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Review Article

Technical Pitfalls and Tips of Management for Critical Limb Ischemia by Distal Bypass Using the Autogenous Veins

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It is a clear fact that many complications in surgical treatment, not just in cardiovascular surgery, are caused by things related to surgical techniques. In other words, postoperative problems are already determined by preoperative surgical management and intraoperative surgical operations. This describes strategies to avoid the surgical complications of distal bypass using the autogenous veins for each item. (This is a translation of Jpn J Vasc Surg 2024; 33: 67–72)

Keywords: CLI, distal bypass, autogenous vein graft, surgical complications

Introduction

It is a clear fact that most complications in surgical treatment, not only in cardiovascular surgery, are due to intraoperative surgical manipulations. In other words, postoperative problems are already determined and initiated by the preoperative surgical design and intraoperative surgical manipulation. Here, we will explain the points to avoid problems after lower extremity arterial reconstruction for each item.

Bypass Graft Related

1. Premature vein graft failure

Early venous graft failure may be caused by imperfect surgical techniques or procedures. The frequency of graft failure is a direct reflection of the surgeon's skill, and the surgeon must directly observe the frequency of graft failure, identify its causes, and make improvements. The following is an explanation for each cause.

Vein graft hemorrhage

Early bleeding from the graft may be due to anastomotic suture failure, inappropriate treatment of the branches of the autologous vein, or the possibility of graft bleeding due to unnoticed vein damage during venous valve treatment. These problems can be solved intraoperatively and are elementary for the vascular surgeon. We must go back to the basics and check the technique.

Causes for vein graft occlusion

1) Anastomotic technique

In some cases, anastomotic manipulation is unskilled, resulting in early occlusion due to poor anastomotic morphology and lack of graft flow. In this case, the surgeon must go back to the basics of vascular anastomosis and check whether the host artery was properly blocked, whether the external anastomosis was completely achieved, and whether the intima of the vein and host artery was inadvertently injured, resulting in intimal dissection. I do not think it is necessary to describe each technique here, but I would like to point out one thing: it is difficult to perform a secure eversion anastomosis with a one-needle continuous parachute anastomosis in vessels of small diameters. In general, a secure eversion anastomosis using two or more needles is generally used. In low-flow vessels, even partial exposure of tunica media and adventitia on the anastomotic surface can lead to primary thrombus formation in the early stages and intimal thickening in the late stages, resulting in graft occlusion or failure.

2) Peripheral runoff problem

Anastomotic site selection is an important factor when performing bypass surgery. The central anastomosis can be shortened by selecting the most distal part of the anastomosis, which provides more secure blood flow. The peripheral anastomosis site should be selected in a vessel

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that is as free of lesions as possible while still providing a vascular bed. Incorrect selection increases the likelihood of premature graft occlusion. If you are in doubt about whether to bypass the anterior or posterior tibial artery system below the knee, you should choose the one with (1) more peripheral vascular beds, (2) less calcification, and (3) a larger vessel lumen. If still in doubt, a site should be selected, considering the site of ulcer necrosis and angiosome. In general, the anastomosis site is determined by the above factors (1), (2), and (3), and the selection of the peripheral anastomosis site that gives priority to the angiosome without considering the above factors (1), (2), and (3) is a low priority in bypass surgery, according to literature[1] that examined the relationship between bypass surgery and foot healing. In some cases, the anastomotic site may be a calcified lesion, or a vascular bed may not be obtained. In this case, intraoperative graft blood flow can be measured to predict early postoperative graft occlusion. As a result, in the case of low-flow graft bypass, the author has used continuous low-concentration intra-graft Prostaglandin E1 for about 3 days to maintain the peripheral vascular bed in the early postoperative period, but there is no evidence that early graft occlusion could be avoided.

