FEMOROPOPLITEAL BYPASS

Barend Mees • Willemien van de Water

The first femoropopliteal bypass using a reversed venous conduit in a patient with peripheral arterial disease is addressed to Kunlin in 1948. It has been performed ever since and using dedication, adequate preoperative workup, and postoperative cardiovascular risk management, it still is a widely used procedure. It is indicated for patients with critical limb threatening ischemia due to femoropopliteal occlusive disease and may also be indicated for patients with disabling claudication, after failure of conservative therapy with supervised exercise therapy. In recent years, the procedure has been competing with endovascular treatment. Clinical symptoms, length of the lesion, previous interventions, local expertise of the operating team, as well as comorbidity and life expectancy of the patient result in an individualized approach for either an endovascular or open surgical therapy.

Major drivers of patency are the type of conduit and the distal landing zone. Single segment autologous vein grafts provide the best results, with a three-year patency of >70% for suprageniculate femoropopliteal bypass and 50 to 70% for the infrapopliteal bypass. Prosthetic grafts have a comparable patency for suprageniculate bypasses during the first two to three years; however, long-term patency is in favor of venous grafts. Below the knee, prosthetic bypass performs worse, with a three-year patency of approximately 50%.

PREOPERATIVE ASSESSMENT OF INFLOW, OUTFLOW AND CONDUIT

Preoperative planning is crucial for success of infrainguinal bypass surgery. Preoperative workup includes imaging of the arterial inflow and outflow, as well as evaluation and selection of bypass conduit. Computed tomographic angiography (CTA), magnetic resonance angiography (MRA) or digital substraction arteriography (DSA) may all accurately visualize arterial inflow and outflow.

Often the common femoral artery (CFA) is the inflow vessel of choice, but the profunda/deep or superficial femoral artery (SFA) may also suffice for the proximal anastomosis. The distal anastomosis is performed at a segment of normal caliber and free of stenosis and calcification. Runoff of at least one tibial artery running continuously into the foot is deemed necessary for adequate outflow and patency. In general, a suprageniculate landing zone is feasible, when the popliteal artery is healthy proximal of the cranial border of the patella. Extension of atherosclerotic disease beyond this point will often necessitate an infrapopliteal landing zone of the bypass.

Selection of a proper conduit is critical to optimize patency. Preferably an autologous, venous conduit is used. Duplex ultrasound of the great saphenous veins (GSVs) helps to assess the quality of the vein; it should be at least 3 mm in diameter, and easily compressible without thrombus or fibrotic scarring. In case the GSV is not suitable, the short saphenous, cephalic and basilic veins should be mapped as potential parts for reconstruction of a spliced bypass. When no vein is suitable, a prosthetic graft can be used, commonly expanded polytetrafluoroethylene (ePTFE), which is available with or without heparin coating.

ANATOMY

The anatomy of the CFA and femoral bifurcation is extensively described in Issue 2, 'Common femoral endarterectomy'.

The SFA runs in the anteromedial side of the upper leg, bordered by the sartorius muscle on the lateral side and the adductor longus muscle on the medial side. Halfway the upper leg, the artery travels down to midposterior, through a hiatus in the adductor muscle which is called Hunter canal. From here, it runs posterior from the femur as the popliteal artery.

The popliteal artery travels further distally between the two heads of the gastrocnemius muscle and anterior of the popliteus muscle. Along its course, several genicular branches take off. Approximately 4 to 6 cm below the knee joint, it divides into the anterior tibial artery and the tibioperoneal trunk.

SURGICAL TECHNIQUE

The patient can be operated under general or regional anesthesia and is placed on the operating table in supine position. Ultrasound can be used to mark the course of the GSV prior to incision. To minimize time with an open exposed groin, which is important to decrease risk of postoperative wound infection, often the following order in the procedure is used; first the distal landing zone is exposed and assessed for suitability, followed by harvesting of the vein and lastly the proximal landing zone is dissected. With an experienced surgical team, exposure and harvesting can be done simultaneously.

Proximal exposure

Exposure of the CFA and proximal superficial and profundal femoral artery is described in Issue 2 'Common femoral endarterectomy'. In case the proximal superficial artery is healthy, one may opt for a more distal inflow of the bypass, particularly when the length of suitable venous conduit is limited. The mid-SFA can be exposed by a longitudinal incision on the medial thigh, at the lateral border of the sartorius muscle (Figure 19.1). After dissection of the subcutaneous tissue and division of the fascia, the muscle is retracted medially, and the artery is mobilized above Hunters canal.

Distal exposure of suprageniculate popliteal artery

The leg is externally rotated with minor flexion in the knee. Placement of a sterile pillow underneath the calf releases tension off the supergeniculate muscles and facilitates dissection. A longitudinal incision is made at the distal third of the medial thigh, between the adductor magnus and anterior border of the sartorius muscle (Figure 19.2). After incision of the fascia between the adductor magnus tendon and the sartorius muscle, the muscle is retracted posteriorly. A fascia bridge between the semimembranosus muscle and adductor magnus tendon sometimes needs to be divided for adequate exposure. The popliteal artery and accompanying veins are located in the ceiling of the plane that has now become apparent. It can be freed from the surrounding fatty tissue by sharp dissection. The artery is carefully mobilized and isolated from the adjacent veins. The popliteal artery can be dissected more proximally toward Hunters canal. At this location, care should be taken not to injure the most proximal genicular artery and the greater saphenous nerve. The latter exits from Hunters canal to travel along the GSV. Distally, the popliteal artery can be dissected to the level of the cranial border of the patella. The quality of the distal landing zone should be confirmed by palpation; it should be soft and free from calcifications to facilitate an adequate anastomosis. Vessel loops are placed proximally and distally of the location for the anastomosis.

