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How to get the most out of your gastrocnemius and soleus flaps

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Summary: Gastrocnemius and soleus flaps represent the workhorse local flaps to cover soft tissue defects of the proximal 1/3 and middle 1/3 of the leg, respectively. An important consideration before conducting a local flap is whether the flap can provide adequate coverage. The utility of the gastrocnemius flap can be increased using multiple techniques to increase the arc of rotation including the posterior midline approach, dissection at the pes anserinus and medial femoral condyle origin, scoring the fascia, and inclusion of a skin paddle. Concerning the soleus flap, the hemisoleus flap represents a technique to increase the arc of rotation. With a soleus flap, one must consider the soft tissue defect location, size, and perforator blood supply because these factors influence what soleus flap technique to use. This article discusses how to make the most out of gastrocnemius flaps and soleus flaps regarding maximizing coverage and ensuring successful flap outcome.

Keywords: soft tissue, gastrocnemius, soleus

1. Introduction

Gastrocnemius and soleus flaps represent essential orthopaedic procedures to cover soft tissue defects of the proximal 1/3 and middle 1/3 of the leg, respectively.[1] Soft tissue defects in these areas may arise in setting of trauma, tumors, infections, or extensor mechanism discontinuity.[2] The medial gastrocnemius head, lateral gastrocnemius head, or both combined can be used as gastrocnemius flaps with the medial gastrocnemius flap offering more extensive coverage compared with the lateral gastrocnemius flap individually. The soleus flap can either be proximally based or distally based and transposed either completely or as a hemisoleus flap. Advantages of these local flaps include great reliability, easy harvesting, and an ability to fill dead space.[2,3] Disadvantages include inadequate coverage for large defects, potential loose suture tension between muscle and skin, and different cosmetic and functional properties than native skin.[2,4] This article will discuss how to make the most out of gastrocnemius flaps and soleus flaps regarding maximizing coverage and ensuring successful flap outcome.

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2. Gastrocnemius Flap

An important consideration for addressing soft tissue defects is whether the flap will provide adequate coverage. The gastrocnemius flap has been described as the workhorse for soft tissue defects around the knee being cited as reaching defects up to 15 cm away.[2] Of the 2 gastrocnemius muscle bellies, the medial gastrocnemius is the most common flap used because it is larger, extends more distally, and thus can provide more soft tissue coverage.[2] However, the potential area of soft tissue coverage remains constrained by the size of the muscle and the distance it can reach. Furthermore, the spindle shape of the muscle and its distal taper limits coverage at the flap's most distal aspect. One technique to increase the coverage is to score the gastrocnemius fascia, which makes the muscle more malleable and extends its reach (Fig. 1). However, more coverage may be required. Different surgical techniques to increase medial gastrocnemius flap coverage have been described, which include the posterior midline approach, dissection at the pedicle and medial femoral condyle origin, and inclusion of a skin paddle.

2.1. Medial Approach: Dissection at the Pes Anserinus and Pedicle

With the medial approach, the extent of dissection at the pes anserinus and the medial gastrocnemius pedicle influences the flap coverage. Various techniques can be used through this approach to improve excursion of the flap, which can extend beyond the proximal pole of the patella (Fig. 2). Veber et al[5] describe the flap reach offered by 3 different dissection techniques through the medial approach, which included the standard medial approach, dividing the pes anserinus insertion, and dividing the pes anserinus insertion concomitantly with dividing the gastrocnemius medial femoral condyle origin. While the standard medial approach is highly reliable and easy to use, the authors noted that dividing the pes anserinus in isolation or with concomitant division of the gastrocnemius medial femoral condyle origin significantly increases the medial gastrocnemius flap reach.

The standard medial approach with the pes anserinus dissection increases the reach of the medial gastrocnemius flap proximally and laterally. Masquelet and Gilbert[6] first described this technique, which involves dividing all pes anserinus tendons.