3) Quality of vein grafts

The quality of the veins to be used as grafts should be checked preoperatively if autologous veins are used. The vein diameter is satisfactory if the vein diameter after intraoperative dilatation is 3 mm or greater.[2] However, if it is necessary to use a vein with a diameter of 3 mm or less, it is important to note the defective area in the operative record clearly. This clarifies the cause of graft occlusion and the extent of repair in the event of failure. In terms of vein graft quality, it is important to select veins with the best possible diameter and dilatation in the remaining lower extremity veins.

Treating branches, vein valve lysis, and vein–vein splicing, as well as the need for protective handling to maintain the endothelial cells, are all important in autologous vein grafting. Furthermore, when veins are used in situ or non-reversed, the vein valves must be destroyed entirely. After lysis of the venous valves, it is essential to check for vigorous blood flow from the center to the periphery. If there is a site of poor dilatation due to valve remnant during the procedure, it is necessary to check whether the valve has remained intact.

***Venous valve lysis method**

There are various methods of destroying venous valves, but the first venous valve located at the center of the great saphenous vein (GSV), that is, the saphenous femoral junction, is removed with scissors under direct vision. In short lengths of extracted veins, it is also possible to resect the venous valves by turning them completely inside out. Otherwise, the procedure is generally performed with equipment specialized for venous valve lysis. The following are the main points to keep in mind when using valve cutters.

a) Catheter with variable incision diameter endovascular valve cutter (Expandable LeMaitre Valvulotome: LeMaitreVascular Inc., MA, USA)

Four blades for vein valve lysis are attached to the tip of the hydrophilic-coated catheter in a basket (hoop) configuration, and the blades are retracted into the catheter's outer casing. When the catheter is inserted into the vein lumen and the hoop is deployed from the outer casing, the tip is centered in the vessel to reduce damage to the vessel wall by the valvulotomy blade. The diameter of the valvulotomy blade is adjusted to the appropriate vessel diameter by the hoop with a cutter, which follows the vessel wall well and ensures that the vein valve is lysed.

In the in situ method, the catheter tip hoop is not directly visible, so the tip of the catheter may be tilted (not centered properly), and the blade of the cutter may catch on the branches of the vein or the sinuses of the valves, causing the vein to be split longitudinally as it is. If there is strong resistance, the catheter should not be forcibly pulled, but the hand should be stopped, and the hoop should be stored in the outer casing, pushed back to the center, and then reopened to pull out the catheter. In the non-reversed method (translocation method), the vein has been removed, and the valve can be safely dissected under direct vision, allowing for safer valve lysis

b) Catheter with fixed-diameter endovascular valve cutter (LeMills Valvulotome: LeMaitre Vascular Inc., MA, USA)

The metal stick has a hook-shaped blade at its tip and is inserted into the lumen of the vein to destroy the valves. There are two types, the push-off and pull-off types. The push-off type is inserted against the venous blood flow and the hook is pressed against the valve to destroy it. The pull-off type is inserted along the venous blood flow, and the hooked blade catches the vein valve and destroys it as it is withdrawn. Use is with the vein removed. It is often used in cases of poor venous quality because it is performed under direct vision and allows for the lysis of the venous valves in a protective and reliable manner. Because venous valves are bilobed, it is necessary to invert the hook to the contralateral side and destroy the paired valve.

4) Graft pathway

No matter how good the vein used, the anastomotic site selected, and the anastomosis performed, problems with the graft pathway can cause early and late graft occlusion.