Distal exposure infrageniculate popliteal artery

The leg is externally rotated with minor flexion in the knee. Placement of a sterile pillow underneath the distal thigh releaves tension off the calf muscles and facilitates dissection.

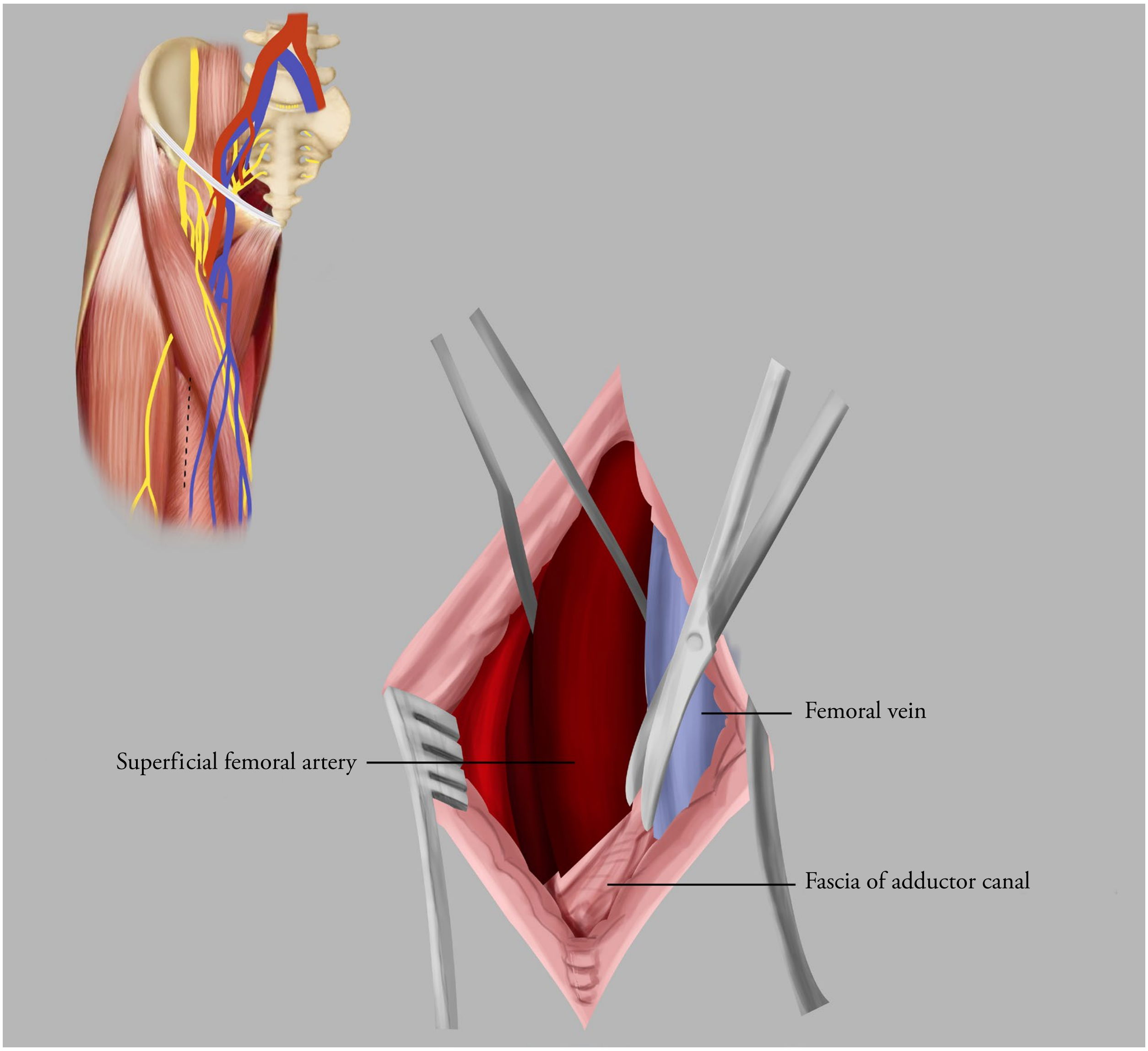

Figure 19.1. Exposure of mid superficial femoral artery.

A longitudinal incision of 10 to 12 cm is made on the medial side of the lower leg just below the knee joint, approximately 1 cm posterior to the tibial margin and following its course distally. The GSV usually runs in this area and care must be taken not to injure the vein (Figure 19.3). After dissection of the subcutaneous tissue, the fascia overlying the soleus and gastrocnemius muscle is incised approximately 1 cm posterior to the tibia, after which an avascular plane is developed by gently sweeping of the index finger, bordered by the medial head of the gastrocnemius muscle on the posterior side and the tibia on the anterior side. The neurovascular bundle is located anterior in the plane, right underneath the tibia. Frequently it is needed to transect the semimembranosus and semitendinosus tendons to facilitate proximal exposure. The popliteal vein is encountered first. Often the popliteal artery is accompanied by two veins, which are closely adhered to the artery, one on the medial side and hence the first structure observed, and one on the lateral side. More distally, after branching off the anterior tibial artery, the venous collateral network expands and often

