SOLEUS FLAP (PROXIMALLY AND DISTALLY BASED)

The soleus muscle is located at the posterior aspect of the leg, deep into the gastrocnemius that is usually large, broad and long, but can vary from one patient to another, and can also be quite short.

It was described as a local pedicled flap to repair defects at the medial and distal aspect of the leg by Ger[40,41] and popularized by Mathes and Nahai[103]. Since then, this muscle has been used as proximally based, distally based[31,93,134,146], either partial[145,159] or total muscle flap[40,101], muscle-adipose[44] or muscle-tendon[16] muscle-skin-bone[22] composite flaps or free flap[75,124].

Despite all published variations and indications, this flap is generally used as a proximally based, entire muscle flap transposition, because:

- There is not a single dominant pedicle that can adequately vascularize the entire muscle segment,
- Vascularization emerges from different source vessels (posterior tibial and peroneal arteries),
- Hemisoleus flaps are usually too narrow to cover current size defects found on middle and distal third defects.
- All pedicles are rather short and will limit rotation, and
- Respecting a muscle segment by raising only one of the bodies (lateral or medial) does not significantly preserve post-operative ankle function.

However, there are also some advantages that have to be balance out with the mentioned disadvantages:

- Independent innervation and vascularization and bipeniform morphology allows for separate harvesting of each muscular belly.
- Practically the only open option to effectively cover distal bone defects of the tibia.
- Has a constant blood supply.

With all this in mind, what follows is the procedure to elevate the soleus muscle flap, proximally based as an entire unit, or as a partial soleus muscle flap, based on its distal pedicle.

Indications

Although the soleus flap can be elevated as a composite flap including fascia, muscle, tendon (partial Achilles tendon), bone (head of the fibula) and skin (skin overlying the fibula head), the classical and more widely deployed use for this flap is coverage of defects of the middle third of the tibia. Defect localization and size will determine the type of flap (pedicled, hemisoleus, free…), but the size and length of the soleus muscle, can vary between patients and may also determine indications. Sometimes soleus muscle is present with a long body, which is able to reach the distal third of the leg, while in other patients the muscle is broad, thick but rather short and difficult to rotate even for middle third defects. In these cases (short muscles) it may be preferable to use the medial hemisoleus flap, which is more versatile and mobile[101], though it is obviously narrow and indicated for limited narrow defects.

Indications can be summarized as follows:

- Medial third defects of the leg, usually post-traumatic injuries to the tibia. In the case of minor bone defects (less than 5 cm long), conventional bone grafts or one-stage ipsilateral fibula transfer with the muscle can provide vascularized bone to the defect[9,31,40,41,93,122].
- Distal third defects of the leg, can be repaired with a distally based medial soleus flap, but the distal minor pedicle is not fully reliable and a second option has to be kept in mind.
- Achilles tendon injuries and defects[16,44].
- Maxillo-mandibular reconstruction[9,120].

Anatomy and Vascularization

The soleus muscle is a large, broad and usually long muscle (though in certain patients it can be rather short) located deep to the gastrocnemius muscle at the posterior aspect of the leg. It has two heads, the medial and lateral separated at its distal part in the midline by a septum. The lateral head originates from the fibula head and shaft, while the medial head originates from the medial side of the middle third of the tibia (see fig. 7.123). Both heads join together to form the dorsomedi-

al and dorsolateral part of the Achilles tendon with the fibers coming from the gastrocnemius muscle. Both heads, through the Achilles tendon, insert to the calcaneum tuberosity.

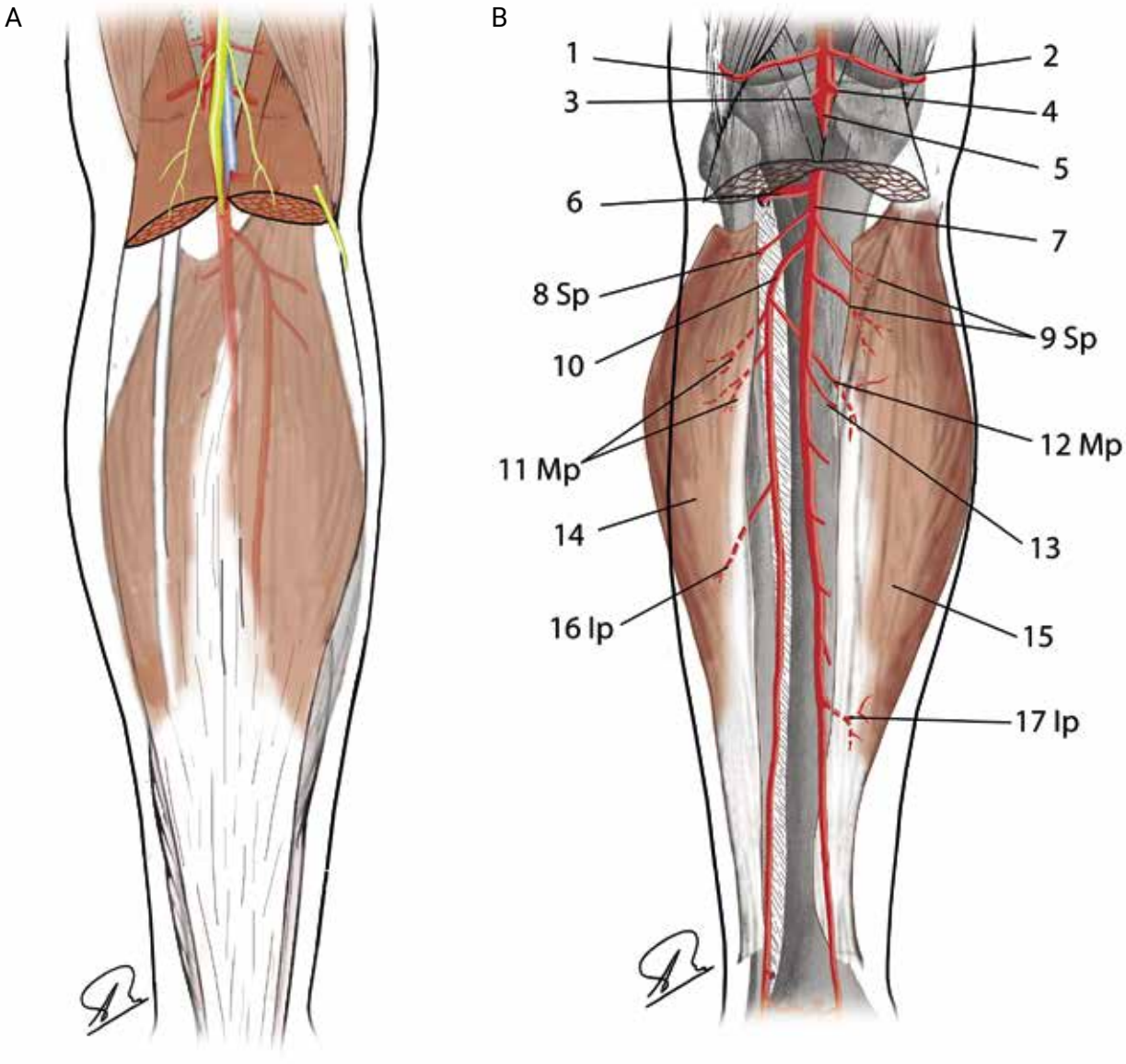
Vascular supply and innervation according to Baudet et al.[9] is:

a. Lateral soleus muscle is vascularized by three pedicles and innervated by branches from the medial popliteal and tibial nerves. Upper and middle pedicles come from collateral branches branching off from the peroneal vessels, while the inferior pedicle comes from the posterior tibial artery.

   - Upper pedicle is constant and dominant and penetrates the muscle 2.2 cm below the fibula head (fig. 7.62 B-8 Sp).
   - Middle pedicle consists of two branches (fig. 7.62 B-11 Mp). The upper branch of this middle pedicle originated from the tibioperoneal or the peroneal arteries and penetrates the muscle at approximately 7.5 cm from the head of the fibula. The lower branch originates from the peroneal artery and enters the muscle at 9.9 cm from the head of the fibula.
   - Inferior pedicle is absent in 18% of patients and branches off from the peroneal artery (50%) or the posterior tibial artery (50%) (fig. 7.62 B-16 Ip).

b. Medial soleus muscle is vascularized by several vessels branching off the peroneotibial and posterior tibial vessels and is innervated by branches from the posterior tibial nerve. The medial belly has three dominant pedicles and some other minor ones:

   - Upper pedicle: branches emerging from the tibial artery (fig. 7.62 B-9 Sp).
   - Middle pedicle: Branch emerging from the peroneal artery (fig. 7.62 B-12 Mp).
   - Inferior pedicle: Branch from the posterior tibial artery (fig. 7.62 B-17 Ip).



1. Lateral inferior genicular artery
2. Medial inferior genicular artery
3. Lateral sural artery (lateral gastrocnemius pedicle)
4. Medial sural artery (medial gastrocnemius pedicle)
5. Popliteal artery
6. Anterior tibial artery
7. Posterior tibial artery
8. Sp: Superior pedicle for the lateral soleus.
9. Sp: Superior pedicle for the medial soleus (usually two arteries)
10. Peroneal artery
11. IMp: Middle pedicle for the lateral soleus
12. Mp: Middle pedicle for the medial soleus
13. Nutrition artery for the tibia
14. Lateral soleus belly
15. Medial soleus belly
16. Ip: Inferior pedicle for the lateral soleus (50% of cases it comes from the peroneal artery, as shown in the illustration and in the other 50% of cases, it may come from the tibial artery)
17. Ip: Inferior pedicle for the medial soleus

Figure 7.62. Soleus Anatomy and vascularization: A) Complete soleus muscle belly, both gastrocnemius muscles have been removed. The tendon of the plantaris muscle is seen on the lateral aspect. B) Both soleus bellies have been split longitudinally to allow visualization of the pedicles.

Markings

For these highly versatile flaps, design and outlining will finally depend upon whether the flap has to include the following: a cutaneous paddle (or not), a fibula fragment or tendon fragment, or will be raised as a whole soleus muscle, a lateral belly or medial belly, or will be raised as proximally based, distally based or free flap.

If the soleus muscle is transferred with a cutaneous paddle, the island has to be outlined on the upper third of the lateral soleus muscle, as it is there where the main musculocutaneous perforator vascularizes the overlying skin.

As mentioned above, it is important to be aware of the length of the muscle; as some can reach the malleoli and others are rather short for that goal. For those patients with long muscle bellies, these can be transferred proximally based, to repair distal third defects of the leg. For those soleus muscles that are rather short, if proximally based, they will only be able to give covering to middle third leg defects.

Medial approach: A line is traced from the medial malleolus up to the proximal third of the leg at 1.5 cm posterior to the medial border of the tibia. On reaching the proximal third of the leg, if necessary, the line is continued as an "S-shaped" incision to the popliteal fossa for better exposure of the pedicle.

Lateral approach: A line is traced longitudinally from the lateral malleolus, along the fibula axis up to the fibula neck. The skin incision starts at the junction of the middle and distal third, and continues up over the traced lined to the fibula neck, where it bends towards the popliteal fossa.

Composite soleus flap: To elevate the soleus muscle as a musculocutaneous or composite fibular-musculocutaneous flap (fig. 7.75), the skin island should then be outlined more posteriorly than the usual muscular approach; centered over the septum, between the lateral soleus and peroneus longus, as it is from there that the septocutaneous perforator vessels emerge to the skin. These perforators are usually found at the upper third of the leg and consequently it is from the upper third, where the cutaneous paddle has to be harvested.

Elevation

Medial soleus muscle flap

Elevation of the muscle is best done under controlled ischemia by using an inflatable tourniquet. Muscle incisions and section are rather bloody and this will challenge precise identification and isolation of the pedicles. In order to preserve the mechanics and function of the gastrocnemius-Achilles tendon, the soleus muscle and fascia have to be carefully divided proximally, to the Achilles tendon.

It is important to highlight the fact that pedicles for distally based soleus flaps are not consistent and reliable. If a distally based soleus is planned, distal pedicles should be explored and identified, before any proximal vascular supply or muscle fibers are divided.