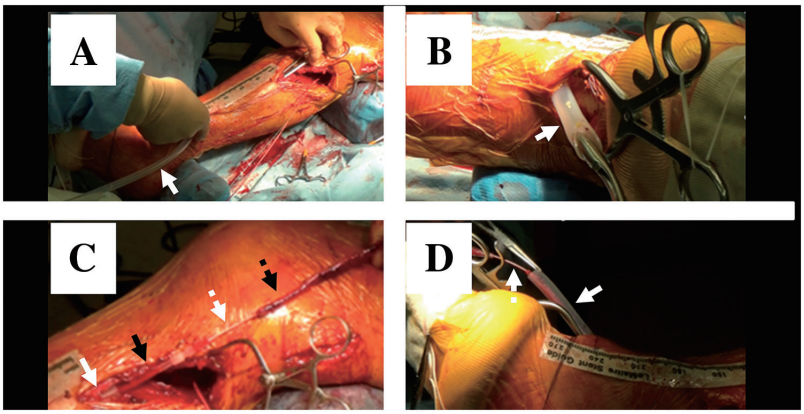

Fig. 1 The tunneling methods for using vein graft. (**A–D**) The blow-knee popliteal–dorsal pedis bypass using the GSV by translocation method. White arrow: 8-mm silicon tube; black arrow: infusion extension tube; white dot arrow: cannulation tip; black dot arrow: vein graft; GSV: great saphenous vein

Careful attention should be paid to the graft pathway. The basics of the graft pathway are to make the pathway as short as possible, to pass as deep as possible, and to release external sources of compression, such as ligaments and tendons. Nevertheless, it is the surgeon's preference if they choose a subcutaneous route to deal with late graft failure. In any case, the vein graft should be passed along the pathway to avoid external compression and prevent the graft from twisting in the process.

The author's graft pathway establishment procedure is shown below.

* **How to create a graft pathway**

(1) Mark with a continuous line in the direction of the long axis (because marking with a point does not confirm that there is no torsion). (2) The dressing forceps are guided bluntly to the path to be established, and an 8-mm silicone tube is grasped at the tip of the forceps and pulled out of the path. This will also prevent bleeding in the pathway where the silicone tube placement was created. The above operations should be completed prior to systemic heparinization (**Figs. 1A** and **1B**). (3) An infusion extension tube is passed from the end of the implanted silicone tube to the center. (4) An infusion extension tube is connected from the center to the olive tube at the end of the graft (**Fig. 1C**). (5) The graft is pulled out to the periphery, with attention to the markings to prevent twisting and guide the entire length of the graft into the pathway. (6) The location of the graft is determined and the silicone tube is pulled out peripherally. (7) The silicone tube is pulled out along the infusion tube connected to the olive tube at the end of the graft and removed from the body (**Fig. 1D**).

5) Arteriovenous fistula due to residual vein graft branches in an in situ technique

In the in situ technique, arteriovenous fistula (AVF) due to residual venous branches may occur at the time bypass is established. Graft angiography can be used as a means of avoiding intraoperative AVF remnants. Another method is to identify a residual AVF using graft blood flow as a guide without performing a contrast examination. This method is useful because it does not use contrast media and does not expose the patient to X-rays. The method consists of first placing a blood flow meter probe near the central anastomosis and performing graft blockade segmentally from the proximal part of the blood flow meter probe, and the presence of AVF is suspected between segments if the blood flow rate does not reach 0 mL/min. In such cases, the grafts contained in the segment are dissected and the branches are ligated. Finally, if graft blockade near the peripheral anastomosis does not produce blood flow, the AVF is considered to have been treated. However, in some cases, AVFs may not be identified intraoperatively, and their presence may only become apparent postoperatively. In such cases, AVF ligation is recommended in cutaneous stasis caused by AVF or in chronic limb-threatening ischemia (CLTI) cases.

6) Graft failure due to hypercoagulability

Unexpected occlusion of the bypass graft within 2 days after surgery is rare. In this case, it is necessary to consider whether there is a disease that causes hypercoagulability. Many of these are caused by changes in the amount or function of proteins in the blood that control coagulation. Diseases that cause coagulation disorders are listed below.

- Activated protein C resistance (factor V Leiden mutation), protein C deficiency
- Protein S deficiency, antithrombin deficiency, etc.

Hypercoagulable states may also be caused by acquired diseases. Such diseases include disseminated intravascular

coagulation syndrome (often caused by cancer) and antiphospholipid antibody syndrome (including the presence of lupus anticoagulant factors). Since the activity of blood coagulation factors is excessive, graft thrombosis occurs due to hypercoagulability.