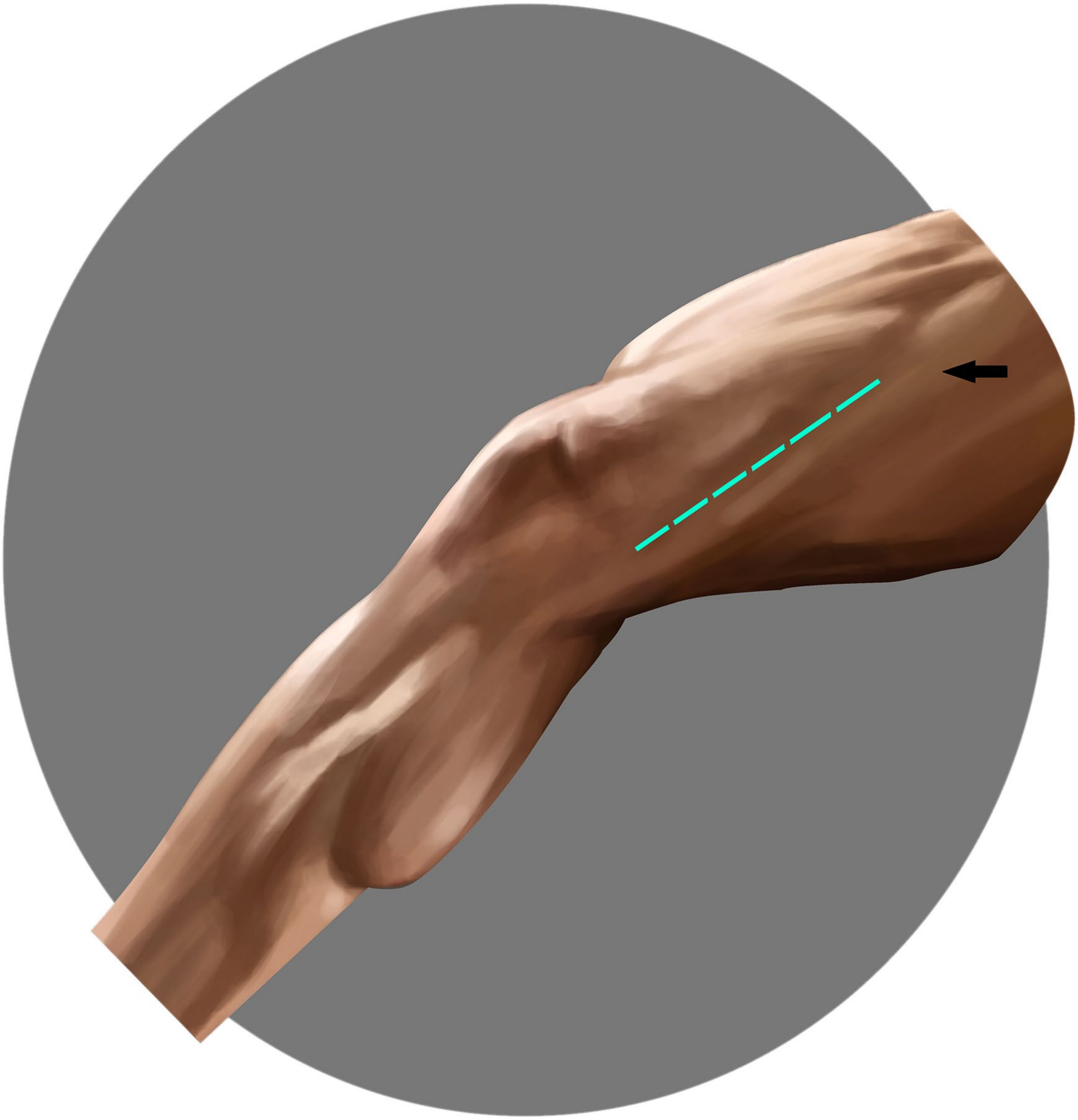

Figure 19.2. Incision for the suprageniculate popliteal artery (arrow: sartorius muscle).

crossing veins need to be ligated for adequate exposure of the artery. If needed, the soleus can be detached from the tibia by electrocautery to extend distal exposure. The popliteal artery is dissected free from its surrounding vein(s) and encircled with two vessel loops. The quality of the distal landing zone should be confirmed by palpation; it should be soft and free from calcifications to facilitate an adequate anastomosis.

Vein harvest

Preoperative ultrasound visualization and marking of the venous conduit is recommended to facilitate exposure, minimize dissection and prevent vein injury. The GSV can be exposed in supine position with the leg externally rotated. An incision is placed right above the vein to prevent large subcutaneous flaps. The incision is deepened