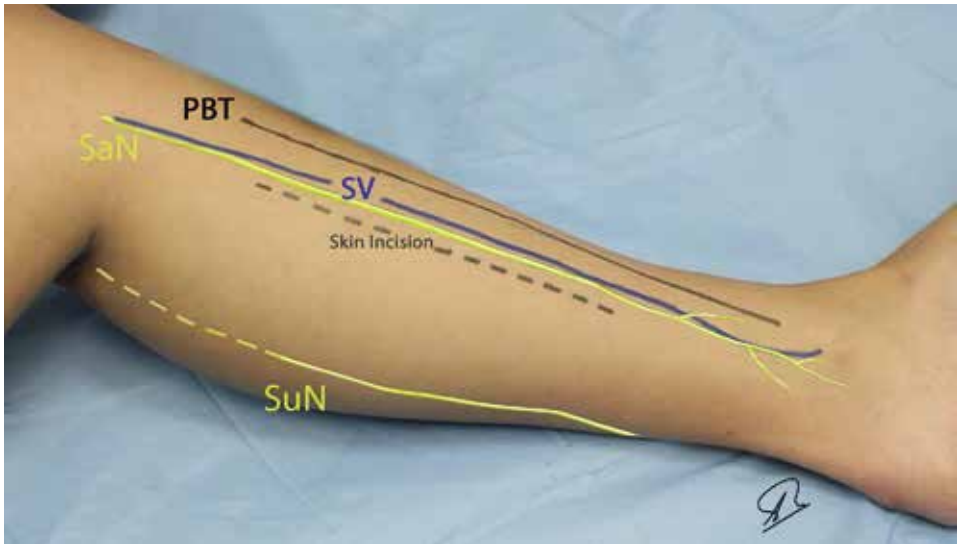


Figure 7.63. Muscular soleus flap approach: Great saphenous vein (SV) and saphenous nerve (SaN) are usually found, two fingers width posterior to the posterior border of the tibia (PBT). A longitudinal incision is then outlined posterior to these structures.

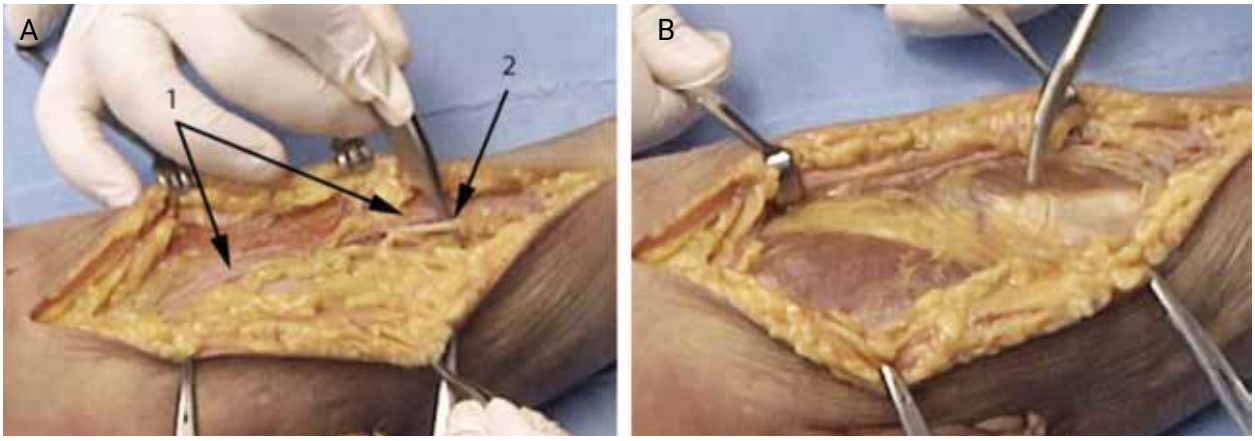


Figure 7.64. A) Anterior retraction of the skin allows direct identification of the great saphenous vein (1) and saphenous nerve (2) that are respected. B) Subfascial dissection continues posteriorly exposing the medial belly of the gastrocnemius and the medial body of the soleus muscle.

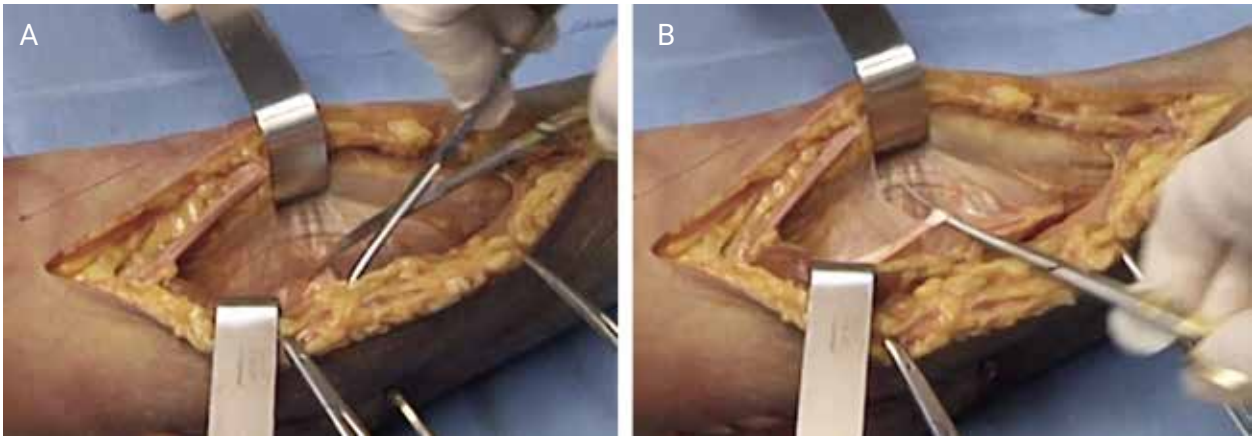


Figure 7.65. A) The fascia enclosing both muscles is incised and by sharp dissection, soleus muscle is separated from the gastrocnemius. B) The tendon of the plantaris muscle (arrow) identifies the right plane of dissection between gastrocnemius and soleus muscles.

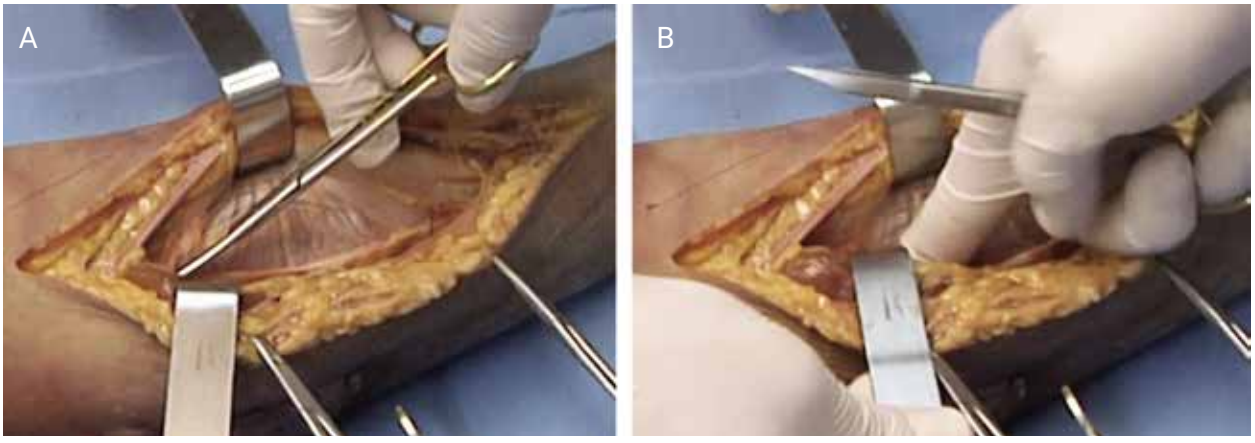


Figure 7.66. A) By sharp dissection the medial soleus is separated from the medial gastrocnemius and any tibial attachment. B) Deeper, separation of the soleus from the flexor digitorum longus, Tibialis posterior and flexor hallucis longus muscles can be easily done by blunt dissection (using the finger as an instrument).

