surgery

Most of the published series describing aortic graft infection suggest that ‘cure’ cannot be achieved without full explantation of infected grafts. Mycotic aneurysms are a different pathology to fistulae, and there may well be a chance of cure with antimicrobial therapy with an endovascular graft remaining in situ [11, 66]. This may relate the duration or preoperative antimicrobial therapy and pre-deployment ‘control of sepsis’, but data are inconclusive [11]. The difficulty remains in predicting the patients in whom we can safely stop antimicrobial therapy once the mycotic aneurysm has been treated,

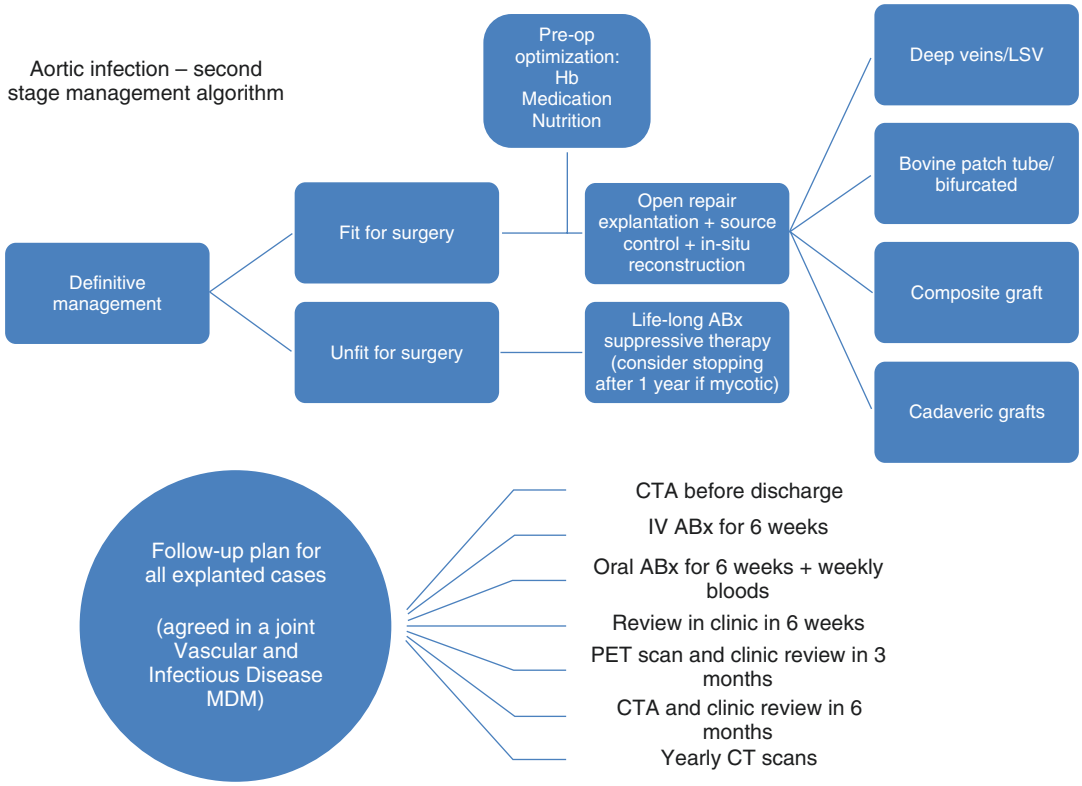

Fig. 34.3 Aortic infection second stage management

and 18F-FDG PET/CT may play an important role. The long-term outcomes of this approach remain questionable [11, 12].

34.8.3.1 Perioperative Planning Considerations

We cannot emphasise enough the importance of thorough planning in these cases. Planning is a fundamental part of the operation, required in order to achieve good outcomes. The patient's condition may deteriorate rapidly, and we suggest that these plans should be in place shortly after the patient's initial emergency presentation.