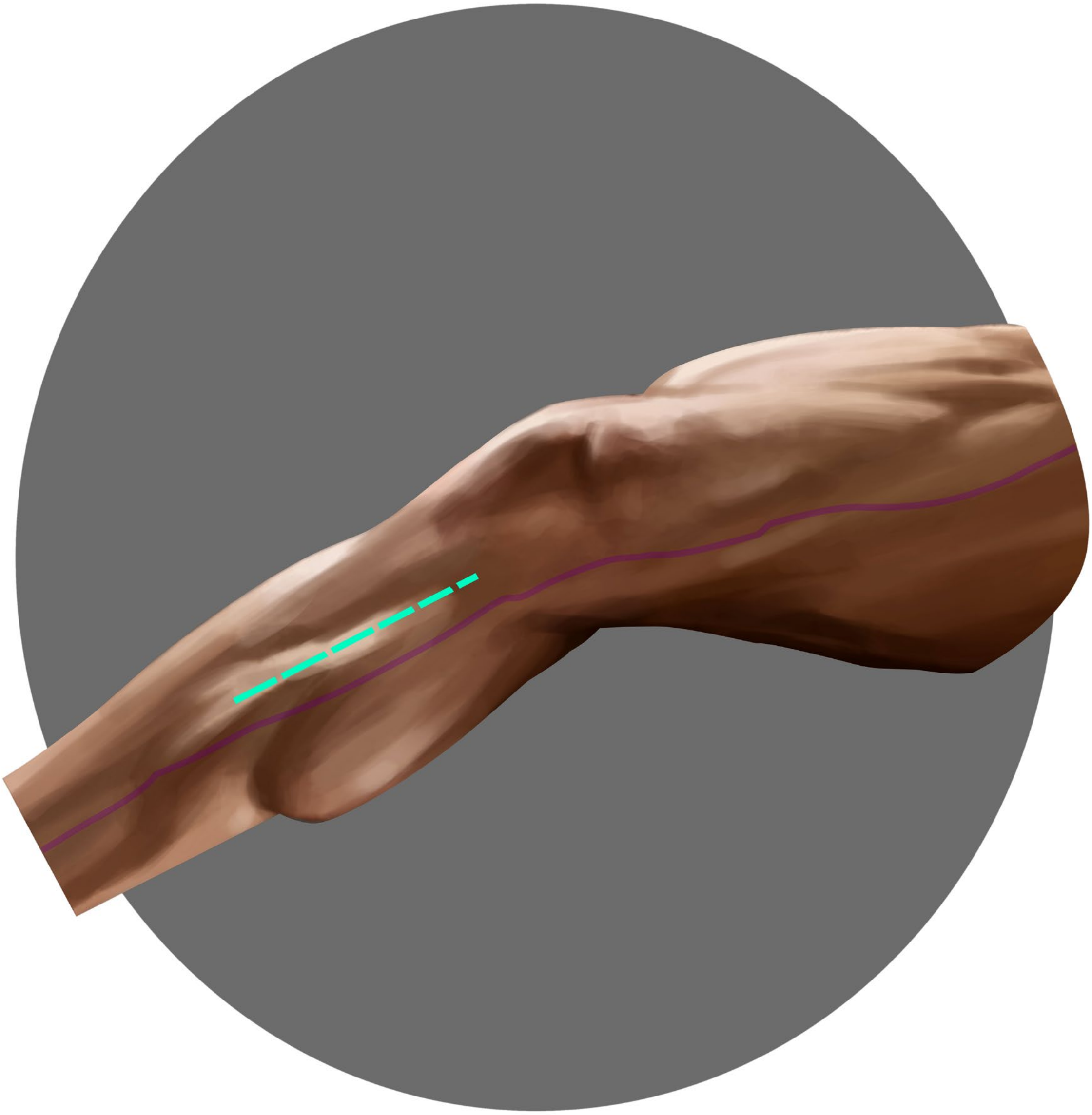

Figure 19.3. Incision for the infrageniculate popliteal artery. Please note the medial border of tibia and the course of great saphenous veins.

through the subcutaneous tissue and after dissection of scarpa's fascia, the vein is exposed. Be aware that below the knee, the vein can be positioned very superficial in the subcutaneous plane.

The small saphenous vein is best exposed in prone position. However, this requires turning and re-prepping the patient afterwards. The incision is placed straight over the vein and deepened through the subcutaneous tissue. After dissection of scarpa's fascia, the vein is exposed. Be aware of the sural nerve which traverses on the lateral side of the short saphenous vein.

While harvesting veins from the arm, one long segment cephalic vein may be sufficient. Alternatively, the basilic vein and cephalic vein, joined by the median antecubital vein, may be harvested as one segment. In the latter case, the non-reversed segment needs to be treated with a valvulotome.

Several incisions can be made along the course of the vein, to leave skin bridges in between. Once the vein is dissected circumferentially, further dissection may be facilitated by putting a single vessel loop around the vein, to gently mobilize it in the wound bed. Trauma to the vein should be minimized. Side branches need to be ligated carefully using a 3/0 silk ligature. A short stump is left at the side of the conduit, to avoid stenosis from the ligature. Clips are best avoided as they may come off during tunneling.

After confirmation of adequate length, the vein is taken out. Adequate bypass length should always be measured with the knee extended. If the bypass is too short, tension on the vein may result in para-anastomotic stenosis. On the other side, if the bypass is too long, elongation may result in kinking.

A bulldog is placed on the proximal side and the bypass is flushed with heparinized saline from the distal end to evaluate the quality and assess for leakage. The vein should distend fully, but overdistention may damage the vein. Take time to identify any side branches not controlled yet, and repair with a ligature or a transverse 7/0 prolene suture. If a focal vein fibrosis or stenosis is observed, this may need to be excised. A venovenostomy is created in the same way as a spliced bypass is constructed (see below). The bypass graft is placed in heparinized saline. When using a spliced bypass, this is the time to connect the different segments. In order not to create a stenosis at the venovenostomy, a spatulated, wide oval anastomosis is created. Moreover, to prevent purse stringing by pulling the suture, use a two-suture running technique or, alternatively, interrupted sutures.