While the pes anserinus is known to contribute to knee stability, functional studies do not demonstrate any loss of function in the nonathlete.[6] The utility of this surgical technique comes into play when soft tissue defects are potentially out of reach with the standard medial approach in the prepatellar and distal thigh region. Compared with the medial approach, the pes anserinus dissection significantly increased the straight proximal reach of the flap from 13.6 ± 2.76 cm to 16.5 ± 3.8 cm, along with the proximal lateral reach from 22.9 ± 2.21 cm to 26.4 ± 3.17 cm. These significant increases in flap reach were 21% and 15%, respectively. Of note, reinsertion of the pes anserinus tendons once the flap is transposed is not recommend because it poses risk of pedicle compression especially with anticipated postoperative swelling.[5]

Conducting pes anserinus dissection with concomitant medial femoral condyle origin dissection through the medial approach can further extend the medial gastrocnemius flap reach.[5] Compared with the medial approach, this technique significantly increased the straight proximal flap reach from 13.6 ± 2.76 cm to 20.3 ± 5.8 cm, the proximal lateral flap reach from 22.9 ± 2.21 cm to 31.2 ± 2.81 cm, and the straight medial flap reach from 9.6 ± 3.10 to 12.5 ± 3.27 cm. These significant increases in flap reach were 49%, 36%, and 30%, respectively. The technique involves thorough dissection from the popliteal artery until the medial sural artery's confluence with the muscle belly. In essence, the technique forms a vascular island that allows great mobilization of the flap. When considering this technique, one must understand there are anatomical variations of sural vasculature, which may restrict the flap mobilization.[7] The classic teachings describe the popliteal artery giving off the medial and lateral sural arteries at the level of the knee joint.[2] Whitney et al[7] assessed 50 limbs and discovered the medial sural artery originates on average 32.2 ± 14.5 mm above the distal femur line. However, 16 of their 50 limbs (32%) were found to possess a common sural artery, which would limit mobilization of a flap made by a pedicle dissection.

2.2. Posterior Midline Approach

Alternatively, a posterior midline approach can be used, although it is the authors' experience that the medial approach is the workhorse for this flap.[8,9] The posterior midline approach involves an incision directly between the medial and lateral gastrocnemius heads. While the medial approach is commonplace, Lamaris et al[9] advocate that the posterior midline approach offers a greater flap reach and surface area. In their study, they performed a medial gastrocnemius pedicled flap on 25 cadavers, using one leg for the medial approach and the contralateral leg for the posterior midline approach. They concluded the posterior midline approach increased muscle reach by a mean of 2.02 cm^2 ($P < 0.05$) and surface area by a mean of 20.3 cm^2 ($P < 0.05$). Of note, the width between the left and right gastrocnemius muscle in each cadaver was statistically equal, so the difference in muscle reach and surface area between the 2 approaches was due solely to the posterior midline approach.

The posterior midline approach provides greater muscle reach and surface area coverage for multiple reasons. First, the approach allows direct visualization of the vascular pedicle.[8,9] Thus, the dissection can extend safely to the popliteal fossa improving the mobilization of the gastrocnemius flap, the arc of rotation, and ultimately the amount of coverage. Second, the approach allows access to the pes anserinus insertion to a much greater extent.[8,9] This is useful because dissecting the fascial attachments around the pes anserinus, especially those deep to it, results in increased gastrocnemius mobilization. Moreover, completely dividing the pes anserinus tendons has been shown to increase the medial gastrocnemius arc of rotation.[5] Third, the approach yields better access to the gastrocnemius muscle origin at the medial femoral condyle, which can be fully divided to allow greater muscle flap reach.[5,8,9] Finally, the approach also makes the lateral gastrocnemius accessible in the scenario where both the medial and lateral gastrocnemius are desired for the flap.[9]

Arnold and Mixter[8] originally described the posterior midline approach in 1983 calling it a stocking seam incision. Like Lamaris et al, they describe their vertical incision through the popliteal fossa as providing the best exposure to the muscle, pedicle, and tendinous attachments. While the posterior midline approach offers advantages with respect to flap coverage, a surgeon may still have hesitancy to performing surgery in the popliteal fossa. However, both articles express the safety of the posterior midline approach. The fear of damage to the neurovascular structures is actually alleviated by the improved visualization. Therefore, in cases requiring extensive flap coverage that may not be otherwise covered using a medial approach, a surgeon may elect to use the posterior midline approach.