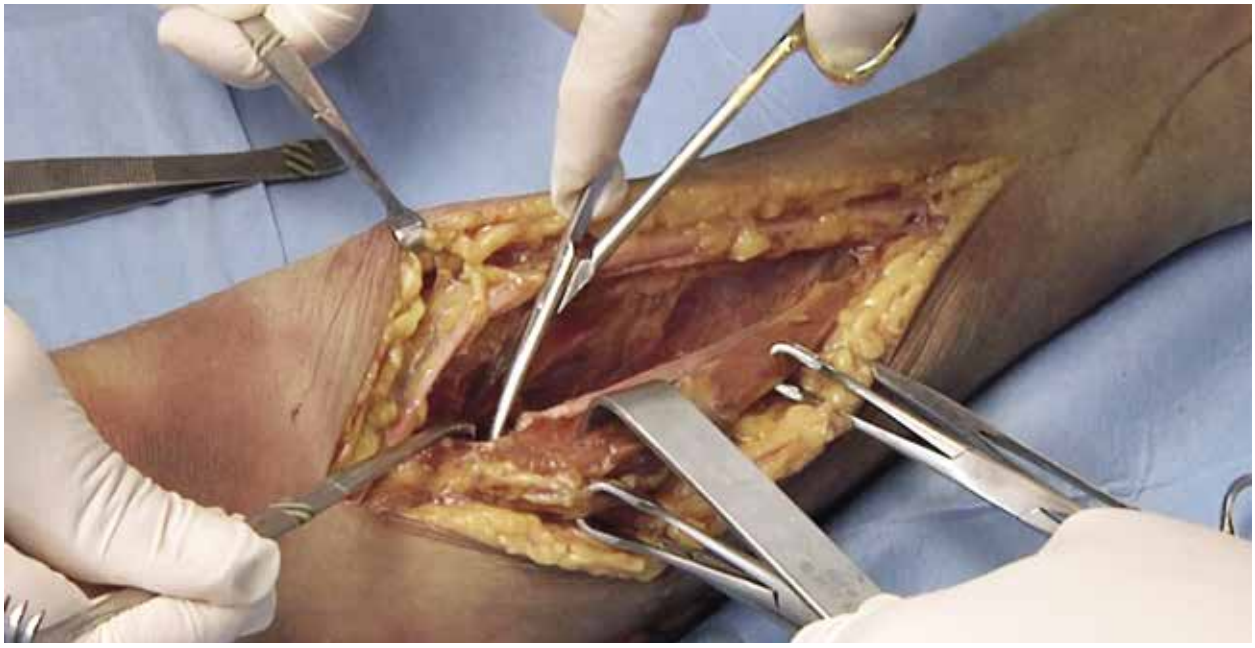


Figure 7.67. The medial soleus belly is pulled posteriorly to expose its deeper aspect. The proximal pedicle is found at this point, entering the muscle.

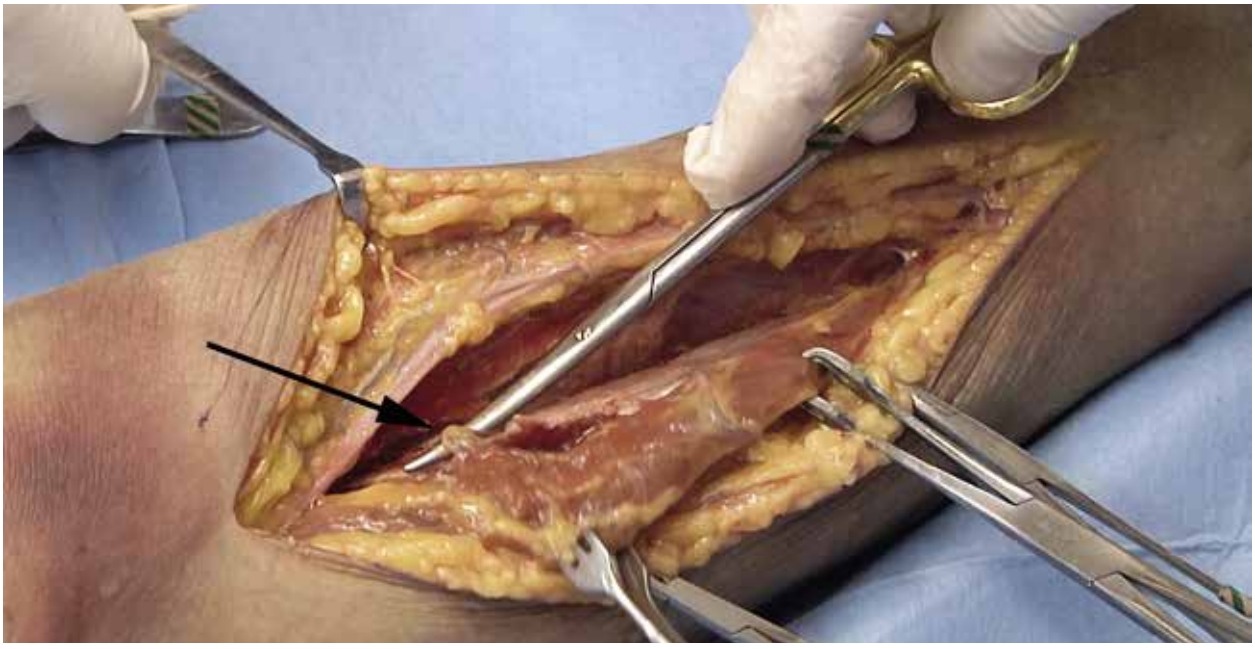


Figure 7.68. Proximal pedicle is identified and gently isolated by blunt dissection. The pedicle is preserved.