Reversed versus *in-situ* bypass

A reversed femoropopliteal venous bypass is simpler to use and tunneled, distant from possible wound infections. However, the main advantage of an *in-situ* bypass is the better size matching between the artery and the vein. Some argue that the use of the valvulotome to cut the valves may result in endothelium damage. Literature shows equivalent patency for *in-situ* and reversed bypasses.

If the vein is left *in-situ*, it does not need to be dissected as described above. Various techniques are used to create an *in-situ* bypass, using the similar principles; the vein is mobilized for 5 to 10 cm at the proximal and distal landing zone to facilitate anatomoses. The first venous valves can be excised under direct visualization with Potts scissors. After completion of the proximal anastomosis, the remaining valves are cut with a valvulotome from the distal side. This is best done under arterial pressure to avoid collapsing of the vein, which may than be injured by the valvulotome. Flow should be pulsatile before completion of the distal anastomosis. Side branches are identified by Duplex ultrasoud or angiography and ligated using small incisions.

Tunneling

Tunneling is preferably done before systemic heparinization. The tunnel trajectory can be anatomically or extra-anatomically. To prevent kinking, the bypass should not be tunneled through dense fascia or through the belly of a muscle. Short segments may be tunneled by forceps or blunt finger dissection. Tunneling devices are essential for longer segments.

For a suprapopliteal bypass, the tunneling device is passed subfascial or subsartorial toward the groin. Its course can be facilitated by gentle pressure from outside, and to make sure to keep the curve of the tunneling device in an upward position.

For an infrapopliteal bypass, the tunneling device is passed from the popliteal fossa between both heads of the gastrocnemius muscle and femoral condyles, and progressed in the subsartorial space toward the groin. Its course can be facilitated by gentle pressure from outside, and by making sure to keep the curve of the tunneling device in an upward position.

The tunneling device consists of a tube with a rounded, detachable head, and an inner obturator with at the end either a clamp or a hole to fixate the bypass with a suture (Figure 19.4). In the opinion of the authors, the tunnel is created easiest from a distal to proximal direction. Once the tunnel trajectory is completed, the head is detached from the tube. The inner obturator is progressed from the distal side and the bypass is fixated to the obturator (Figure 19.5).

Currently, it is of utmost importance to gently pass the bypass through the tube without kinking or torsion. Although different techniques are used to prevent this, they all use the same principle; keep the bypass inflated and under gentle pressure while passing it through the tube, allowing kinks and twists to resolve. This can be done by continuous heparinized saline injection from the proximal side,

