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Femoral Vein Reconstruction for Aortic Infections

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While rare, abdominal aortic infections remain one of the most technically and emotionally challenging cases that a vascular surgeon may face. Secondary infections of either endovascular, or open aortic reconstructions range from 0.2% to 8%. Primary aortic infections are much more rare. Diagnosis can be elusive, depending upon the virulence of the causative microbes, and extent of the infection. Patients are often brittle, with immunocompromise and malnutrition prevalent in this patient population. The gold standard diagnostic test remains a computed tomographic angiogram. The mainstay of management requires vascular control, and wide debridement of all infected materials and revascularization. Multiple methods exist to reconstruct the vascular supply. The neo-aortoiliac system (NAIS) is attractive as it utilizes the patient's own femoral veins to reconstruct the vascular supply after the infection has been extirpated. The procedure is demanding upon the patient and surgeons alike. Also, the rarity of aortic infections limit experiences the literature to centers of excellence. However, the NAIS resists infection well, leaving the patient without any remaining foreign bodies. No further costs for conduit are incurred. Moreover, multiple experiences show excellent durability. While comparative effectiveness literature remains sparse, we believe the NAIS to be the optimal method of revascularization for select patients. In this article, we will review the use of NAIS for primary and secondary aortic infections. In particular, we will emphasize procedural details to help enable the reader to apply this procedure most effectively to their own patients.

Key Words: Aorta, Infections, Femoral vein

INTRODUCTION

Abdominal aortic infections are devastating albeit rare complications. These include mycotic aortic abdominal aneurysms (AAAs) as well as secondary aortic graft infections (AGIs) following intervention for aneurysmal or aortoiliac occlusive disease. Traditionally open AAA repairs and aortofemoral bypasses comprised the majority of secondary AGIs. However, endovascular aortic repair (EVAR) is currently resulting in an increasing proportion of AGIs [1,2]. Two mechanisms can cause secondary AGI: a) metastatic seeding from a distant infectious focus; b) local contamination related to and adjacent abscess or aortoenteric fistulae (AEF). EVAR and open AGI incidence is similar in most series, estimated to range from 0.2% to 8% of the total population of both grafts [3-5]. Mycotic AAAs result from aortic degeneration caused by infection or secondary seeding of a pre-existing aneurysm [6]. Treatment of all aortic infections requires a balance of competing needs: a) complete explantation of infected material and debridement of adjacent infected native tissue to control infection; b) maintenance of perfusion to the visceral vessels, pelvis and

lower extremities; c) minimizing morbidity and mortality.

The neo-aortoiliac system (NAIS) procedure was first reported in 1993 [7] in response to the need for durable re-vascularization options for AGI patients. The repair utilizes autologous femoral vein (FV) as an *in situ* reconstruction. Traditionally, repair had required aortic ligation with extra-anatomic bypass. Extra-anatomic bypass was confronted with problems regarding durability, high re-infection rates, poor disease-free survival and morbidity. The benefit of NAIS includes low risk of reinfection, no aortic stump, and no indication for long-term anticoagulation or antibiotics [8]. However, the procedure is technically demanding, prolonged and carries the risk of lower extremity venous insufficiency. There is also a known risk of fasciotomy with the operation [9]. While there is a known high morbidity and mortality, NAIS remains an excellent option for reconstruction in this challenging patient population.

We believe NAIS should be considered as the reconstructive option of choice in experienced centers for younger patients without septic or cardiogenic shock. The patients must be anatomic candidates for the procedure, and the patient must have a reasonable chance to survive the operation and return to a meaningful quality of life. This review will focus on diagnosis, preoperative planning, technique, postoperative management and outcomes.

DIAGNOSIS

The diagnosis of primary aortic and secondary AGI can be challenging [10]. Many patients present with either anastomotic pseudoaneurysm (Fig. 1), gastrointestinal bleeding, or focal drainage and/or bleeding from their groin incisions. Pseudoaneurysms in particular should increase the suspicion of involvement of the distal anastomoses due to a >60% presence of infection (Fig. 1) [11]. Systemic signs of infection are often absent with low-virulence organisms. Patients with frank bleeding, sepsis or herald bleeding require rapid diagnosis and treatment. However, many patients will present with vague non-specific symptoms of fatigue, weight loss, or other constitutional symptoms which require a high index of suspicion to diagnose. There are strengths and weaknesses to each diagnostic modality. We will focus upon computed tomographic angiography (CTA) to diagnose primary and secondary infections [10,12].