2.3. Using a Myocutaneous Flap

Incorporating a skin paddle to form a gastrocnemius myocutaneous flap represents a strategy to increase flap coverage. The gastrocnemius myocutaneous flap was first described in the 1970s and harvests overlying skin with the gastrocnemius muscle.[10,11] The gastrocnemius myocutaneous flap increases coverage because the skin paddle can be harvested up to 5 cm distal to the distal end of the muscle, as perforator vessels from the muscle supply this skin.[11] This extra 5 cm of flap can then be subsequently used to increase flap reach. Mayoly et al and Agarwal et al both describe reaching soft tissue defects in the distal 1/3 thigh using gastrocnemius myocutaneous flaps that would otherwise not be reached.[4,12] The myocutaneous flap combines the advantages of muscle flaps and fasciocutaneous flaps to obtain soft coverage because it is surgically easy and reliably successful, while also replacing skin with skin to closely restore native cosmetics and mechanical properties.[4,13] Furthermore, the myocutaneous flap adds other unique advantages. First, the skin paddle removes the need for a split skin graft at the defect site in most cases. In fact, if a split skin graft is required, it is usually for the donor site and not the soft tissue defect site.[4] Second, the skin paddle offers direct and tight cutaneous suturing for closure at the soft tissue defect site.[4] This is noteworthy because tight suture is sometimes difficult to obtain with a standard gastrocnemius flap and can predispose to inset failure. Finally, the cutaneous nature makes the flap more resistant to potential future surgeries.[4] Owing to the increased flap coverage and added benefits of the gastrocnemius myocutaneous flap, Mayoly et al claim this technique deserves consideration as first-line treatment for soft tissue defects about the knee.

2.4. Soleus Flaps

The soleus flap represents the local flap workhorse for soft tissue defects in the middle 1/3 of the leg with also having utility in covering the distal 1/3 of the leg.[1,14–16] Multiple techniques have been described for the soleus flap, which include a proximally based flap, a distally based flap (reverse flap), and then determining whether to transpose the entire soleus muscle or only half of it as a hemisoleus flap.[17,18] When considering the extent of

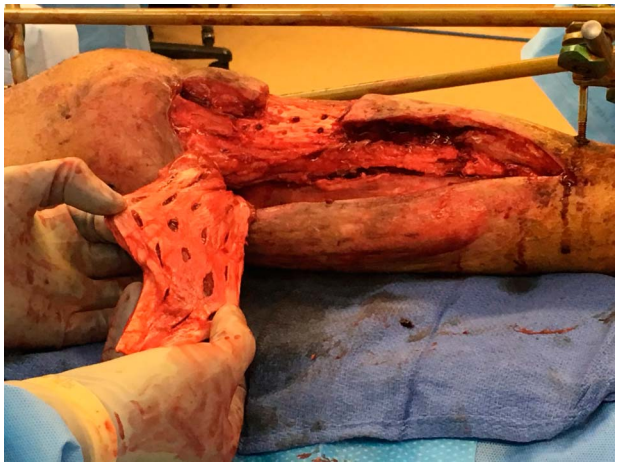

Figure 1. Intraoperative photograph of medial gastrocnemius flap to cover soft tissue wound. The flap is scored longitudinally to improve width-wise coverage of the flap. Alternatively, scoring width-wise can improve length excursion of the flap.

flap coverage for a soleus flap, one needs to understand 2 concepts. First, one must balance the arc of rotation with the preservation of perforator arteries. Second, one must recognize the exact location and size of the defect on the lower extremity. Unlike the gastrocnemius which receives perfusion from one dominant pedicle, the soleus receives blood from both a proximal dominant pedicle and distal minor pedicles.[19] Preserving this blood supply as much as possible ensures the success of the flap.[17] Therefore, one must strategically use different soleus flap techniques to cover defects of different locations, while also keeping the preservation of the blood supply in mind.

2.5. Proximally Based Medial Hemisoleus Flap

To cover a soft tissue defect in the middle 1/3 to the proximal aspect of the distal 1/3 of the leg, one can use a proximally based medial hemisoleus flap.[17] In general, hemisoleus flaps offer a greater arc of rotation compared with conventional soleus flaps.[18] Moreover, a proximally based flap possesses a greater arc of rotation than a distally based flap.[17] It is possible to split the soleus along its raphe because of the medial and lateral muscle bellies having different blood supplies and innervations.[18] With half of the soleus muscle released, one can gain greater flap reach because it is no longer tethered by the neurovascular structures of its other half. The medial hemisoleus flap can also be oriented more obliquely and longitudinally because its pivot point on its pedicle lies closer to the tibia, which ultimately allows greater flap reach.[3] When elevating a proximally based hemisoleus flap, a surgeon must prioritize preserving the distal minor pedicles as they are critical blood supply to the distal soleus. This elevation proceeds meticulously until an adequate arc of rotation is obtained to cover the defect.[17]