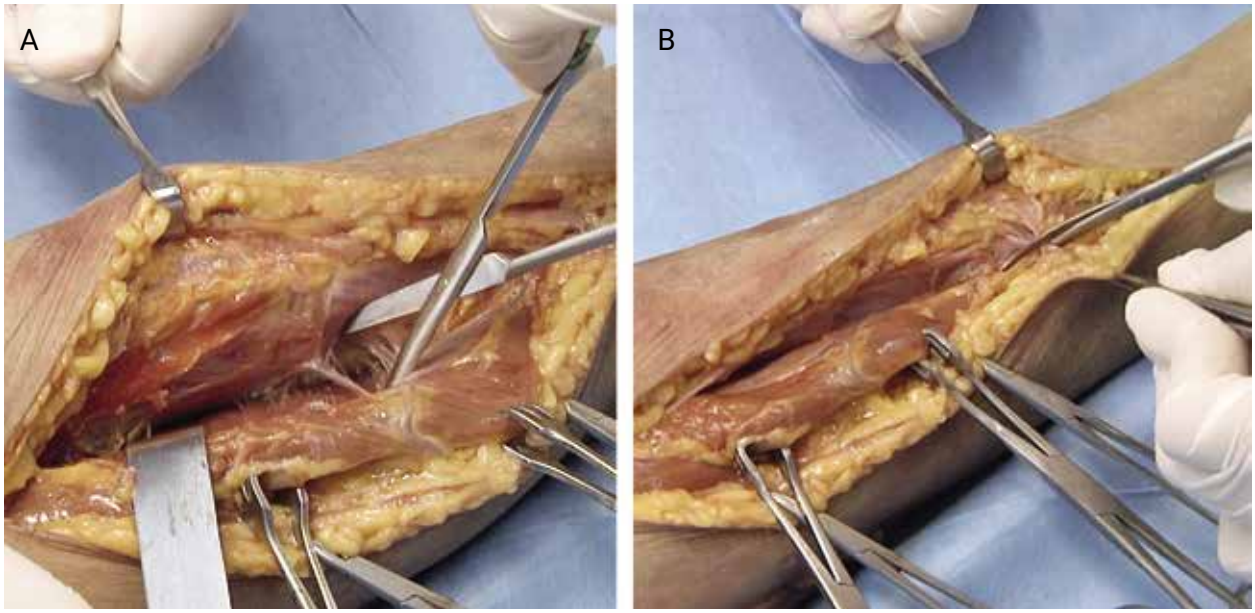
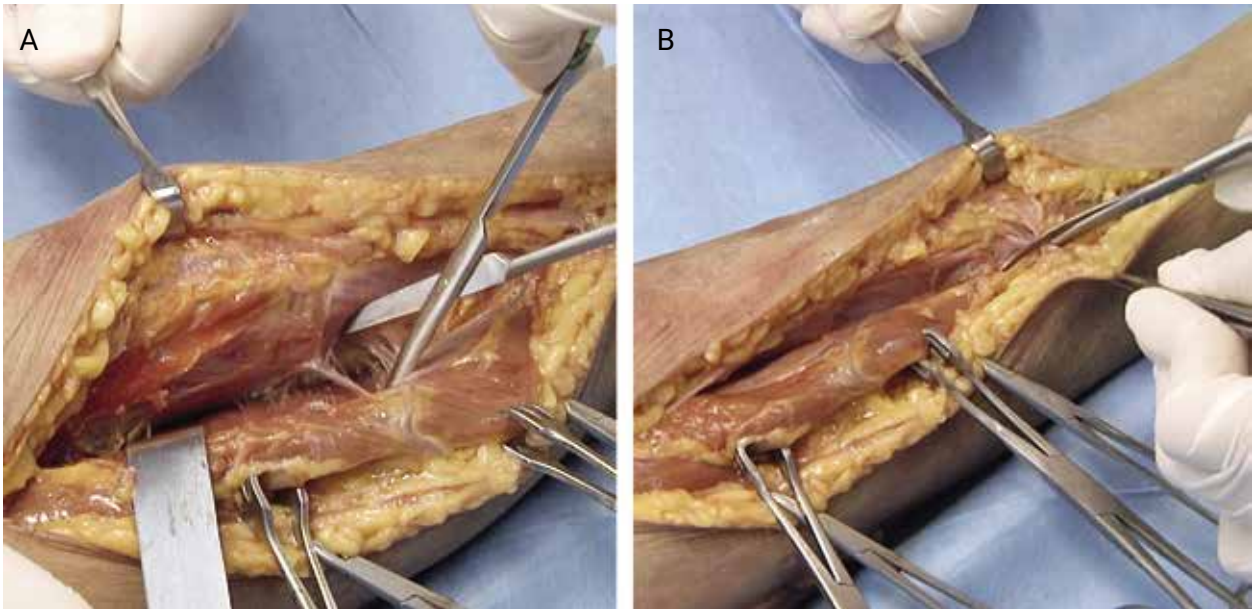


Figure 7.69. A) Muscular vessels bridging the gastrocnemius to the soleus are divided. B) Distally, subcutaneous tissue and subcutaneous vessels are divided to reach the deep fascia.



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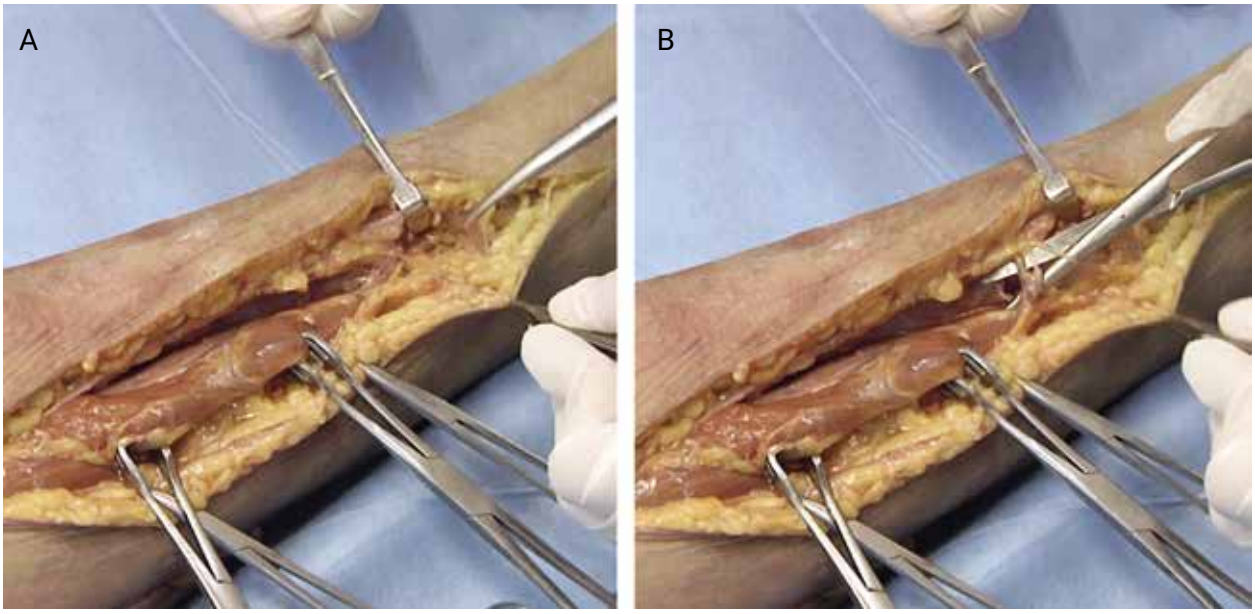