IMAGING MODALITIES

CTA has become the primary diagnostic evaluation of all arterial infections, but particularly in the thorax, abdomen and pelvis. CTA is readily available in most centers, with greater than 96% of U.S. hospitals reporting CTA capabil-

ity [13]. The main limitations of CTA include metal artifacts limiting visualization, contrast allergies and exposure to ionizing radiation. Additionally, there is a risk of contrast-induced nephropathy. We perform CTA for all patients, especially for those with AEF, hemorrhage or overt sepsis. For these patients, potential delays in diagnosis are more detrimental than the risks contrast-induced nephropathy, even for patients presenting with acute renal failure.

Findings consistent with infection of the native aorta or graft include adjacent air and/or fluid, discontinuity of the aortic wall, and soft tissue stranding (Fig. 2) [14]. AEF specifically presents with pseudoaneurysm, focal bowel wall thickening, and ectopic gas (Fig. 2). Abscesses or other infectious foci (i.e. pneumonia) can also be visualized with CTA. Additionally, CTA is critical to provide anatomic detail for operative planning.

The sensitivity (40%-90%) and specificity (33%-100%) varies significantly depending upon the virulence of the organism [15]. Less virulent microbes incite a less vigorous immune response and therefore have less soft tissue stranding, fluid, or ectopic gas. Early infections are also more difficult to diagnose, as air is normally present for up to two months. Small amounts of fluid may be normally present for up to 3 months after the reconstruction [14].

Magnetic resonance imaging (MRI) avoids the use of ionizing radiation and contrast, as patency of the arteries can be inferred by T1- and T2- imaging [16]. MRI may be better at distinguishing early AGIs from perigraft fibrosis. Additionally, MRI may have increased ability to distinguish
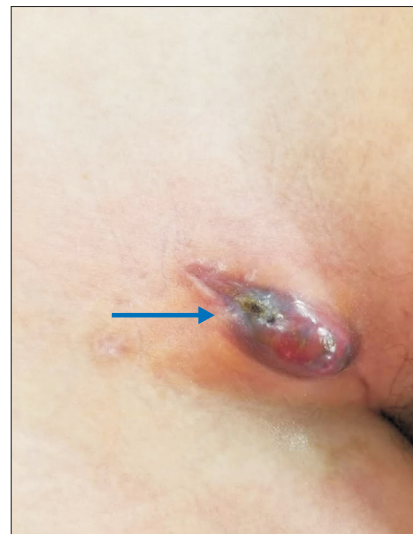

Fig. 1. Image of a right groin femoral pseudoaneurysm with excoriation (arrow), which hid a contained rupture of a mycotic right common femoral pseudoaneurysm after prior aortofemoral bypass.
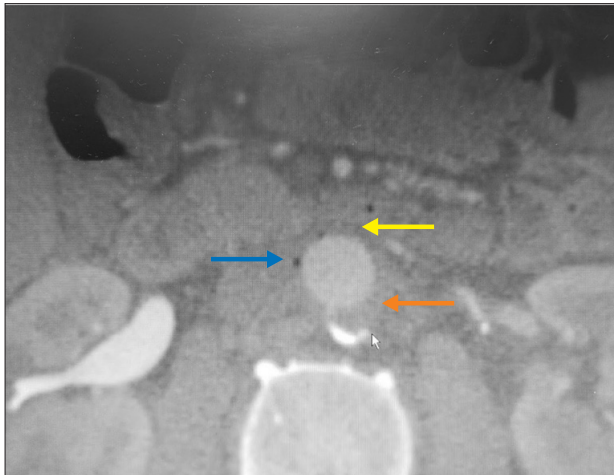
Fig. 2. Computed tomographic angiography showing many of the characteristic signs of an aortic graft infection. Here, there is evidence of effacement of the soft tissue planes between the aortic graft and the adjacent duodenum (yellow arrow). Also, there is evidence of soft tissue thickening surrounding the graft (orange arrow). Finally, there is a small focus of ectopic air outside of the duodenum adjacent to the aortic graft (blue arrow). This patient was found to have an aorto-enteric erosion between the fourth portion of the duodenum, and the right limb of the previously placed aortobifemoral bypass graft.

etween biofilm and normal perigraft inflammation [17]. Disadvantages of MRI include longer examinations times, increased cost, contraindication with ferromagnetic implants and decreased availability compared to CTA.

Duplex ultrasound (DUS) utility has limitations due to body habitus and overlying bowel gas. There is significant inter- and intra-observer variability in the performance and interpretation of the examinations. DUS is also unable to discriminate between infection and normal postoperative changes <3 months after a prosthetic implant has been placed. Finally, visualization of the adjacent anatomic structures is inadequate for appropriate surgical planning, necessitating either a CTA or MRI.