34.8.3.2 Damage Control Plan

A damage control plan allows the team to prepare well for the definitive management and to get the patient to be ready for such a major intervention. Patients may be haemodynamically unstable at presentation (or may become unstable) due to the combination of sepsis and haemorrhage. A plan to stop any bleeding, whether this is a ruptured aorta or an aorto-enteric/aorto-bronchial fistula, should always be in place. Endovascular intervention is the best option for this, and unless it has been agreed that it will be the definitive option, the aim here is to temporise the bleeding, and so endograft deployment should be planned to avoid making the complex open repair more difficult (Fig. 34.4).

Endografts are very effective in the thoracic segment. Covering one or more of the visceral arteries with a chimney or snorkel technique may be required, but we would advise to do this only when it's the only way to control haemorrhage. We would consider keeping the visceral stents as proximal as possible in the target vessel origin to

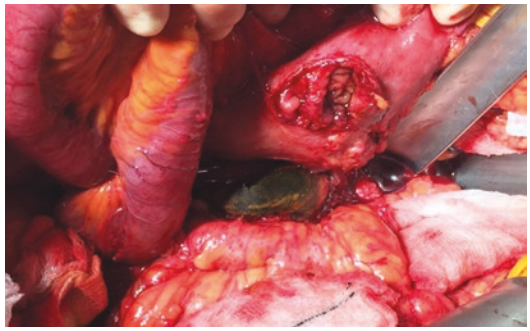

Fig. 34.4 Source control. An aorto-enteric fistula has been disconnected

facilitate future explantation. Since the aim here is to control the bleeding temporarily, long-term durability is not an issue, and the more aorta is covered, the more complex the next step will be. Consideration should be given to sites of aortic and visceral artery clamping during subsequent operations.

34.8.3.3 Preoperative Optimization Plan

This should include the preoperative workup and investigations as well as a nutrition plan and any other cardiorespiratory intervention or medical optimization to improve fitness. Some patients may require temporary filtration during that period. Anaesthetic and intensive care team involvement is valuable when it comes to the operative planning.

34.8.3.4 Intraoperative Plan

Graft explantation and aortic reconstruction are complex surgical procedures and the pathologies encountered are heterogeneous. Although the general concepts and stages of the procedure can to an extent be standardised, the details can make all the difference. For example, a failure to perform adequate debridement of *all* infected tissues may render the entire operation pointless (relative to a nonoperative management). In our experience, spending time in planning and discussing the technical details of various steps and bailout options have never been a waste of time and may highlight further risks, which may require rediscussion within the multidisciplinary team.

Involvement of the visceral segment significantly increases the complexity of these procedures. In a frail patient, open surgical procedures may be considered futile, and other alternatives including long-term suppressive therapy or indeed short-term palliation should be considered.

The following stages of this operation can be considered as separate entities for the sake of detailed planning; however, eventually there will be overlap and cross implications when it comes to the execution of the plan intraoperatively.

34.8.3.5 Access

This should be planned with consideration not only of the steps of the present operation but also bailout options and potential future operations. If at all possible, a single position for the whole procedure should be sought, avoiding the need for intraoperative repositioning. This may not always be possible. We recommend a very generous access incision from the beginning, keeping in mind access to easy vascular control (mainly the proximal), the need for cardiopulmonary bypass (full or left heart) and the possibility of enteric fistula, which will need to be disconnected and dealt with.

If the thoracic aorta is involved, we prefer a standard left thoracolaparotomy, whilst if the affected segment is totally abdominal, we tend to use a rooftop incision with a transperitoneal approach and left visceral rotation. This incision gives good access for supracoeliac control, both iliac arteries and very good exposure for the bowel, and it is very well tolerated. The incision cannot easily be extended, and if there is doubt about the proximal control, a thoracolaparotomy would be the incision of choice.

34.8.3.6 Control

Although the general concepts of aortic surgery apply here, a few extra considerations need to be kept in mind. The use of endovascular 'bridging' techniques has helped significantly in making exposure and control much more pre-

dictable, which reflects on the overall outcome. Temporary stenting allows full access and usually full preparation of the surgical field without significant blood loss or need for aortic cross clamping, thereby shortening the visceral ischaemia time.