Figure 7.70. A and B) Distal fascia is carefully incised as the distal pedicle can be found nearby. Distal pedicle is not always constantly found, so great care has to be taken to preserve any vessel entering the muscle before a reliable distal pedicle is identified.

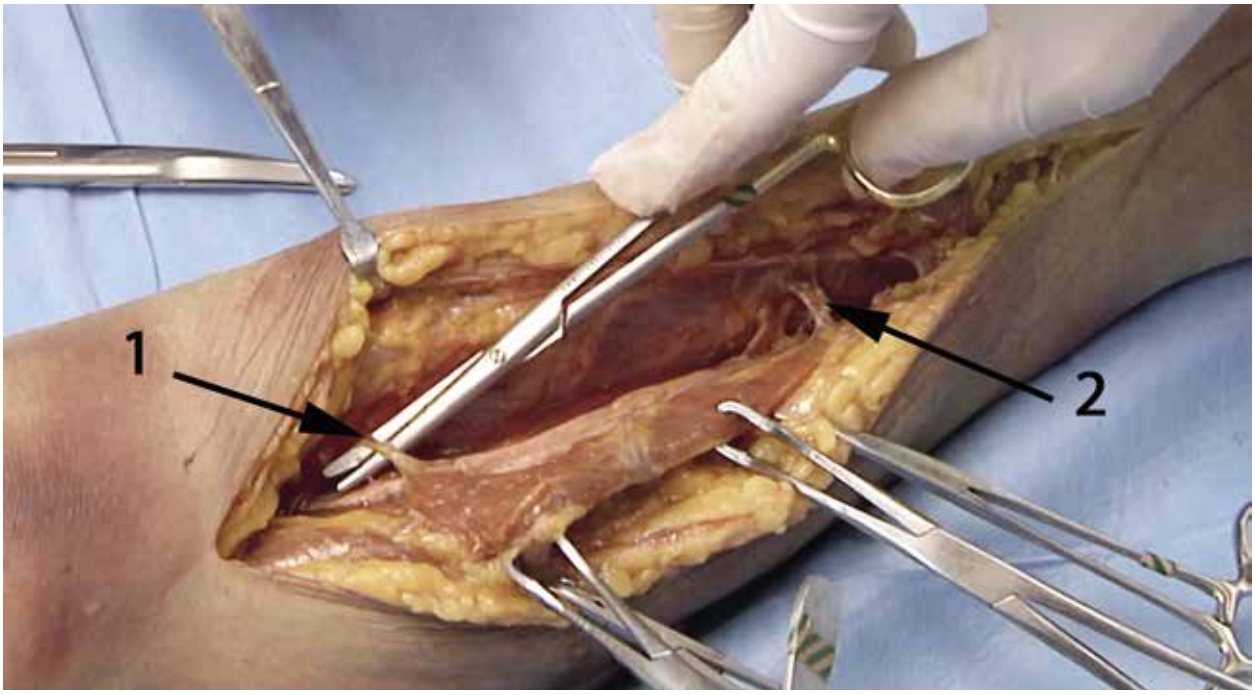


Figure 7.71. Both pedicles are isolated, proximal (1) and distal (2). Depending whether the muscle will be proximally or distally based, the distal or the proximal pedicle will be divided.

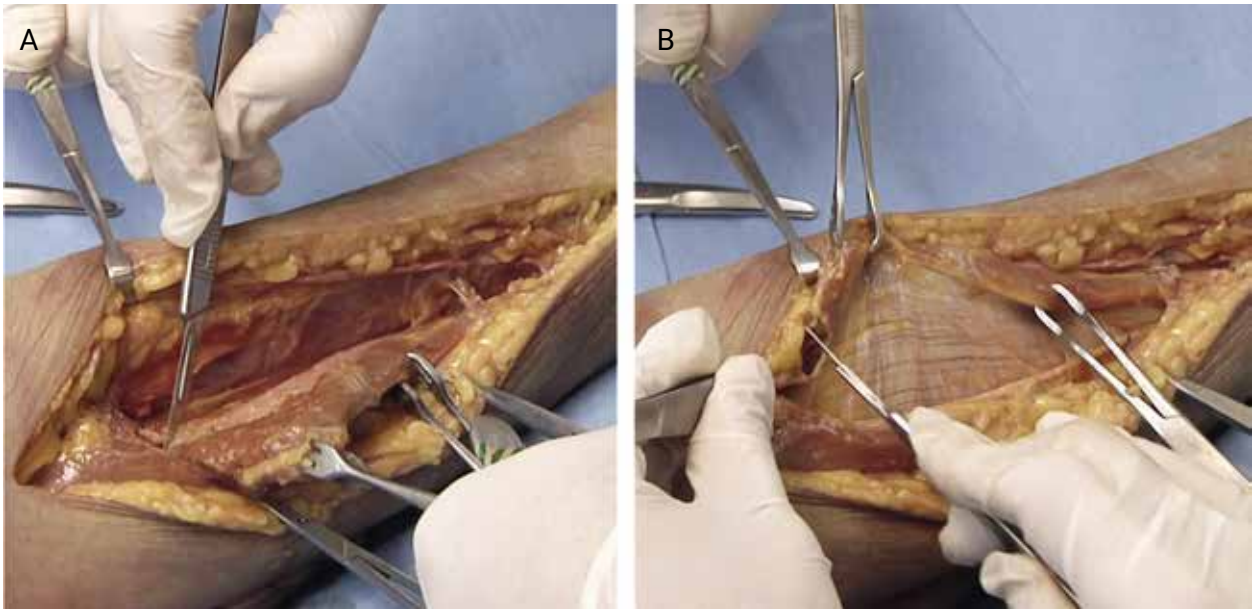


Figure 7.72. A) The proximal and deep aspect of the soleus is exposed and incised at the boundary between the medial and lateral bellies. B) The superficial aspect of the soleus is then shown and the fascia incised proximally to expose the musclle fibers.