Radionuclide imaging can be an effective adjunctive examination for diagnosis of aortic infections [18]. Tagged white blood cell scans can be used to localize a source of inflammation, often discovering an otherwise occult, indolent infection [19]. Additionally, leukocyte scintigraphy can be utilized with concurrent antibiotic use. They are effective in diagnosing both primary and secondary aortic infections. This exam is limited in patients with urgent AGIs due to prolonged study times, heavy labor requirements and significant inter- and intra-observer variability. Additionally, false positives occur at a relatively high rate in patients with recently placed grafts and with thrombus within the

reconstruction [17]. Due to these limitations, we feel that this study is useful primarily as an adjunctive role, particularly in patients with low-virulence or indolent infections.

Additionally, [18]Fluorodeoxyglucose positron emission tomography (PET) can localize inflammation associated with infectious processes. Fusion of PET with CTA has improved anatomiclocalization of infection. While early results with PET/CTA have been encouraging, there is not a consensus in the literature regarding the utility of this study [17,20].

In addition to imaging modalities, other adjunctive measures are available for diagnosis of aortic infection. Perigraft aspirates are rarely used, but are considered the gold standard for the diagnosis of aortic and AGI. This is limited by insufficient fluid, proximity to nearby vessels and bowel, and tissue and fluid viscosity preventing safe aspiration. Additionally, there is a risk of contamination of a previously sterile field. Esophagogastroduodenoscopy (EGD) is useful to exclude other causes of upper gastrointestinal bleeding when cross sectional imaging fails to identify an AEF [21]. AEF can also be diagnosed at the time of EGD. EGD can also localize the segment of bowel involved with an AEF. We reserve EGD for hemodynamically stable patients where prior diagnostic evaluation has been inconclusive.

PREOPERATIVE PLANNING

Patient selection for NAIS requires consideration of multiple subjective and objective measures. This procedure requires a considerable operative time (9.2 ± 2.1 hours) [9]. Therefore, it should be reserved for patients who are hemodynamically stable with resuscitation and delivery of broad spectrum antibiotics. Empirically, we provide antibiotics with gram-positive, gram-negative and anaerobic coverage. In the setting of AEF, we add antifungal coverage due to the high prevalence of fungal contamination in AEF. Patients with overwhelming sepsis or bleeding AEF prior to operative intervention may not tolerate the prolonged operation. Additionally, severely debilitated patients with inadequate cardiovascular reserve are unlikely to tolerate the operation or return to a reasonably high quality of life following intervention. This should be discussed with the patient and/or family prior to intervention.

A physical examination should be performed at the time of initial consultation to evaluate for previous abdominal operations, abdominal wall hernias and a baseline lower extremity vascular examination. This should include a pulse and Doppler exam at the groin, popliteal and ankle level and clearly documented immediately prior surgery.

ANATOMIC CRITERIA

Several anatomic considerations must be made preoperatively to ensure that the patient meets anatomic criteria. Cross-sectional imaging should be reviewed thoroughly to elucidate the extent of native aortic, visceral vessel and runoff vessel involvement. Infectious involvement at, or cranial to the visceral vessels will limit the ability to perform a NAIS reconstruction. This is because multiple grafts may be required to revascularize the visceral vessels as well, for which, there is not adequate FV. Additionally, imaging will reveal concomitant occlusive disease which may require further reconstruction in addition to the NAIS reconstruction. This could involve debranching of visceral branches to maintain organ perfusion as well as infrainguinal bypass to optimize outflow.

Additionally, patients should undergo ankle-brachial indices (ABI), toe pressure measurement, and venous DUS. Patients with low preoperative ABI (<0.4) and toe pressure (<40 mmHg) are at a higher risk of limb complications. Hence, the need for adjunctive lower extremity bypass and fasciotomy should be discussed with the patient [22]. DUS of the bilateral FVs and the greater saphenous veins is required to evaluate their utility as a conduit [22]. The femoropopliteal veins (FPVs) should be ≥6 mm in diameter and should not have evidence of chronic occlusion or stenosis.

ANESTHETIC CONSIDERATIONS

Extensive dissection and prolonged exposure of the peritoneal and retroperitoneal tissues will lead to extensive fluid losses and drops in core body temperature. Fluid losses should be judiciously replaced, often requiring blood transfusion and colloid replacement. In anticipation of this, large-bore central venous access should be obtained prior to the procedure. Moreover, the patient should have platelets and fresh frozen plasma available to combat derangements of coagulation associated with consumption and dilution due to fluid and blood transfusion. Aggressive maintenance of core temperature should be maintained with forced air warming blankets, warmed fluids and warmed ambient operative room temperatures. Finally, preoperative delivery of broad spectrum antibiotics should be given to cover gram-positive, gram-negative and anaerobic organisms prior to intervention.

EVAR STENT GRAFT CONSIDERATIONS

Effort should be made to identify the type of device previously used for endovascular exclusion prior to intervening on infected EVAR devices due device variability.

