Effect of medial hemisoleus muscle flap on wound healing in the medial and distal thirds of the lower leg

ABSTRACT

Introduction: The use of many flaps has been described to repair substance loss in the medial and distal thirds of the lower leg. The main advantage of the muscle medial hemisoleus flap is preserving one half of the innervated medial soleus muscle in situ and keeping the foot’s plantar flexion power. Moreover, the flap has a longer arc of rotation. As recently described, new vascular concepts and techniques have increased flap viability. This study aimed to examine the use and advantages of the medial hemisoleus flap with emphasis on an indication and complication analysis. Methods: Over a 10-year period, nine medial hemisoleus flaps were executed to repair traumatic wounds with tibial exposure in eight patients. We describe the indications and surgical techniques in detail. Results: Complete wound healing was achieved in all patients. There was a low donor-site complications rate. One patient suffered from partial necrosis of the extremity flap. The mean operative time was 2 h. Conclusions: The medial hemisoleus flap is useful for repairing substance loss and provides coverage with intermediary thickened tissue, high vascularity, minimal donor-site morbidity, foot plantar flexion power preservation, faster rehabilitation, accessible surgical techniques, and a shorter operative time.

Keywords: Reconstructive surgical procedures; Lower extremity; Muscle, skeletal; Surgical flaps.
When local muscle flaps are carefully indicated and implemented, they can provide rich vasculature coverage and intermediate thickness. The main muscles used for medial- and distal-third reconstruction include the flexor digitorum longus, tibialis posterior, flexor hallucis longus, peroneus brevis, peroneus longus, extensor digitorum longus, extensor hallucis longus, reverse tibialis anterior, and soleus. Limitations and probable contraindications include patients with severe muscle and vascular-associated traumas and the presence of peripheral vascular disease.

Soleus flaps were first described by Magee et al. in 1980. In 1985, Tobin systematized and correlated the morphology of the soleus muscle with the vascular pattern of its pedicles and intramuscular and extramuscular branches, allowing the creation of a large pediculated flap made with the longitudinal half of the hemisoleus flap. This flap can be constructed using the medial or lateral belly of the soleus muscle using direct or reverse blood flow.

Therefore, four flaps are possible: medial hemisoleus pediculated proximally, medial hemisoleus pediculated distally (or reverse), lateral hemisoleus pediculated proximally, and lateral hemisoleus...
pediculated distally (or reverse)\textsuperscript{13}. The main advantage of these flaps is the preservation of the innervation of the half of the soleus muscle that remains in the donor site, which maintains the plantar flexion force. In addition, the hemisoleus flap has a larger rotational arc than the conventional soleus flap\textsuperscript{13}-\textsuperscript{15}.

In 2005 and 2008, Pu described surgical refinement techniques establishing parameters and increasing reliability for medial hemisoleus flaps\textsuperscript{6,16}. More recently, the association of the technique with angiosome principles (three-dimensional tissue blocks whose irrigation is provided by a branch of a specific deep stem artery)\textsuperscript{17} described by Taylor & Palmer (1987)\textsuperscript{17} the design of the flap and the need for careful dissection with the benefit of obtaining a thinner flap with lower donor-site morbidity rates, especially for reverse flow flaps\textsuperscript{1,9,18}.

The medial hemisoleus flap is the most frequently used because of its proximity to the defects that occur more frequently in the three-quarter proximal tibia and because it presents a greater rotation arc than the lateral hemisoleus flap\textsuperscript{1,6,13}.

**OBJECTIVE**

This study aimed to report the use of the medial hemisoleus flap proximal (direct flow) or distal (reverse flow) (Figure 1), emphasize its advantages, confirm its indications, and analyze the complications of this procedure as an alternative in the surgical arsenal to repair substance losses of the medial and distal thirds of the leg.