It is very important to note that the healthy aortic wall may be further from the diseased region than is evident on the preoperative CT scan, i.e. the normal diameter aortic adjacent to mycotic aneurysms may be infected and unable to hold sutures (or endografts). The extent of infected artery can progress very quickly, and what was previously a healthy zone for clamping can become weakened in the days between the scan and the operation. A CT scan within a week of surgery is ideal and sometimes just preoperative if in doubt of any progression.

Adhesions and obliterated tissue planes may mandate more generous control, at least initially, and clamps can subsequently be moved closer to the reconstruction area once explantation has been completed, in order to reduce the visceral ischaemia time.

Particular consideration must be given to endovascular stent grafts with suprarenal fixation, which typically extends for a few centimetres and across the origins of the visceral vessels up to coeliac origin. We usually use two proximal clamp sites, one for the explantation and then a second more distal clamp for the reconstruction [67–73].

If the distal control site is the iliac arteries, then balloon endoclamping may save a lot of time and the hassle of difficult dissection and avoid iliac vein injuries. It is particularly helpful when the right iliac artery is not easily accessible in a left thoracolaparotomy.

34.8.3.7 Specific Considerations for Thoracic Aorta

If the thoracic aorta is involved, then a thoracotomy will be required; we recommend cardiopulmonary bypass to be used in these cases whether a left heart bypass or a deep hypothermic circulatory arrest, depending on the extent of repair and the site of the proximal clamp. A short shunt bypass or a right axillobifemoral bypass could also be used to allow distal and visceral perfusion as an alternative but less controlled technique, and the use of cardiopulmonary bypass is recommended.

34.8.3.8 Explantation and Debridement

Once the proximal and distal control sites are fully dissected and ready for clamping, following a brief rehearsal of the following steps with the team, the dissection should now extend distally towards the affected segment of the aorta aiming at trying to identify visceral vessel origins from the outside and also take some samples for microbiology. In some cases this would allow moving the proximal clamp a bit distal or at least prepare the second clamp space to minimise the visceral ischaemia time (Fig. 34.5).

34.9 Techniques of Reconstruction

There are many techniques described in the literature for reconstruction, and although using an in situ biological graft is our preferred option, sometimes it is deemed to be too complex, risky or not feasible; hence, other options of reconstruction should be considered. Regardless of the reconstruction material chosen, continued infection (sometimes termed ‘reinfection’) is a significant problem in a proportion of patients [74, 75].

A very important decision to be made ideally in the preoperative planning stage is whether the visceral vessels will be reconstructed with a visceral patch or separate branches, which could be tailored within the graft or made separately as an extra-anatomical bypass. The backup of selective visceral perfusion should also be considered. If on cardiopulmonary bypass selective visceral perfusion techniques can be used, and if not a shunt bypass at least to the SMA allows more time to reconstruct the visceral segment.