This includes the presence of suprarenal fixation devices, aortic tack placement, number of modular components and the requirements to release or constrain the device. There is growing evidence demonstrating poor proximal aortic neck related not only to the infection of stent grafts, but also due to prolonged radial force application from the stent grafts and compromise of tissue integrity related to fixation [23,24]. Additionally, in order to avoid inclusion of suprarenal fixation, supraceliac or balloon occlusion of the aorta is often required until the endograft has been removed. The suprarenal fixation of the graft may be divided from the main body of the graft and left within the healthy aorta to avoid further damage to the tissue.

TECHNIQUE

Due to the prolonged nature of the operation, a regimented approach needs to be taken to minimize operative times and physiologic stresses. The ideal approach to the operation minimizes lower extremity ischemia time and exposure of the peritoneal cavity. The procedure includes six distinct steps. The patient should be in the supine position, with arms extended to allow for self-retaining retractor placement. The patient's trunk should then be prepped with betadine or chlorhexidine from the nipples to pubis. Each leg should be prepped circumferentially and included in the surgical field. The feet may be isolated with sterile towels. The entire surgical field should be then covered with iodine impregnated adhesive drapes. The legs must be mobile to allow for external hip rotation and knee flexion that permits "frog-legged" positioning for the vein harvests.

1) Dissection of femoral veins

The dissection begins with incisions within a line from the anterior iliac spine to the medial femoral condyle to follow the tract of the FV deep to the sartorius muscle (Fig. 3). This will concomitantly permit exposure of the profunda femoral artery away from the previously scarred and infected field. The lateral border of the sartorius is then identified, and reflected from lateral to medial, as the blood supply for this muscle comes from the medial border. The subsartorial canal is entered to expose the FV and superficial femoral artery (SFA). The vein should be exposed in its posterior position to the SFA from the adductor (Hunter's) canal to the confluence of the profunda femoris vein (PFV). Additional length of the popliteal vein can be obtained by dividing the adductor magnus tendon. It is essential to preserve the patient's great saphenous vein and collateral SFA and PFA branches during this dissection, especially in patients with lower extremity peripheral artery disease. Addi-

tionally, the saphenous nerve should be preserved to avoid postoperative neuralgia (Fig. 4). All branches of the FPV segment should be ligated and branches >3 mm should be doubly ligated with silk ligature. After branch ligation and mobilization of the vein, the vein should be left in situ and excluded with moist sponges.

2) Dissection and control of femoral target arteries

In the event that a previous bifemoral reconstruction was performed or infectious involvement of the femoral vessels is anticipated, the femoral arteries must be exposed. The femoral vessels can then be isolated through an extension of the previous exposure lateral to the previous operative exposure. This will allow for isolation and encircling of the SFA, PFA and proximal common femoral artery. If a previous aortobifemoral graft is present, this should also be exposed and controlled. If all vessels cannot be safely exposed from a lateral exposure, an additional medial incision may be required. Significant scarring should be expected both with previous graft placement and/or percutaneous closure devices. Additionally, distal anastomotic pseudo-aneurysmal degeneration can be present and should be meticulously exposed and controlled to avoid significant hemorrhage.

3) Dissection and control of aorta proximal to planned proximal anastomosis

It is critical to plan the level of aortic exposure required

to safely clamp the aorta while leaving sufficient healthy neck to perform the proximal anastomosis. Severely calcified aortas should be exposed proximally until a level of soft aorta is present. With endograft infections, special consideration of suprarenal fixation is critical and often will require exposure of the supra-celiac aorta. For all infection, we favor selecting an aortic clamp site free of significant inflammation and infection. Many cases will require at a minimum suprarenal exposure of the aorta. We have a low threshold for exposure of the supra-celiac aorta to provide a safe region to clamp.

Transperitoneal and retroperitoneal exposures are both acceptable for exposure. A self-retaining retractor should be placed to allow for safe and stable exposure of the aorta. We prefer an Omni retractor, though both Thompson retractors and Buchwalter retractors can be utilized. A retroperitoneal approach will often allow for avoidance of intraperitoneal adhesions. A transperitoneal approach will often be beneficial when planning coincident intestinal resection and reconstruction in the event of a known AEF.