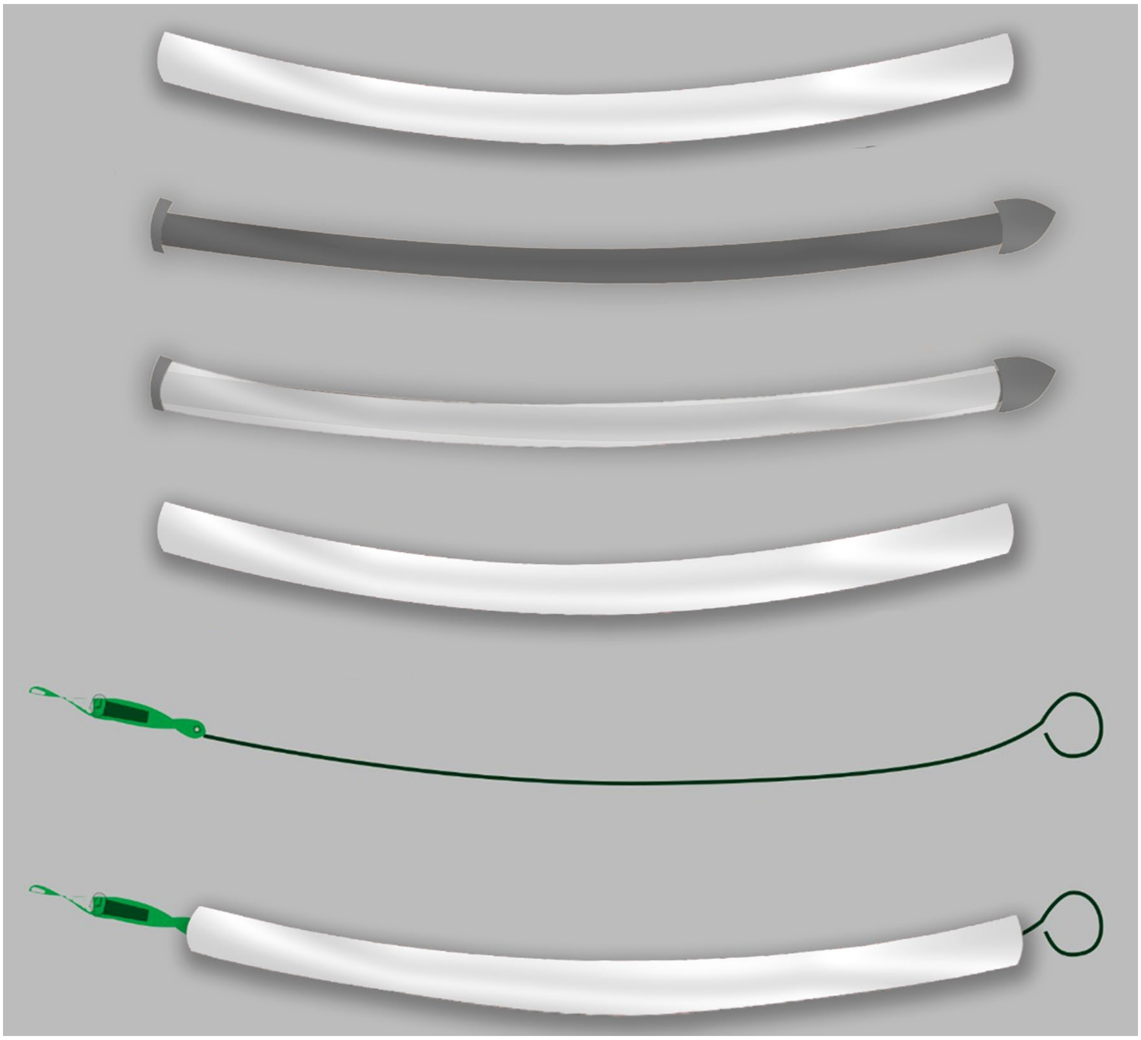

Figure 19.4. Tunneling device.

or by arterial pressure. In the latter case, tunneling of the bypass is done after creation of the proximal anastomosis. To facilitate visibility of torsion, a sterile marker can be used to mark along its length to check configuration and orientations of the bypass. After putting the bypass in place, the tube may be removed. To check for straight orientation, the bypass can be flushed from proximally, which should be effortless.

Anastomosis

Different orders are described for the anastomosis of the bypass. The authors prefer to create the distal anastomosis first, to decrease size mismatch; any surplus bypass will be cut off at the proximal side, where the vein is at its smallest. Moreover, after completion of the distal anastomosis, the bypass can be flushed from the proximal side with heparinized saline, and kept filled with a bulldog proximally. This way, stasis of blood in the bypass is prevented. Others argue to create the proximal anastomosis first, to tunnel the bypass under arterial pressure to prevent twisting and torsion. Both options are feasible.

Distal anastomosis

After systemic heparinization with 70 to 100 IE/kg, flow in the popliteal artery is interrupted by vascular clamps or gentle traction on the vessel loops. While using vessel loops, excessive tension

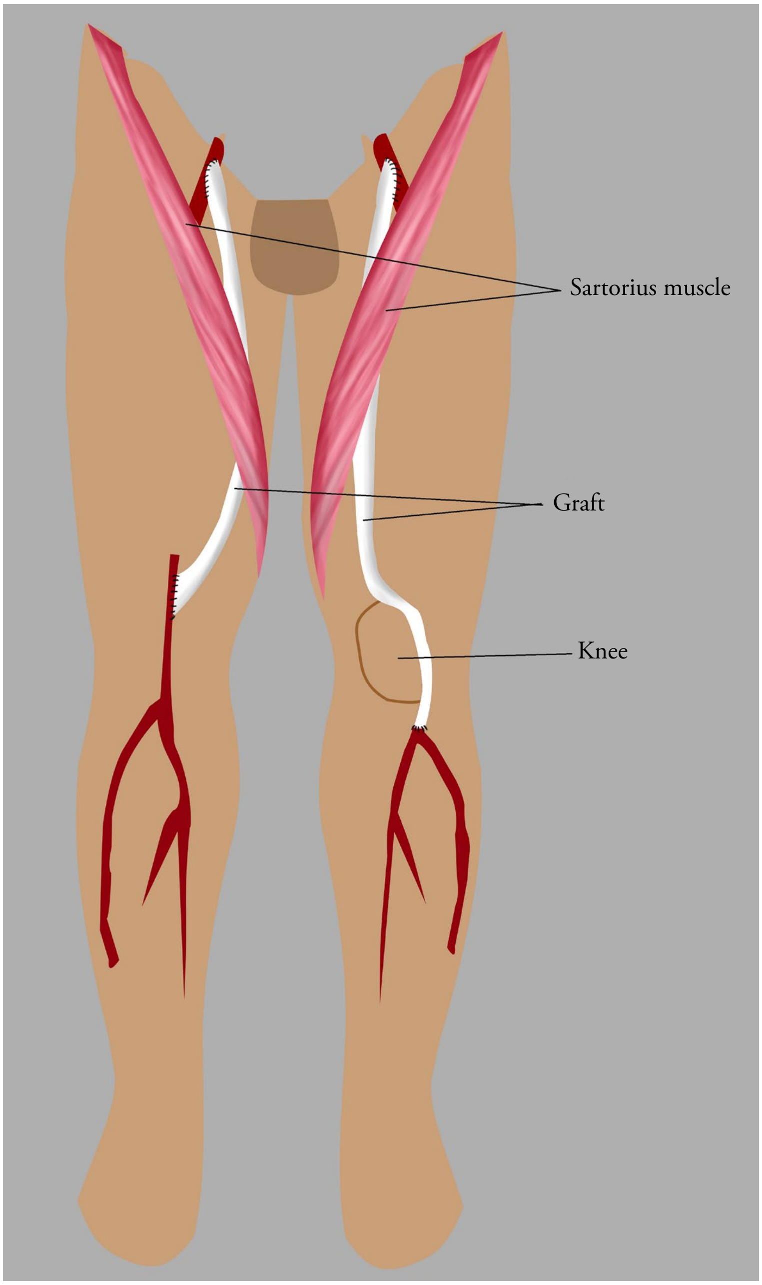

Figure 19.5. Tunnel trajectory.

may injure the arterial wall; therefore, the least amount of tension resulting in flow interruption should be applied.