**METHODS**

Over a 10-year period, a total of nine medial hemisoleus flaps were created in eight patients (six men, two woman) to repair substance losses of traumatic etiology with tibial exposure. The surgeries were performed at the Ibiapaba Cebams Hospital of Barbacena - MG. The Medical Ethics Committee of Ibiapaba Cebams Hospital analyzed and approved this study (protocol number 001/2018).

The inclusion criteria were as follows:

1. Presence of a wound with exposed bone or osteosynthesis material in the medial or distal third of the leg comprising an area < 50 cm\textsuperscript{2}.
2. Stabilization of the fracture when present.
3. Lack of peripheral vascular disease or other conditions that could compromise the vascular pattern of the soleus muscle, such as diabetes, smoking, paraplegia, or previous history of vascular obstruction of the lower limb.
4. Lack of trauma evidence of compromise of the medial muscle belly of the soleus.
5. Treatment of established infectious condition with debridement, dressings, and systemic antibiotic therapy before the procedure.

The soleus muscle has a characteristic bipeniform morphological pattern (98.8\% of cases) in which the medial and lateral belly present independent neurovascular supplies and are longitudinally separated at the medial line. The medial belly originates in the proximal tibia and inserts into the dorsomedial aspect of the calcaneal tendon, while the lateral belly originates in the proximal fibula and inserts into the dorsolateral side of the calcaneal tendon. In the distal half, the medial and lateral bellies of the muscle are separated longitudinally by an intramuscular septum; in the proximal half, these same bellies are fused\textsuperscript{19}.

The vascularization is type II Mathes & Nahai\textsuperscript{19}. There are two proximal dominant pedicles: the tibialis posterior branch that nourishes the medial belly through segmental branches and the fibular branch that nourishes the lateral belly through proximally segmental branches and distally axial segmental branches\textsuperscript{6,6}. A distal perforating branch of the tibialis posterior artery near the medial malleolus also nourishes the distal portion of the medial belly and forms the base of the medial reverse hemisoleus flap\textsuperscript{6}.

The medial and lateral bellies of the soleus muscle are independently innervated.

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The medial branch of the medial (superficial) popliteal nerve and the medial branch of the tibialis posterior nerve (motor) innervate the medial belly of the soleus, whereas the lateral belly of the soleus is innervated by the lateral branches of the medial popliteal and posterior tibial nerves\textsuperscript{13}.
Surgical technique

A longitudinal cutaneous incision is made on the medial side of the leg parallel to the medial border of the tibia. The existence of external orthopedic fixators should be considered an inherent part of this surgical procedure, since they are present in most cases (Figure 2). The skin is carefully retracted and allows opening and exposure of the subcutaneous and fascial planes. Whenever possible, superficial nerves (sural, saphenous) and vessels (saphenous vein) should be preserved. The gastrocnemius muscle is separated from the medial portion of the soleus muscle by blunt dissection, the deep fascia is opened, and the soleus border is detached from the tibia with the scalpel. The major and secondary vascular pedicles are identified. Careful dissection of the pedicles enables a larger arc of rotation and, consequently, greater flap reach.

In the preparation of the proximal pedicle medial hemisoleus flap, the main pedicle (proximal) is maintained and the secondary pedicles are sectioned (Figure 3). The medial hemisoleus is then disinserted from the calcaneal tendon using a scalpel or other acute cutting instrument featuring lower trauma such as those described by Pu, and the separation of the medial and lateral bellies of the muscles is guided by the intramuscular septum (Figure 4).

In the preparation of the reverse medial hemisoleus flap, the main pedicle is maintained (distal perforating branch of the posterior tibial artery) and the proximal main pedicle and other secondary pedicles are sectioned. According to the angiosome principle, the flap will be sectioned 2–3 cm proximal to the connected secondary pedicle since the next pedicle must be the distal perforating branch of the posterior distal artery. Separation of the medial and lateral muscle bellies is also performed under intramuscular septum guidance (Figure 5).