At this time, the extent of reconstruction should be determined based on examination of the tissue. If isolated involvement of the aorta and common iliac vessels is present, the entire reconstruction can be planned from the abdomen. In the event that first time bifemoral reconstruction is planned, careful tunneling should be performed with a blunt clamp or finger dissection posterior to the ureters and anterior to the common and external iliac arteries. If a previous bifemoral graft is present, the tunneling should
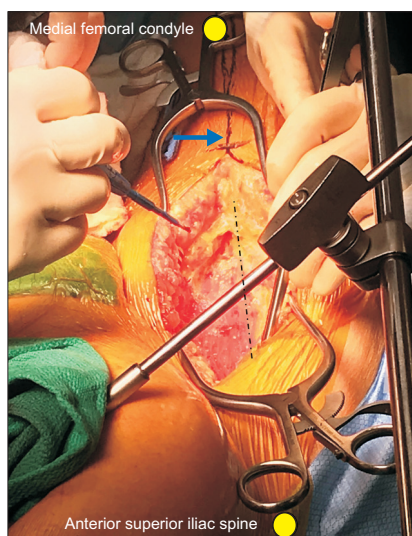

Fig. 3. Example of the incision. The line drawn on the patient's skin (arrow) extends from the anterior superior iliac spine to the medial femoral condyle (yellow dots). This exposes the lateral border of the sartorius muscle (dashed line).
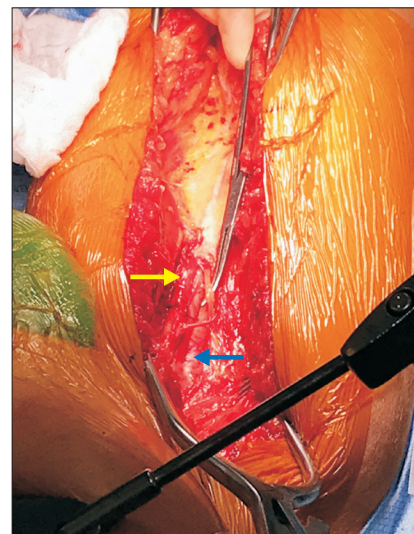

Fig. 4. Example of the saphenous nerve (underneath the tip of the forceps), which is closely associated with the femoral vein (blue arrow) and adjacent superficial femoral artery (orange arrow). This must be carefully preserved during the dissection to prevent postoperative neuralgia.

not be performed, as the tunnel is extremely inflamed and a new tunnel is hazardous. Instead, we debride the former tunnel by passing a betadine-soaked laparotomy sponge through the prior tunnel, and flossing it back and forth to debride the tunnel. We then copiously irrigate the tunnel with saline until no further necrotic debris can be removed. At a later juncture when the previous graft is removed, this tunnel will be reused to avoid creating new tunnels. This tunnel should be maintained with by placing red rubber catheters or umbilical tape through the tunnel. Maintaining perfusion to the pelvis via the hypogastric arteries is also crucial. Either antegrade perfusion via a reconstructed iliac bifurcation or retrograde perfusion via the external iliac artery must be maintained to one, or both hypogastric arteries. At this time, a clamping strategy of either the iliac arteries or the femoral arteries should be planned and appropriate clamps should be selected.

4) Harvest and reconstruction of femoral veins into bifurcated conduit

Prior to harvesting the venous segments, a plan for venous configurations should be made (Fig. 5). At this time, estimated lengths of graft needed can be obtained. Often, one limb will require more vein conduit than the contralateral side. Consideration should also be made for the size of the proximal anastomosis. In our experience, for diameters up to approximately 18 to 27 mm, a single FV can be beveled to accommodate the diameter discrepancy. When the diameter exceeds 27 mm, we consider the "pantaloon" technique, where to vein grafts are sewn together proximally to create a larger proximal orifice that can then be sewn to the aortic stump (Fig. 5). Alternatively, a V-patch of the aorta can be created to decrease the diameter of the aortic neck, prior to sewing the vein graft. These numbers are guidelines, however, and require some adjustments depending upon the original diameter of the FVs relative to the aortic diameter.

At this time, focus should be returned to the previously exposed and isolated FPV. Once appropriate length of vein is determined, the distal popliteal vein should be doubly suture ligated and the proximal divided end should be closed over an olive tip cannula with a 2-0 silk suture to allow for perfusion with vein solution to distend the conduit gently. The proximal FV should be clamped with a vascular clamp at the confluence of the PFV and FV. At this time, any missed branches or tears can be repaired with 6-0 or 7-0 prolene sutures in a transverse manner. Adventitial bands or kinks can be divided carefully with tenotomy scissors. Only the most restrictive adventitial bands are divided, to prevent weakening the wall of the vein graft. The proximal

vein should be ligated flush with the profunda and at such an angle to allow for a smooth transition effectively eliminating any FV stump which would be susceptible to thrombosis. This should be oversewn with running 5-0 prolene suture in a Cameron fashion.