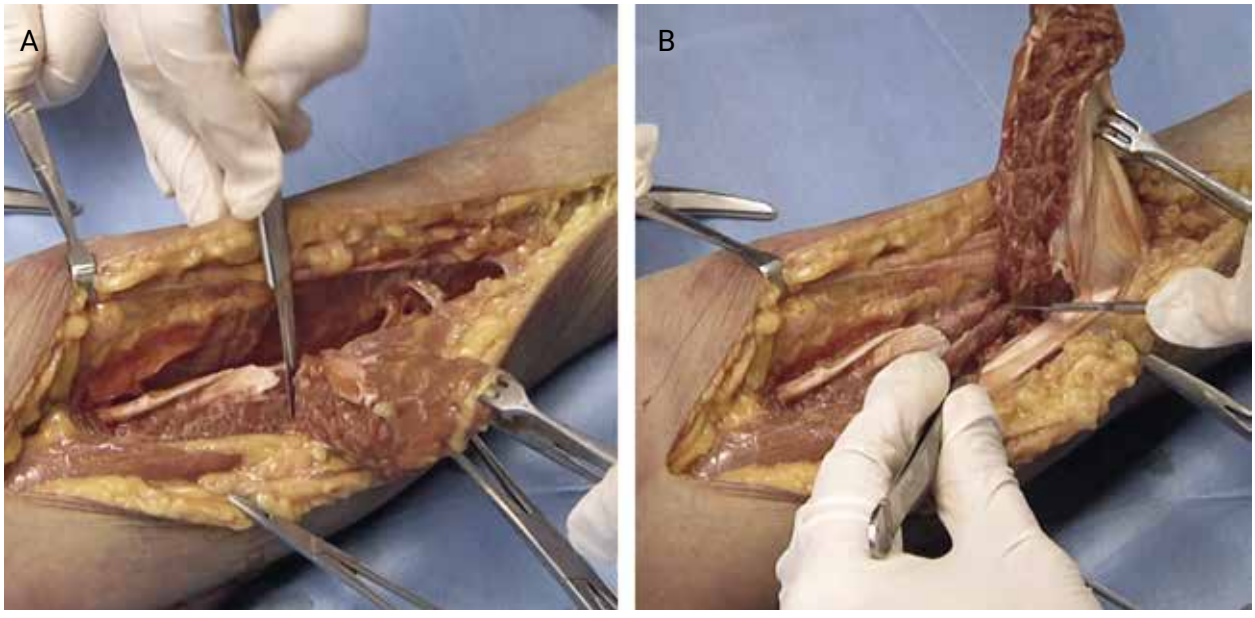


Figure 7.73. A and B) With the muscle belly exposed, its fibers are divided from proximal to distal. While transversal vessels can be divided and ligated, great care has to be taken to respect and preserve vessels running longitudinally into the muscle, especially when approaching the pedicle.

Figure 7.74. Once free, the medial soleus distally based can be rotated to give coverage to the distal third of the tibia.

If the intention is to harvest the soleus as a proximally based flap, the proximal pedicle is then preserved and the distal one divided and ligated. The soleus aponeurosis is then distally released from the gastrocnemius, separating both components of the Achilles tendon.Then the soleus component is divided.

Lateral soleus composite flap

To elevate the soleus muscle as a muscle, musculocutaneous or composite fibular-muscle flap, the cutaneous incision has to respect the vessels that vascularize the skin. These vessels emerge through the septum between the soleus and peroneus muscles at the upper third of the leg. The incision for either the osteocutaneous flap or the musculocutaneous island flap should then be outlined more posteriorly than usual, over the septum, between the lateral soleus and peroneus longus muscle.

Though the composite soleus muscle is not part of this book, an overview and some technical details about this version of the flap are discussed below. Harvesting the flap is similar to the osteocutaneous fibula flap. The vessels supplying the skin from the peroneal artery run through the septum between the posterior aspect of the peroneus brevis and longus and the anterior aspect of the lateral soleus. The particular section of septum, the fibula fragment, a portion of the lateral soleus muscle and the peroneal vessels should be preserved and harvested as a compound unit. As for the fibula flap, a generous cuff of muscle fibers should be left attached to the bone and septum to avoid accidental damage to the vessels. Great care has to be taken to safely perform the fibula osteotomy with a Gigli saw.

However, especially if the skin island is rather small, perforators should be previously localized by Doppler assistance, and precisely identified by direct visualization, before incising the entire perimeter of the skin paddle.