An arteriotomy is performed with a No. 11 scalpel, directing the blade upward. The tomy is extended using Potts scissors for approximately 1.5 times the diameter of the bypass. If needed, one or two 7/0 prolene sutures can be placed along both sides to keep the artery open (stay sutures), to facilitate the anastomosis. The vein is incised to create a spatulated anastomosis, if needed the edges are trimmed. Often a 6/0 prolene suture is used for the distal anastomosis. Again, there are multiple techniques to perform the end-to-side anastomosis.

The authors prefer a running suture using the parachuting technique, with the first five stitches placed along the heel of the anastomosis before adhering the bypass to the artery. Alternatively, the heel of the bypass may be secured first. It is critical to create an everted, symmetrical anastomosis. Before completing the anastomosis, flush the backflow and inflow, and rinse with heparinized saline. Then, the anastomosis is finished and flow over the popliteal artery is restored. Flush with heparinized saline to fill the bypass and place a delicate bulldog just proximal of the anastomosis on the bypass so the anastomosis can be tested, and no stasis of blood occurs in the bypass.

Miller cuff

In case of a prosthetic graft, a substantial mismatch between the graft and the distal landing zone may occur. A venous cuff (a Miller cuff or St. Mary's boot) is recommended to overcome the diameter mismatch and improve patency (Figure 19.6).

Proximal anastomosis

For the proximal anastomosis, the CFA, or any alternative inflow location, is clamped. An arteriotomy is performed with a No. 11 scalpel, with the blade directed upwards. If needed, an endarterectomy can be performed; for details, please see Issue 2. When a substantial longitudinal arteriotomy is needed to do so, one may first close the arteriotomy with a patch plasty and, consequently, anastomose the bypass distally on the patch and create a small bypass anastomosis (Figure 19.7).

In case of a substantial diameter mismatch between the vein and femoral artery, it is sometimes possible to include a side branch of the vein in the

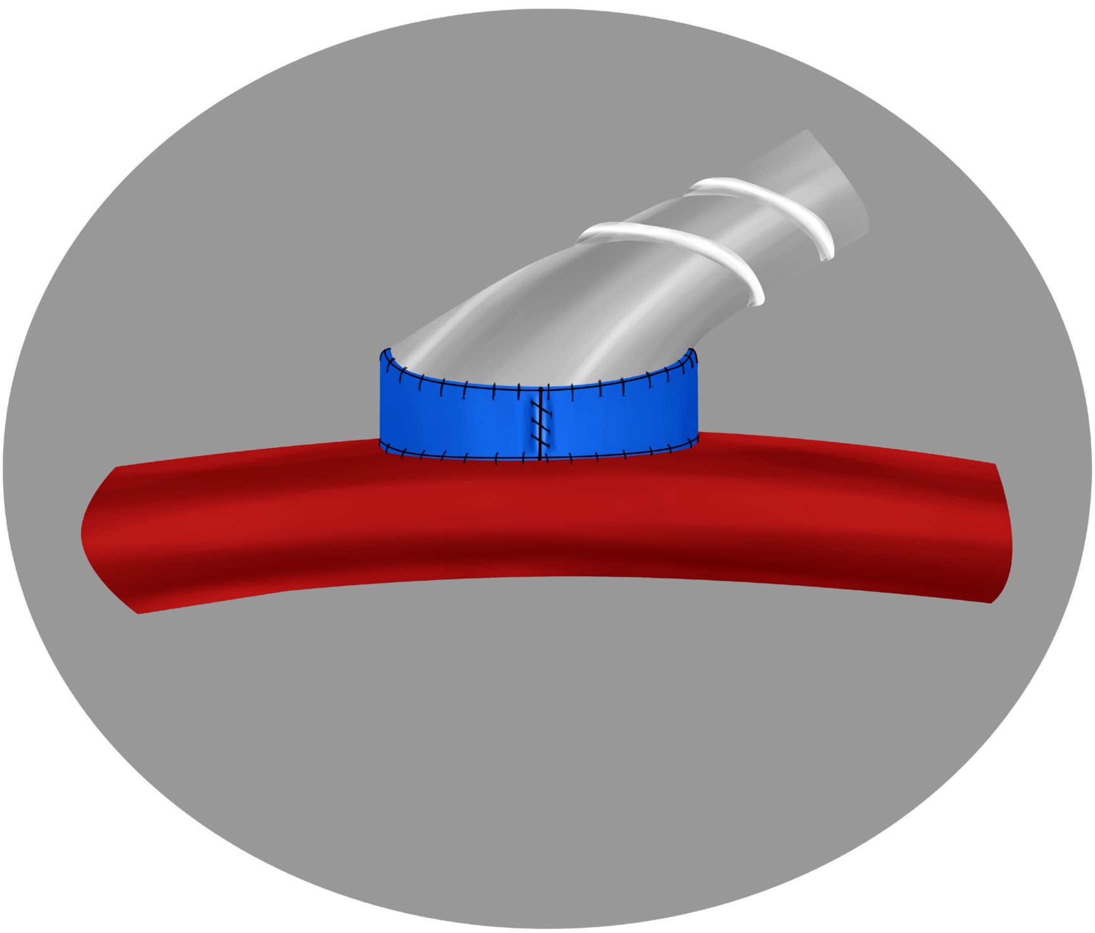

Figure 19.6. Miller cuff.