The reconstruction requires non-reversed configurations of the vein segments to optimize size matches. This requires direct valve lysis, performed by everting the vein on itself and sharply excising all valve tissue (Fig. 6). The use of valvulotome lysis is associated with early graft failure [9]. There is no appropriately sized valvulotome for the FV. The vein graft is then reverted, and distended to insure no inadvertent injuries during valve lysis.

5) Clamping of aorta, removal of infected aorta or graft, debridement of periaortic tissue

Once all tunneling has been performed and all vein harvest is complete, the patient should be systemically anticoagulated with 100 units/kg heparin and a therapeutic level (300-400 seconds) should be confirmed and monitored throughout the remaining reconstruction with serial activating clotting time (ACT) assays. When suprarenal/supraceliac clamping is anticipated, we recommend administering mannitol 25 to 50 g prior to clamping. The aforementioned clamps should be applied proximally and distally to allow for complete vascular control.
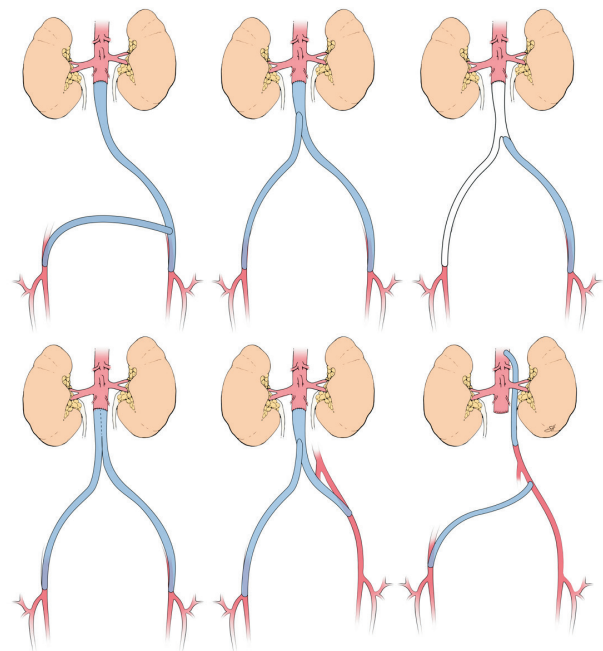

Fig. 5. Examples of various configurations of the femoral vein used to create the neo-aortoiliac system (NAIS).

In the event of an infected aortic graft, the distal limbs should be clamped first and all synthetic material should be excised from the proximal anastomosis, including suture material. All necrotic or abscess tissue should also be removed at this time. Cultures of both the graft material and surrounding septic tissue should be sent to evaluate for gram-negative, gram-positive, anaerobic and fungal species. Note that the femoral segments of the graft are left intact at this time to avoid bleeding from the tunnels or femoral incisions at this time and allow focus on the proximal aspect of the graft.

In the event of an endograft, the aorta should be clamped proximally and distally at this time and the aorta should be opened to expose the entire graft, including each limb. The distal limbs should be clamped, and all lumbar bleeding and inferior mesenteric artery (IMA) back bleeding should be oversewn with 2-0 silk sutures in figure of eight fashion. Multiple methods exist for removing the endograft, with no method being superior to another. At our institution, we favor re-constraining the EVAR similar to how we re-constrain endografts during backtable modifications for fenestrated endografts [25]. With this technique, the endograft is encircled with an umbilical tape by an assistant, and cinched tightly. Adjacent to this umbilical tape, the operator encircles the graft, and then ties and umbilical tape next to where the assistant is cinching the endograft with his/her umbilical tape. This process is repeated proximally and distally until the entire graft is re-constrained. Even with suprarenal fixation stents, this usually permits the surgeon

to gently disengage the fixation elements from the aorta by pushing the entire constrained endograft cephalad slightly, prior to complete removal. Following this, the clamp can then be moved to a suprarenal or infrarenal location as appropriate.

Finally, in the event of a mycotic aneurysm, the aorta should again be clamped proximally and distally, and a trapdoor longitudinal incision should be performed along the length of the involved aorta. All lumbar and IMA bleeding should again be oversewn with 2-0 silk sutures. The entire involved aorta and surrounding septic tissue should be debrided and all branches ligated.