2.6. Distally Based Medial Hemisoleus Flap

To cover a soft tissue defect in the distal 1/3 of the leg, one can use a distally based medial hemisoleus flap.[17,20] Unlike the proximally based flap that relies on the dominant pedicle, the distally based medial hemisoleus flap relies on the multiple minor perforators from the posterior tibial artery.[20] Again, elevation proceeds meticulously until an adequate arc of rotation is obtained to cover the defect. This blood supply is very tenuous, yet greatly determines the success of the flap.[20] Therefore, many authors advocate for the use of a preoperative duplex Doppler scan or CT angiogram to locate the perforators.[17,20] Houdek et al advocate that the distal perforators need to have a $\geq$ 1 mm diameter and the veins $\geq$ 1.5 mm diameter either on CT angiogram or intraoperatively. If the vessels do not meet these criteria, then the medial hemisoleus flap is aborted for a free tissue transfer instead.[21] Furthermore, Song and Pu[17] state the distally based flap should not be used in smokers. These studies all emphasize the importance of maintaining the blood supply in a distally based medial hemisoleus flap. Distal tip necrosis from ischemia may ensue after this flap. However, it is usually clinically

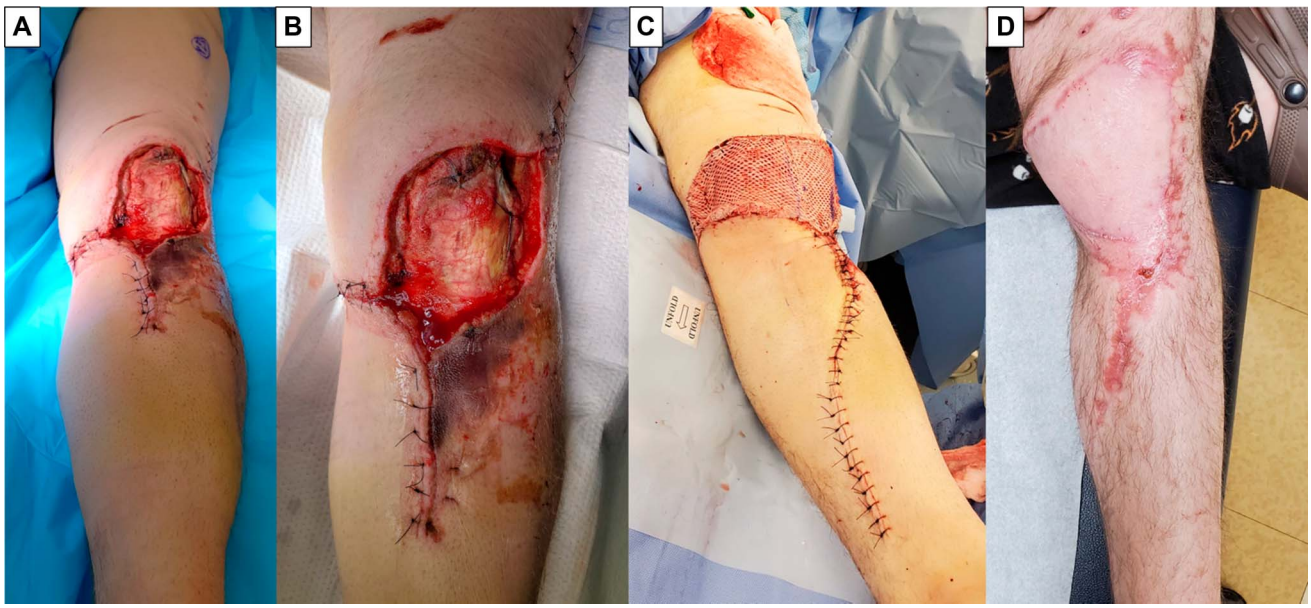

Figure 2. A, B, Traumatic injury to left knee with extensor mechanism disruption. C, The medial gastrocnemius was released to the level of its origin and rotated to cover entire defect, which extended proximal to the patella and laterally. D, This led to a satisfactory outcome.