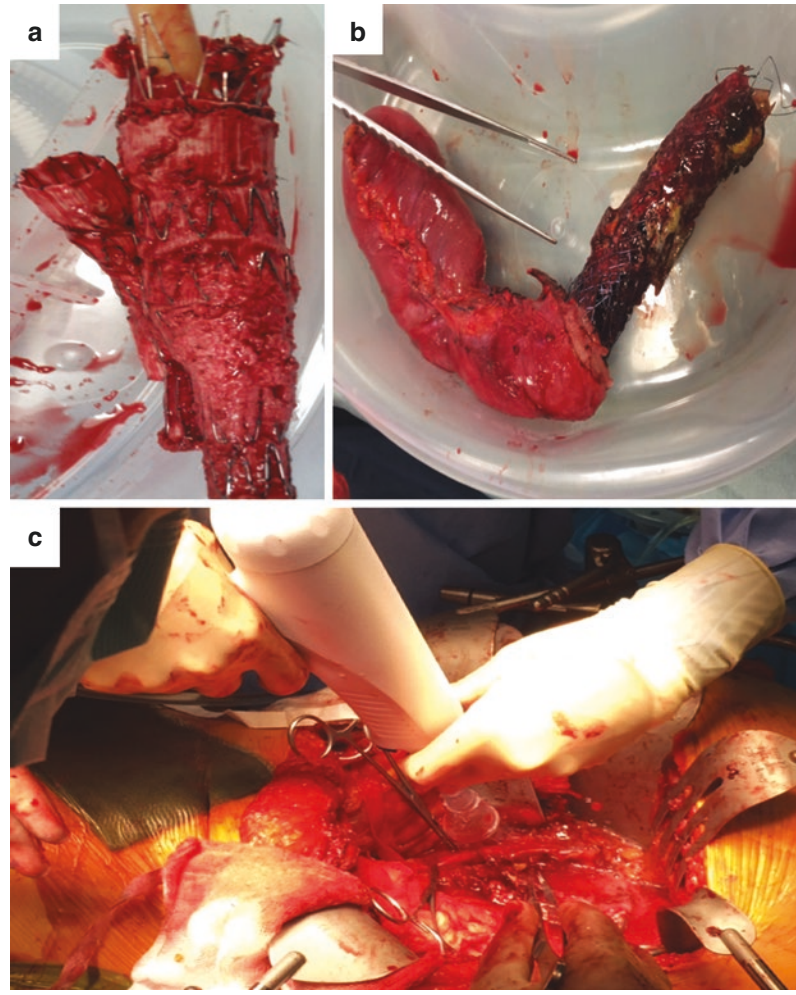

Fig. 34.5 Explanted aortic grafts. (**a**) Explanted endograft with suprarenal fixation. A large intraluminal Foley catheter was used for proximal supracoeliac endoclamping during explantation. (**b**) An aortic endograft has been removed en bloc with a section of duodenum containing duodenal stents (initially placed to treat radiation-induced strictures). (**c**) Extensive pulse lavage of the operative site after debridement of all infected tissues

34.9.1 Extra-anatomic

Right axillobifemoral bypass has always been the most popular option; the ease of the procedure and being away from the infected field made it the gold standard for a period of time; however, sometimes with visceral segment involvement, other options have to be considered [18]. Ascending to infrarenal is a more complex option; however, it allows direct jump grafts to revascularise the visceral vessels. Separate bypasses from the iliac arteries to any of the visceral vessels or hepato-/spleno-renal bypass could also be considered.

Bowel perfusion is of paramount importance, and at least one of the superior mesenteric or coeliac arteries should be perfused as soon as possible.

34.9.2 Deep (Femoral) Veins

Using one or two (panelled) femoral veins is our current preferred option for reconstruction of the aorta (type 4, supra- and juxtarenal); the versatility of the graft, resistance to infection and being autologous make it a very good option. It is time-consuming and adds potential complications of the vein harvest to the procedure (Fig. 34.6) [21].

34.9.3 Spiral Vein Reconstruction

Spiral reconstruction entails using a small calibre vein to create a larger diameter graft to match the aortic diameter. By stitching the longitudinally