At this time, the proximal native aorta to vein conduit anastomosis should be performed in an end-to-end running manner using 4-0 prolene suture. In the event of mismatch, we bevel the vein graft. Also, the mismatch can typically be compensated by using four-quadrant anastomotic technique and taking larger advancement on the aorta compared to the vein graft. Larger mismatches should be anticipated prior to clamping and alternative reconstructive options should be considered, including syndactylization of the vein segments into a "pantaloon" configuration, plication of the native aorta, or using a triangular patch. We typically do not re-inforce the anastomosis with fascia lata or any other material to prevent blow-out. We instead, will find a different site to perform the anastomosis, as shown in Fig. 5 (configuration 6). This requires preoperative planning, and intra-operative adjustments, should the aortic
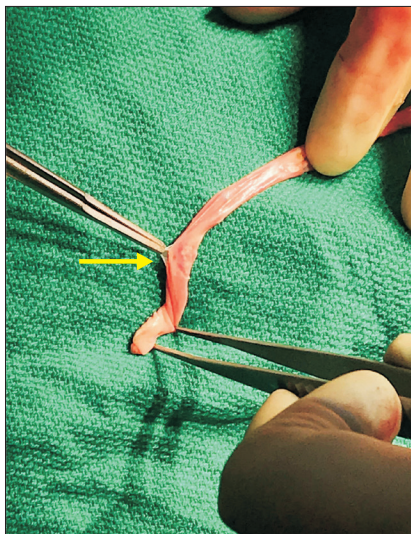

Fig. 6. Example of the femoral vein after it has been turned entirely inside out. The vein valve is held out gently with foreceps (arrow) and then cut flush with the vein. The valves are bicuspid, so there are two at any given level. Typically they are separated by approximately 8 to 10 cm.
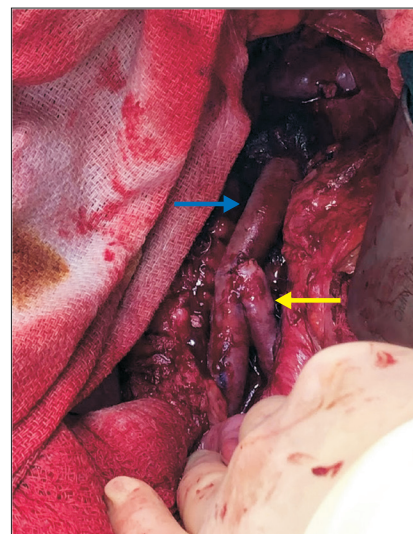

Fig. 7. Example of a femoral vein reconstruction. Here, one of the femoral conduits was sewn in a non-reversed fashion from the aorta to the right common femoral artery (blue arrow). A second graft was then sewn end-side from the mid-body of the previously placed femoral vein graft to the left common femoral artery (yellow arrow).

neck prove too attenuated to safely perform an anastomosis.

Once completed, hemostasis of the anastomosis should be ensured, and the clamp should then be removed and placed on the proximal vein conduit to allow for perfusion to the viscera and/or kidneys. At this time, reperfusion effects should be anticipated, including systemic release of lactate from the previously ischemic viscera and potential for hypotension with decreased afterload. The anesthesia team should be given notice of this planned reperfusion. At this time, additional inspection of the graft should be performed to ensure no bleeding along the conduit. Any areas of bleeding should be addressed with a proximally placed clamp to avoid tearing with suture repairs.

6) Reconstruction of aorta with vein conduit

At this time, focus should be turned to recreating the bifurcation and removing the distal limbs of the graft if they are present. The distal limbs should be disassembled after obtaining control of the femoral inflow and outflow. All graft and suture material should be removed with wide debridement of necrotic and abscess tissues. This can be done with one side at a time to avoid prolonged clamping of the contralateral side and allow continued perfusion through any collaterals present. If necessary, endarterectomy and/or profundoplasty can be performed at this time. Several configurations of a bi-iliac or bi-femoral reconstruction are available (Fig. 5). The FV-FV anastomosis should be spatulated and performed with running 4-0 Prolene suture (Ethicon Inc., Somerville, NJ, USA) with a four-quadrant approach to avoid inadvertently tightening the anastomosis (Fig. 7). Following completion, this anastomosis should be distended with aortic pressure to evaluate for anastomotic leaks and these should be repaired with a proximal clamp applied to avoid tearing of the vein with repair stitch placement. Care should be taken to avoid twisting of the graft. The FV segments should be pulled carefully through either new tunnels or the salvaged tunnels from the previous graft. Care must be taken to avoid avulsing or tearing side branches that were ligated during harvest. The distal anastomoses should be performed with running 5-0 or 6-0 Prolene suture. On release of each limb, anesthesia should again be warned of potential for reperfusion-related hypotension. Doppler signals should be noted in the profunda and superficial femoral arteries, and at the level of the ankle. Based on preoperative Doppler and pulse exams, the need for additional revascularization should be evaluated, with some patients requiring lower extremity bypass at this juncture.