The flap is then rotated under a previously made fasciocutaneous tunnel (Figures 6 and 7) and the area of the defect is fixed with a 4.0 absorbable suture. The fasciocutaneous tunnel cannot overcompress the flap. In this case, a transverse fasciotomy can be performed in the tunnel and even the communication of the access area to the flap with the surgical wound.

Once fixed in place, the flap is covered with a thin partial-thickness skin graft (Figure 8). The donor area of the flap does not require a cutaneous graft and receives a primary suture of the deep fascia and the subcutaneous tissue with polyglecaprone 4.0 strands. The skin suture is made using 4.0 nylon thread (Figure 9). Suction drains are used and the non-compressive dressing generally dispenses with immobilization by a gypsum chute due to the presence of the external fasteners.
In the postoperative period, it is important that the patient remains in bed with the operated limb elevated for 4–5 days to reduce edema and venous congestion.

RESULTS

In this series of eight patients (six men [75%] and two women [25%]), nine hemisoleus flaps were made (Table 1). One of the patients (Table 1: APO) had exposed fractures of the bilateral tibiae and underwent bilateral repair with medial hemisoleus flaps at different times. In three patients, a medial reverse hemisoleus flap was used (Figures 10A, B, and C) to repair substance losses in the lower distal third of the leg caused by burns and exposed tibial fractures. The remaining six cases were treated with proximally pediculated hemisoleus flaps (Figures 11, 12, and 13) for repair of wounds with mid-tibial bone exposure caused by automobile accidents and burns. The mean age was 40.5 years (range, 20–68 years). Seven patients (77.7%) underwent surgery after fracture stabilization with external fixators and had palpable and normal pulses.

Two patients (22.2%) previously underwent rotation of other flaps with unsatisfactory results.
Table 1. Results.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Injury location</th>
<th>Injury cause</th>
<th>Pretreatment</th>
<th>Medial hemisoleus flap</th>
<th>Flap complication or skin grafting</th>
<th>Fracture complications</th>
<th>Follow-up time</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCO</td>
<td>20</td>
<td>Male</td>
<td>Open fracture, medial 1/3 of the left tibia</td>
<td>Automobile accident</td>
<td>Fasciocutaneous reverse calf flap</td>
<td>Proximal pedicle</td>
<td>-</td>
<td>-</td>
<td>30 months</td>
</tr>
<tr>
<td>LMF</td>
<td>27</td>
<td>Male</td>
<td>Open fracture, medial 1/3 of the left tibia</td>
<td>Automobile accident</td>
<td>“Cross-leg” and fracture fixation</td>
<td>Proximal pedicle</td>
<td>-</td>
<td>Pseudo-arthrosis</td>
<td>27 months</td>
</tr>
<tr>
<td>APO</td>
<td>30</td>
<td>Male</td>
<td>Open fracture, medial 1/3 of the right tibia</td>
<td>Automobile accident</td>
<td>Fracture fixation, thoracotomy, and laparotomy</td>
<td>Proximal pedicle</td>
<td>Donor-site hematoma</td>
<td>-</td>
<td>22 months</td>
</tr>
<tr>
<td>APO</td>
<td>30</td>
<td>Male</td>
<td>Open fracture, medial 1/3 of the left tibia</td>
<td>Automobile accident</td>
<td>Hemisoleus medial right flap</td>
<td>Proximal pedicle</td>
<td>-</td>
<td>-</td>
<td>22 months</td>
</tr>
<tr>
<td>GMS</td>
<td>41</td>
<td>Male</td>
<td>Medial malleolus right exposure</td>
<td>Overheated metal burn</td>
<td>Debridement and dressings</td>
<td>Reverse</td>
<td>-</td>
<td>-</td>
<td>4 months</td>
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<tr>
<td>OMS</td>
<td>54</td>
<td>Male</td>
<td>Open fracture, distal 1/3 of the left tibia</td>
<td>Home accident (fall)</td>
<td>Fracture fixation</td>
<td>Reverse</td>
<td>Partial flap loss</td>
<td>-</td>
<td>18 months</td>
</tr>
<tr>
<td>MEF</td>
<td>68</td>
<td>Female</td>
<td>Open fracture, distal 1/3 of the right tibia</td>
<td>Home accident (fall)</td>
<td>Fracture fixation</td>
<td>Reverse</td>
<td>Partial skin graft loss</td>
<td>Chronic osteomyelitis</td>
<td>12 months</td>
</tr>
<tr>
<td>JASB</td>
<td>32</td>
<td>Male</td>
<td>Open fracture, medial 1/3 of the left tibia</td>
<td>Automobile accident</td>
<td>Fracture fixation</td>
<td>Proximal pedicle</td>
<td>Partial skin graft loss</td>
<td>-</td>
<td>6 months</td>
</tr>
<tr>
<td>MLRD</td>
<td>63</td>
<td>Female</td>
<td>Open fracture, medial 1/3 of the right tibia</td>
<td>Electrical burn</td>
<td>Debridement and dressings</td>
<td>Proximal pedicle</td>
<td>Partial skin graft loss</td>
<td>-</td>
<td>5 months</td>
</tr>
</tbody>
</table>