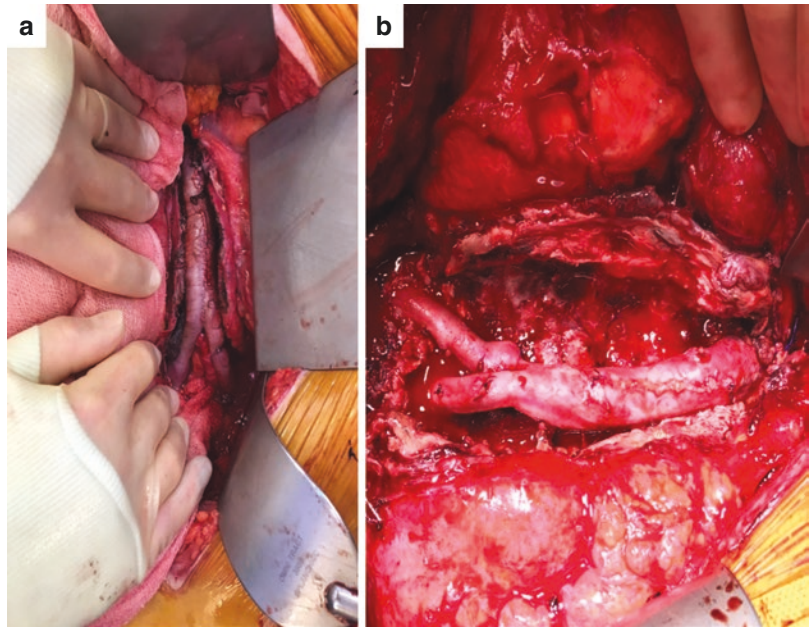

Fig. 34.6 Bifurcated NAIS. (**a**, **b**) Bifurcated neo-aorto-iliac system using superficial femoral veins for in situ reconstruction through transperitoneal and retroperitoneal approaches

spatulated vein in a spiral manner, any diameter can be created; however, this is usually time-consuming with a very long suture line and in visceral segment reconstruction that is less than ideal.

34.9.4 Cryopreserved Human Allografts

Cryopreserved homografts have been an option for the last few decades and have gained more popularity recently with comparable results to deep veins graft in some recent series [76, 77]. Due to calibre match, it's usually the preferred option in the thoracic aorta. Visceral jump grafts can be constructed using a femoropopliteal arterial homograft or native long saphenous or femoral vein.

34.9.5 Rifampicin-Bonded Grafts

There is some evidence that rifampicin-bonded or rifampicin-soaked grafts may allow reasonable outcomes in the medium term [78, 79].

34.9.6 Bovine Pericardial Tube Grafts

This is a relatively new technique and entails an off-label use of the bovine pericardial patches to make a tube [20, 80]. The technique is gaining in popularity as a reconstruction option. It offers a readily available 'off the shelf' solution that can be constructed on the bench to the required diameter and configuration even before the start of the operation. There are a few published reports showing good short-term outcome; however, long-term outcomes are yet to be assessed [20].

34.9.7 Endograft Preserving Techniques

The literature is plagued by small series with relatively short-term follow-up, but some successes have been reported without endograft explantation [81]. Washout, debridement, continuous irrigation and omental wrap techniques are some of the available tools; however, the long-term outcomes remain highly dubious, and we recommend keeping this option as a last resort [82].

34.9.8 Postoperative Care

This can be a long in-hospital journey, and in many cases, the early postoperative days require multi-organ support. Ideally the early postoperative period should be in an intensive care unit, with continuous multidisciplinary team input. The combination of sepsis, major surgical trauma and potentially bleeding can only be tolerated with very prompt and comprehensive postoperative care. Acute kidney injury and cardiorespiratory complications are not uncommon and need to be managed expectantly. If there are any doubts of bleeding, ongoing sepsis or bowel malperfusion, we recommend a very low threshold for early imaging or even re-exploration.

Long-term antimicrobial treatment is a fundamental part of the postoperative care; the details of the antimicrobial treatment are beyond the scope of this chapter.

34.10 Conclusion

Aortic graft infection is fatal in the medium term without explantation and either in situ or extra-anatomic reconstruction. In the visceral segment, this carries a substantial morbidity and mortality; many patients will be unfit for surgical repair, and so optimal multidisciplinary therapy (with the aim of suppression of infection) may remain the mainstay of treatment for many. By definition AGI is suspected when mycotic aneurysms are treated with endografts (a graft placed in an infected field). With appropriate antibiotics cover not all cases progress to reach the diagnostic criteria for AGI, and survival without explant of the graft in the medium term has been shown to be feasible in undetermined groups. Long term outcomes are yet to be assessed and deaths with sepsis do occur. Importantly and towards development of evidence-based clinical guidelines that are presently lacking, the development of diagnostic criteria for AGI provides a consistent diagnostic standard, essential for future clinical trial design and meaningful comparison between diagnostic and therapeutic strategies. Working on developing management strategies using a multidisciplinary team approach could have a positive impact on surgical outcomes. A special focus must be placed on reducing the incidence of aortic graft infection [83].

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