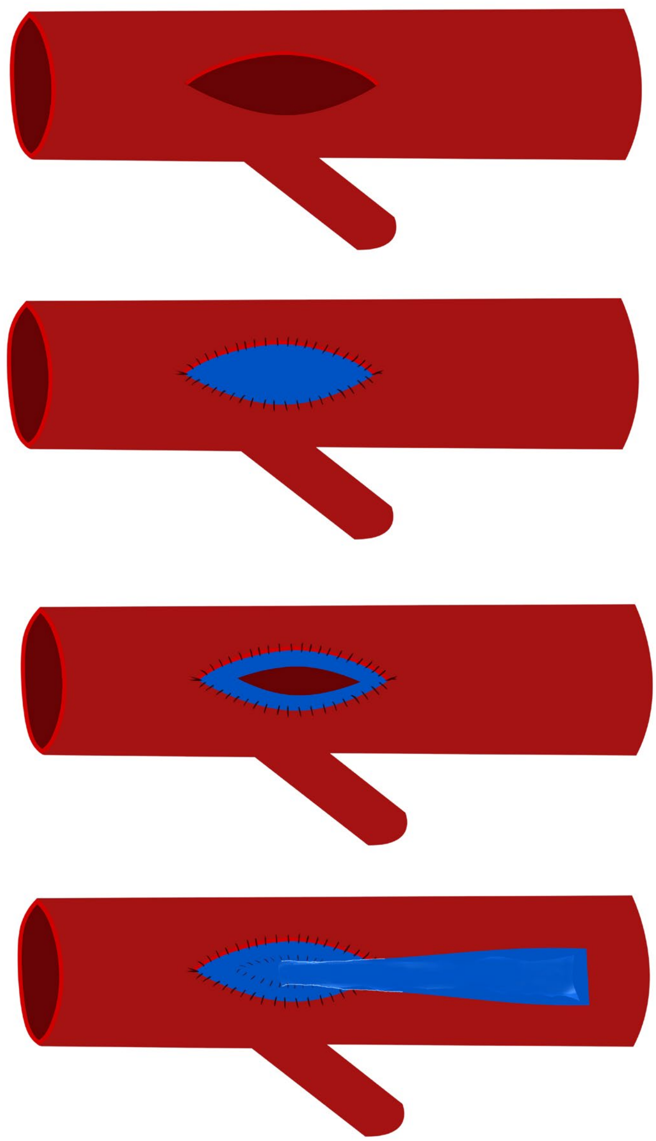

Figure 19.7. End-to-side anastomosis to patch plasty.

venotomy and anastomosis; this way the heel of the bypass will become a bit wider and slightly elevated, to reduce the risk of anastomotic stenosis.

Before starting the proximal anastomosis, the correct orientation of the vein is confirmed. Often a prolene 5/0 or 6/0 suture is used for the proximal anastomosis. The anastomosis is performed in a similar fashion as the distal anastomosis. After flushing and rinsing with heparinized saline, the anastomosis is completed. To prevent distal thrombo-embolization, blood flow is restored first in the profunda or SFA and secondly through the bypass.

Assessment of the bypass

Intraoperative assessment includes evaluation of graft patency, adequate outflow and hemostasis. A sterile Doppler probe can be used to assess the quality of flow through the bypass and the outflow distally of the bypass. It is advised to inspect both ends of the tunnel trajectory and ensure that the bypass is running freely without external compression. An intraoperative completion angiography can be performed routinely or upon indication. Digital subtraction angiography is performed from the proximal graft down to the foot.

Closure

After careful hemostasis, the wounds are closed. Distally, the fascia is reapproximated using absorbable sutures, and the subcutaneous tissue is closed to obliterate dead space. The skin can be closed subcuticularly, or in an interrupted fashion in case of substantial edema. The groin is closed in multiple layers to minimize dead space that may facilitate formation of a hematoma or a lymphocele. Negative pressure wound therapy on the closed skin for several days may decrease the risk of postoperative wound infection.

TIPS & PITFALLS

- Preoperative ultrasound marking of GSV allows easy identification of the conduit and prevents creation of large skin flaps prone to wound dehiscence and necrosis
- The approach to the above-knee popliteal artery and below-knee popliteal artery is avascular not through muscle.
- In case of a short common femoral artery or insufficient venous conduit length, perform proximal anastomosis on profunda femoris artery (PFA) or (endarterectomized) SFA.
- Leave a small patent arteriovenous fistula (in case of *in-situ* venous bypass) just proximal from the distal anastomosis to preserve proximal graft flow in case of graft occlusion.
- If possible, extend venotomy for proximal and distal anastomosis through a suitable side-branch to create a brood hood and prevent narrowing at heel of the anastomosis.
- Leave a proximal tributary of the GSV long for easy access for completion angiogram.
- Always heparinize after the exposure and tunneling has been performed.

TROUBLESHOOTING

- When graft flow is insufficient at completion angiogram, causes can be a twisted or kinked graft, a too small vein as part of a double GSV system, or there is a residual functional valve, which is not cut adequately.
- To avoid kinking: in case of an infrapopliteal bypass, make sure to extend the leg while tunneling the bypass graft to avoid excessive length and risk of kinking of the graft.
- To avoid twisting: mark the vein over the length of the vein when inflated with a sterile marker, facilitates identification of torsion when tunneling.
- To avoid residual valves: cut the terminal valves with Pott's scissors and not use the valvulotome, before making the proximal anastomosis.
- While experiencing bleeding from the tunnel trajectory, usually a clip from one of the side branches has been torn. Avoid clips and use suture ligations for side branches.
- There is nothing better than a good vein. However, a bad vein often results in low patency.

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