7) Closure

Following completion of all revascularizations, the patient should be fully reversed with protamine. Meticulous hemostasis should be obtained in all dissected fields. Only after protamine reversal do we begin closing incisions. This is to prevent hematoma formation after protracted cases with significant risk of coagulopathy due to blood loss, and high dose heparin administration. In the case of gross contamination, the groin incisions should be closed in layers but the skin and subcutaneous tissue should be left open to close by secondary intention. The FV harvest sites should be widely drained with two large-bore closed suction drains to avoid fluid accumulation in the potential space. At this time, any additional intestinal resection and reconstruction should be performed prior to closure of the abdomen. If possible, an omental flap is mobilized, and tacked to the retroperitoneum between the intestines, and the NAIS. The abdomen should also be closed in a standard fashion. The skin is left open to heal by secondary intention only in cases of severe intra-abdominal sepsis.

POSTOPERATIVE MANAGEMENT

The patient should be admitted postoperatively to the intensive care unit (ICU) for close monitoring of respiratory status, hemodynamics and lower extremity pulse exams. Due to the long nature of the operation and potential for fluid shifts, the majority of patients will remain intubated for the immediate postoperative period. Additionally, the patients should maintain central venous and arterial catheter access to closely monitor fluid status and hemodynamics and guide resuscitation. A Foley catheter should also be left in place to accurately monitor urine output. Fluid resuscitation postoperatively is often needed initially to compensate for insensible losses which will occur throughout the operation. Also, hydration will be necessary to mitigate acute kidney injury related to warm ischemia time during suprarenal clamping.

The lower extremities should also be closely monitored. Serial pulse and Doppler examination should occur in the ICU. Additionally, the lower leg compartments should be closely monitored on a serial basis, as compartment syndrome can rarely develop. Subjective data will be lacking from the intubated patient, so monitoring is particularly critical.

In our experience, antibiotics should be continued for fourteen days and tailored depending upon the cultures and sensitivities of the microbial isolates. If all of the foreign material is successfully removed, we discontinue antibiotics at fourteen days. If some foreign remnants remain,

we continue antibiotics for a minimum of six weeks. The patients should also be maintained on intermittent pneumatic compression and prophylactic heparin or low-molecular weight heparin during hospitalization.

OUTCOMES

The use of a patient's own FV for reconstruction carries several advantages and disadvantages. The autologous tissue is less expensive than graft material, less susceptible to infection and potentially offers superior patency. The major downside is prolonged operative times and operative stress on the patient. Additionally, the patients are more susceptible to long-term lower extremity venous congestion and chronic venous insufficiency.

The NAIS procedure carries a perioperative mortality between 8% and 10% [9,24]. Five year mortality rates range between 30% and 50%. Predictors of perioperative mortality included operative blood loss >3 L, infection with *Candida* sp., and American Society of Anesthesiologists Class 4 patients [9].

Re-infection occurred in 5% of patients undergoing NAIS reconstruction. Patency is excellent, with primary patency of 81% at 72 months, and ranges between 81% to 91% at five years. Limb salvage rates were also excellent, with 30 day amputation rates from 2% to 7% and 5 year limb salvage rates of 89% to 96%. Recent meta-analysis data following graft explantation and reconstruction demonstrated 100% limb salvage at 5 years [26]. This meta-analysis did note that autologous venous conduit had lower primary patency rates compared to rifampin-soaked Dacron, but notably lower reinfection risk. A particular benefit to the use of an autologous FV conduit was noted with AEF-related survival [27]. The optimal conduit for all aortic infections is unclear, particularly for AEF, as shown by a recent multi-institutional review showing no difference between in-situ reconstructions and axillo-bi-femoral bypass in the setting of AEF [28]. Large single center experience corroborates the fact that while AEF carries a high mortality, NAIS can be used effectively in expert centers [29]. Survival benefit appears to extend to endograft explantation and reconstruction with NAIS [30].

Early data on the procedure demonstrated a high number (18%) of lower leg four-compartment fasciotomies being performed, often preemptively. This number has decreased on recent series to approximately 12% of patients. This is likely related to ischemia-reperfusion related to prolonged inflow obstruction, crystalloid resuscitation and venous congestion. The risk of fasciotomy increases with concurrent great saphenous vein harvest and low baseline ABIs (<0.4) [22].

CONCLUSION

While technically demanding, the NAIS procedure has evolved into an essential *in situ* reconstruction technique for patients with primary or secondary aortic infections. Optimal patient outcomes require proper patient selection and adherence to meticulous surgical technique. Future appropriate risk-stratified comparative effectiveness studies will be required to determine the optimal method of reconstruction in the setting of aortic infection.

CONFLICTS OF INTEREST

The authors have nothing to disclose.

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AUTHOR CONTRIBUTIONS

Concept and design: ZSP, JC. Analysis and interpretation: ZSP, JC. Data collection: ZSP, JC. Writing the article: ZSP, JC. Critical revision of the article: JC. Final approval of the article: JC. Statistical analysis: none. Obtained funding: none. Overall responsibility: JC.

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