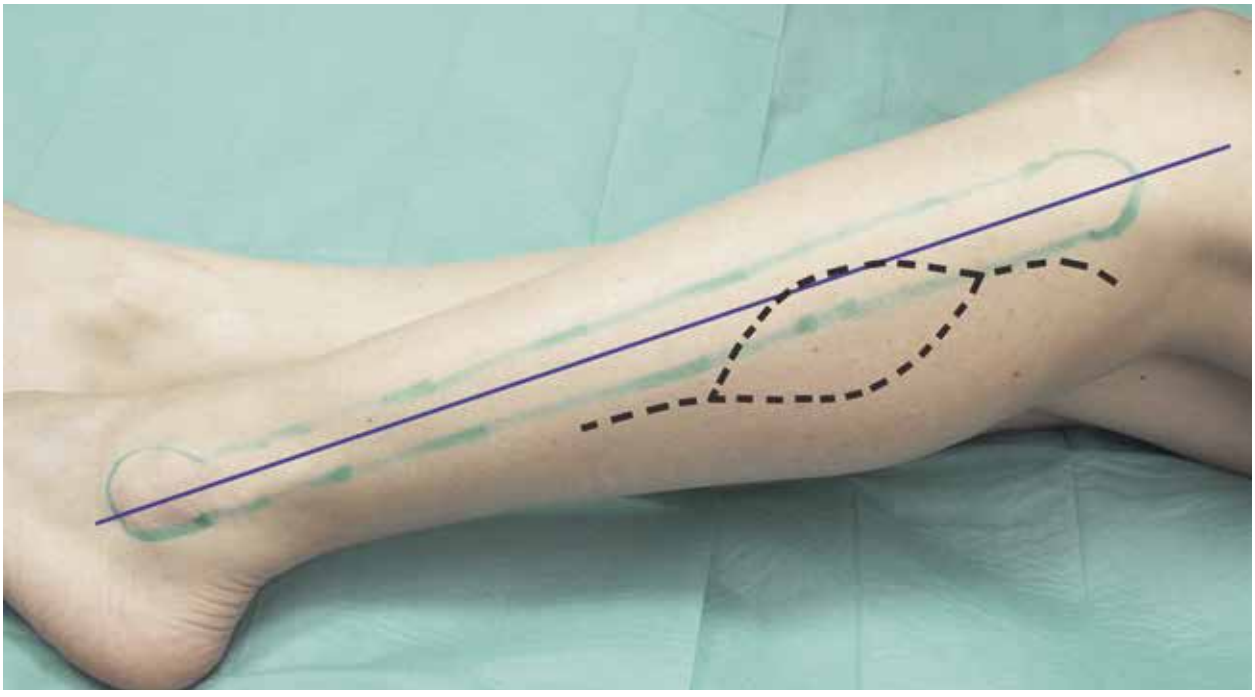
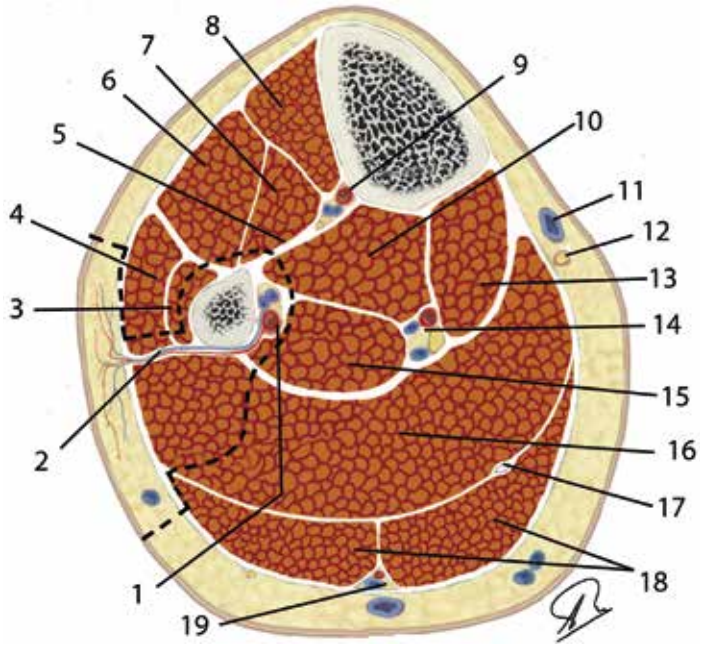
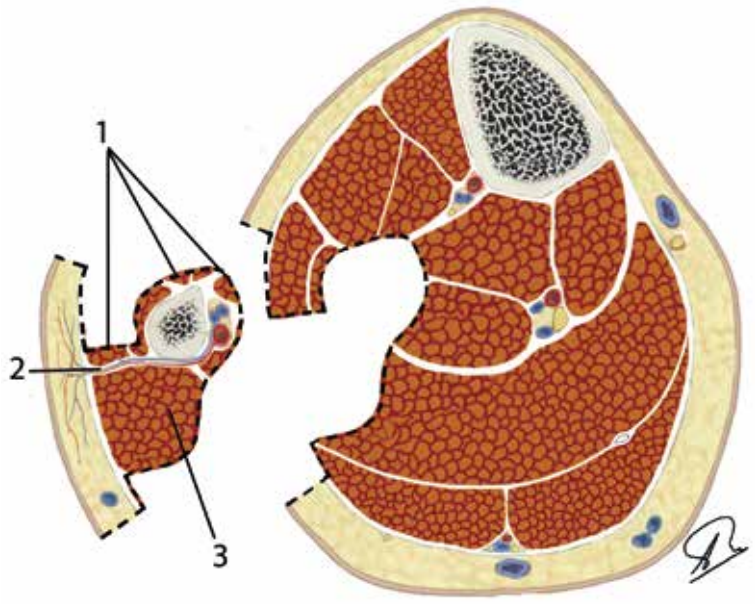


Figure 7.75. A line is traced longitudinally from the lateral malleolus along the fibula axis up to the fibula neck. The skin incision starts at the junction of the middle and distal third and continues up over the traced line, to the fibula neck, where it takes an S-shaped form towards the popliteal fossa. nce free, the medial soleus distally based can be rotated to give coverage to the distal third of the tibia.



1. Peroneal vessels
2. Septocutaneous perforators to the skin
3. Peroneus brevis (lateral compartment, LC)
4. Peroneus longus (LC)
5. Interosseous membrane
6. Extensor digitorum longus (anterior compartment, AC)
7. Extensor hallucis longus (AC)
8. Tibialis anterior (AC)
9. Anterior tibial artery, veins and nerve
10. Tibialis posterior (Deep posterior compartment, DPC)
11. Great saphenous vein
12. Saphenous nerve
13. Flexor digitorum longus (DPC)
14. Posterior tibial artery, nerve and veins
15. Flexor hallucis longus (DPC)
16. Soleus muscle (Superficial posterior compartment, SPC)
17. Plantaris muscle tendon
18. Medial gastrocnemius (SPC)
19. Sural nerve, vein and artery

Figure 7.76. Anatomical references of the composite lateral soleus flap



1. Safety muscular cuff around the bone and pedicle
2. Septocutaneous pedicle
3. Lateral portion of the lateral soleus belly included into the flap.

Figure 7.77. Composite soleus muscle (osteocutaneous muscular) flap

After care management: The patient has to remain in bed for approximately 10 days under strict supervision in case of microvascular transfer (vasodilation and/or anti-thrombotic drugs).

As with all perforator flaps,but especially when a muscle or musculocutaneous flap has been harvested, the recipient site has to be immobilized and protected by a posterior splint for at least 2 or 3 weeks. This has to be kept under control to avoid local compression to the flap or the pedicle. The leg has to be kept elevated to facilitate venous drainage and physiotherapy is used to prevent edema and joint stiffness.

In the case of composite flaps transferring a fragment of fibula, a circumferential cast will replace the splint and has to be maintained until consolidation of the bone fragment has been confirmed (it may take 1 year).

When the flap only includes the muscle belly, it can be skin grafted at the same time or postponed for a few days, to check if the entire muscle is viable and safe, or superficial or deep muscle necrosis have occurred.

Transferring the entire muscle or one of its bellies, as happens when using the gastrocnemius flap, will leave a visible scar on the lateral aspect of the calf and will also leave a moderate contour deformity and asymmetry when compared with the other leg.