The first one developed complete necrosis of the fasciocutaneous reverse flap of the calf caused by the large wound extension and prolonged bone exposure (chronic osteomyelitis). The other patient did not tolerate the immobilization in the postoperative period of a “cross leg.”

One of the patients (11.1%) presented bleeding in the donor area of the flap on the 10th postoperative day caused by disruption of the sectioned distal pedicle that was treated with immediate drainage and there was no compromise of the flap vascularization.

Partial necrosis of the medial reverse hemisoleus flap occurred in one patient (11.1%); the probable causes are related to the presence of local infection, severe venous congestion in the postoperative period, compression by the fasciocutaneous tunnel, and advanced patient age. In this case, the sequential therapy was conservative (debridement, treatment of osteomyelitis and assisted dressings under vacuum) and wound healing was achieved.

Partial-thickness skin grafts were performed at the same surgical time in eight of the nine cases; in three patients (33.3%), there were insignificant losses of skin graft integration without the need for additional surgical procedures (Figure 11B).

The mean surgical time was 2 hours, while the hospital stay after the flap production was 4–28 days (mean, 17.7 days). All patients achieved complete wound healing. In the postoperative follow-up period, three patients required orthopedic surgical treatment with
The minimum postoperative follow-up was 4 months and the mean follow-up time was 16.2 months.

**DISCUSSION**

Therapeutic options for repairing complex wounds of the medial and distal thirds of the leg cannot yet be considered consensual. Several flaps have been described; however, the muscular flaps, particularly the hemisoleus flap, require intermediate procedures between the fasciocutaneous flaps and transfer free flaps.

All patients in the series underwent medial hemisoleus flap transfer based on the favorable location of the wound, and the main feature of this flap is maintaining plantar flexion at the ankle joint. The soleus muscle is responsible, together with the gastrocnemius muscle, for stabilizing the leg over the foot, that is, for maintaining posture and preventing the body from falling forward when in the upright position.21
Preservation of the lateral belly of the soleus at the donor area reduces the use of compensatory mechanisms that arise when the soleus is fully rotated: short step, reduced ability to tilt the body forward, and precocious contralateral calcaneus wound.

Associated with this precious advantage, hemisoleus flaps are interesting because they promote low morbidity in the donor bed with the need for skin grafts in these areas. This was confirmed in the series of patients in this study, in which all donor areas were closed primarily without epidermolysis or necrosis. Only one patient had late complications (bleeding) in the donor area and no impairment of the final healing result in the flap donor and recipient areas.