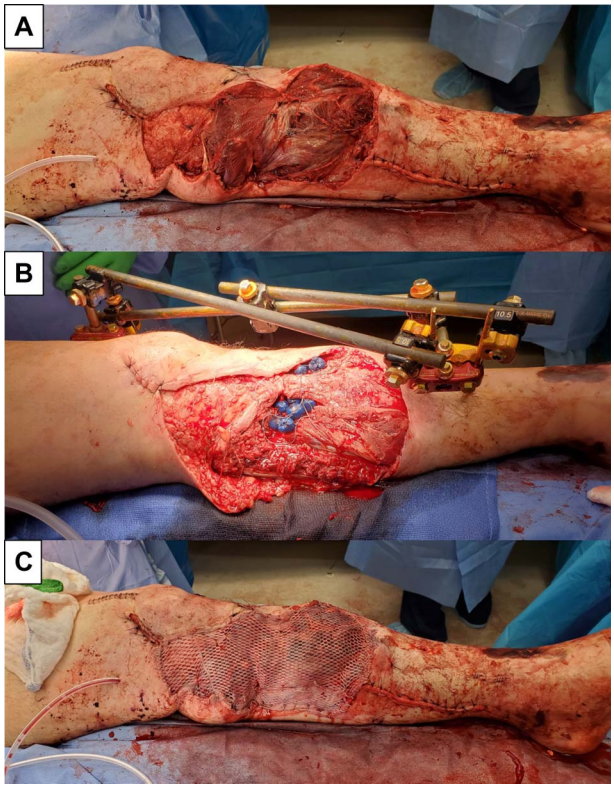

Figure 3. A, Traumatic defect of the medial tibia in the proximal and middle third of the tibia after an auger injury. B, Both the gastrocnemius and soleus flaps are rotated and C, skin grafted. Please note that the muscle was partially damaged from the trauma but can still be rotated if viable.

insignificant and can be treated with debridement and flap advancement.

2.7. Addressing Defect Size

The medial hemisoleus flap can cover soft tissue defects that are <50 cm^2. Pu et al proposed a treatment algorithm where defects <50 cm^2 were considered for a local soleus flap, whereas defects larger than >50 cm^2 were deemed too large and considered for free tissue transfer.[16] However, larger sizes of defects have been served through the soleus flap.

Unlike the gastrocnemius flap, which one can score the fascia both transversely and longitudinally to increase the arc of rotation and the surface area coverage, the soleus is not as robust in this regard.[22] Alternatively, the soleus flap can be combined with other local flaps to cover larger defects. For instance, in the case of large middle 1/3 leg defect when the patient is a poor free flap candidate and needs rapid coverage, a combination of a medial gastrocnemius and medial hemisoleus flap can be used. Song and Pu[17] describe a case where they successfully cover an extensive 13 cm $\times$ 4 cm midtibial wound with this strategy. The medial gastrocnemius flap covers the proximal portion of the wound, while the medial hemisoleus flap covers the distal portion (Fig. 3). The advantages of this local flap combination over free tissue transfer include avoiding a prolonged microsurgery, relatively easy postoperative monitoring, and a cheaper cost. However, using the soleus and the gastrocnemius flaps requires that each muscle is free from injury, which may not be the case in an extensive traumatic injury involving the entire middle 1/3 of the leg. For any flap, the muscle needs to be viable and free from damage. The muscle health can often be assessed at the initial irrigation and debridement with taking note of the muscle's color, consistency, contractility, and capacity to bleed.

When using multiple local flaps, the donor site morbidity requires consideration.[17] The medial hemisoleus flap in isolation has limited donor site morbidity because plantarflexion strength is maintained, especially in the case of a proximally based medial hemisoleus flap where the divided medial tendon is sutured to the intact lateral soleus muscle.[14,22,23] The literature also supports that the combination of the medial gastrocnemius flap and soleus flap does not result in donor site morbidity. Ong, et al demonstrated that all 10 of their patients achieved full weight-bearing and function as they could all perform activities of daily living, ambulate independently, and climb stairs.[24] Pu, et al presented similar results with all 4 of their patients developing no donor site functional deficit.[25] While no objective research exists, the authors postulate that donor site morbidity does not occur because only half of each muscle is sacrificed. This allows the preserved half to adapt over time and function at a high level.[25] An animal study in rats demonstrated hypertrophy of the remaining synergistic muscles after the medial gastrocnemius was sacrificed.[26] Nonetheless, surgeons should justify the benefits of performing a flap over the potential donor site morbidity and other potential complications.

3. Conclusion

The gastrocnemius and soleus flaps represent surgeries that traditionally cover soft defects about the proximal 1/3 and middle 1/3 of the leg, respectively. This article presents techniques to maximize coverage and make the most out of these flaps without compromise. Dividing the pes anserinus, releasing the medial femoral condyle origin, incorporating a skin paddle, scoring the fascia, and potentially a midline incision are all safe ways to increase the coverage of soft tissue defects about proximal 1/3 leg, the knee, and even the distal 1/3 thigh. Using the hemisoleus flap with a proximally based technique, a distally based technique, or in combination with other local flaps demonstrate safe ways to cover soft tissue defects in the middle 1/3 leg. The arc of rotation for a soleus flap needs to be balanced with the preservation of the blood supply. With these techniques, a surgeon stands prepared to safely address soft tissue defects that require more coverage.

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