If the condition is known preoperatively, these conditions can be treated by increasing the strength of intraoperative and postoperative anticoagulant therapy.

2. Hybrid surgery

In hybrid surgery, in which endovascular therapy (EVT) and bypass surgery are performed simultaneously, the following points should be considered when determining the treatment design.

- EVT is performed on lesions where EVT patency is ensured.

In other words, if the lesion treated with EVT develops restenosis or occlusion several months later, the effect of the bypass performed at the same time will be lost. In the case of surgery combined with EVT, which remains an unavoidable concern, careful postoperative blood flow surveillance is necessary. If restenosis develops, prompt therapeutic intervention should be performed.

3. Wound healing failure

1) Graft exposure due to postoperative skin incision wound healing failure

A particularly serious graft complication is graft exposure caused by inadequate skin incision healing at the graft harvest site or anastomosis. Graft exposure will result in graft rupture, requiring graft repair. In this case, the need for additional venous material, change in the site of anastomosis, and additional skin incision sites may be necessary, which may have a significant impact on the prognosis of the leg. In the case of bypassing the dorsal and plantar arteries, the graft pathway near the anastomosis is subcutaneous, exposing the graft in the case of dehiscence of the skin immediately above the anastomosis due to necrosis. For this reason, the author makes a lateral skin incision about one fingerbreadth away from the anastomotic site directly above the artery and covers the graft with fascial tissue or a support band around the incision to prevent graft exposure at the time of closure. Care should be taken to ensure that the graft is not compressed by the covering surrounding tissue.

2) Artificial vascular infection

Revascularization of the femoral artery with an artificial vessel is a common procedure for lower extremity revascularization. However, the rate of postoperative vascular infection in the inguinal region is known to be higher than in other regions.[3] The main reasons for this may be the proximity to the perineum, having an artificial object forming a shallow pathway, and the abundance of lymphoid tissue. Therefore, when artificial vessels are used in the femoral artery in the groin, great care must be taken against infection. The following is a summary of the U.S. guidelines for surgical site infection prevention.[4]

a) Avoid prolonged preoperative hospitalization to reduce the development of more resistant nosocomial infections.
b) Showering, scrubbing, and wiping with alcohol-based soaps (e.g., chlorhexidine) should be performed for 1–3 days before surgery.
c) Control any infections brought in by the patient prior to the elective surgery.
d) Remove hair from the surgical site immediately before surgery, taking care to avoid injuring the skin.
e) Iodine-impregnated plastic drapes or antimicrobial-impregnated towels/sponges are used to protect the artificial vessels from contact with the exposed skin of the operative field.
f) Avoid concomitant use with gastrointestinal procedures during vascular grafting procedures.
g) Use prophylactic antimicrobials (30–60 minutes before skin incision) prior to artificial vessel laparotomy.
h) If two or more patient-related high-risk factors for surgical wound infection are identified, such as extremely advanced age, malnutrition, prolonged hospitalization, infections brought in by the patient, immunosuppressive medications, revision surgery, or history of radiation to the surgical site, a longer duration of antimicrobial therapy before and after surgery may be considered.
i) Measures to control methicillin-resistant Staphylococcus aureus (MRSA) include the use of disposable barriers (gowns, gloves, masks) by all persons in contact with MRSA carriers to reduce direct transmission in the hospital, routine MRSA screening (nasal swabs) of all hospitalized patients, use of mupirocin ointment before surgery, and chlorhexidine skin washes are repeated.
j) Close attention should be paid to sterilization techniques. Careful tissue handling, prevention of hematoma formation, and multilayered closure of inguinal incisions to reduce lymphatic resection/ligation and dead space are essential to reduce wound complications. Suturing the skin without tension minimizes the occurrence of dermal ischemia and gangrene at the wound margin.