The concept that covering wounds with a rich vascular supply is important in cases of bone exposure favoring fracture consolidation is widely advocated by adherents of muscle flaps. However, controversy persists regarding the true beneficial potential of the rich vascularization of muscle flaps in primary fracture consolidation, which seems to have been suggested in this series in which three patients (37.5%) still required orthopedic surgical complements for fracture healing.

The mean surgical time did not exceed the 2 hours, a fact that has a direct positive impact on technical execution, treatment cost, and postoperative morbidity rate.

The importance of microsurgical transfer free flaps is based on the potential of promoting coverage in a single procedure with tissue considered healthy and not associated with trauma. It combines the development of vascular techniques, surgical microscopes, delicate instruments, microsurgical threads, and differentiated surgical strategies that, in most cases, are the major limiting factors of this therapy. In this context, the hemisoleus flap can be very useful in the treatment of substance losses of the medial and lower leg when the
compromised area is <50 cm². Conventional soleus muscle flaps may cover a mean area of 26 cm² according to Hughes et al., who performed numerical studies on cadavers comparing the arcs of rotation of different muscle flaps of the leg.

Pu and Dumanian stated that wounds up to 50 cm² can be safely repaired with medial hemisoleus flaps, reporting a significant gain in extent for this flap. Detailed knowledge of the morphological and neurovascular anatomy of the soleus muscle is obviously the initial condition for performing this procedure. For this purpose, previous dissections in cadavers can be very enlightening and illustrative. The technical refinements described by Pu involve the delicacy of the surgical approach to the muscle, dissection of the main pedicles with the purpose of lengthening the rotation arc, use of sharp blades for the medial soleus tendon transversal section that is intimately connected to the gastrocnemius tendon, and suture of the medial tendon of the hemisoleus in the lateral segment of the muscle to minimize functional losses.

By combining this knowledge with the described angiosome principles, especially for reverse flaps, high success rates can be achieved. The main complications described (postoperative bleeding, partial graft losses, and failure of previously used flaps) were observed at the beginning of the series; therefore, they may be related to technique and indications. The use of the more accurate technique and more rigorous indication criteria, which occurred gradually throughout the series, reduced the complication rates of this flap. Therefore, the learning curve is a considerable factor in the improvement of this surgical technique.

Some complementary steps are also being gradually added in the treatment of these wounds, such as: assisted vacuum closure in the preoperative preparation to reduce injury extent, preoperative angiography in the evaluation of the flap’s vascular potential, postoperative Doppler use, design of the most viable flap design, and description of patch associations for extensive wound closure. The insertion of these concepts into the therapeutic plan may reduce the postoperative complication rates and increase the technical reliability of this procedure.

CONCLUSIONS

The use of medial hemisoleus proximal (direct flow) or distal (reverse flow) flaps is very useful for repairing substance losses from the medial and distal thirds of the leg and allow wound coverage with intermediate thickness tissues, rich local vascularization, a low donor-area morbidity index, preservation of the planter motor function, faster postoperative rehabilitation, accessible surgical technique, and shorter operative time.

These flaps may be considered a secondary alternative to transfer free flaps in the reconstruction of these defects or even the first treatment option in cases in which a minor injury or the presence of comorbidities does not justify the complexity of using a transfer free flap.

The association with the angiosome concept and the technical refinements described recently increased hemisoleus flap manufacture safety, reaffirming that the establishment and observation of the indication criteria in preoperative planning is essential to guarantee greater therapeutic success and reduce the postoperative complication rate.

COLLABORATIONS

EJC Analysis and/or data interpretation, conception and design study, conceptualization, final manuscript approval, realization of operations and/or trials, supervision, writing - review & editing.

MLPN Analysis and/or data interpretation, data curation, final manuscript approval, realization of operations and/or trials, software, writing - original draft preparation.

LACF Analysis and/or data interpretation, data curation, final manuscript approval, writing - original draft preparation.

DMCJ Analysis and/or data interpretation, data curation, final manuscript approval, realization of operations and/or trials, writing - original draft preparation.

REFERENCES


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