Unfortunately, the treatment of artificial vascular infections depends on the degree of infection, and it is important to first evaluate the degree of spread of the infection.

The basic treatment for infected patients is the removal of the infected artificial vessel and revascularization by a non-anatomic route. However, in cases of infection that meet the following conditions: (1) localized infection, (2) causative organism other than MRSA or Pseudomonas aeruginosa, and (3) the artificial vascular anastomosis site free from infection, treatment methods that preserve the infected graft (covering of the infected graft with a suture muscle valve and continuous negative pressure aspiration therapy) have also been reported and are informative.[5,6]

Foot management of comprehensive severe CLTI with foot defects

The most important aspect of managing foot tissue loss in CLTI is infection control. The dilemma of wound healing and tissue preservation exists in CLTI because attempts at primary wound closure in the foot with tissue loss result in more tissue loss than necessary, and early wound closure cannot be expected if tissue preservation is the primary goal. Wounds must often be managed as open wounds for extended periods of time to achieve greater tissue preservation. In addition, CLTI patients often have predisposing factors such as diabetes mellitus, renal dysfunction, and heart failure that make them susceptible to infection and failure to heal, increasing the risks of recurrent infection. The following points need to be taken into account in the management.

Deep infection of the foot

The infection may be exacerbated by an open wound after amputation of the toe, causing deep infection of the foot. This can also occur preoperatively in CLTI, but deep infection of the foot can present with erythema and swelling along the toe tendons, sometimes with a foul odor. Infection spreads rapidly within a few days, so if deep infection is suspected, the infected area must be incised and drained promptly. The deep plantar infection spreads from the flexor digitorum tendon and forms an abscess under the plantar fascia. Abscesses may sometimes form in the flexor digitorum brevis muscle and under the tendon of the flexor digitorum longus muscle. Deep infection on the medial side of the foot often involves the extensor hallucis longus and flexor hallucis longus, and on the lateral side of the foot, the infection may spread from the proximal metatarsal end of the fifth toe, forming an abscess under the extensor hallucis longus and reaching the distal part of the Achilles tendon. It is important to identify the site of abscess formation and to completely free the abscess if it is to be drained by incision.

Pyogenic arthritis-osteomyelitis

If the ankle joint components (talus, tibia, and fibula) become infected, major amputation is inevitable. Even when the healing of the foot is progressing due to the granulation of the wound surface, we should aggressively suspect pyogenic osteomyelitis due to foot infection if the patient has severe foot pain, fever over 38°C, and persistent inflammatory findings of moderate severity or higher. If the pyogenic osteomyelitis is contained at the level of the metatarsal bone, the bone should be surgically removed immediately. However, when osteomyelitis is present in the ankle joint or the tibia or fibula, foot preservation is not possible. MRI is useful for diagnosis based on the above local findings, and joint and bone conditions should be confirmed.

Recurrent/remnant foot ischemia

If healing progression is not achieved or ischemic gangrene flares up during the course of wound management, an ischemic evaluation of the foot should be performed. Even if the bypass graft is open, the progression of arterial lesions can cause a decrease in blood flow due to central lesions, stenosis in the middle of the graft, and peripheral anastomotic stenosis, which can stagnate or worsen healing in the foot. Detailed evaluation of blood flow by echography and angiography should be performed promptly, and interventional treatment should be performed to improve blood flow in the presence of problems.

Conclusion

Avoidance of problems after lower extremity artery reconstruction is described. When a surgeon achieves a good treatment result, the sense of accomplishment gives him or her confidence for the next step. It is a surgeon's destiny to take measures to avoid postoperative problems, and it is important to exchange information with other surgeons, who are trained and experienced in the field, on a regular basis. The surgeon must always strive for theoretically correct procedures.

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Conception and design: TK and TS
Data collection: TK, SO, and KN
Manuscript preparation: TK
Critical review and revision: all authors
Final approval of the article: all authors
Accountability for all aspects of the work: all authors

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