An Introduction to Lower Limb Muscle Flaps and Reconstruction: A Cadaveric Atlas

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PREFACE

There have been significant technological advancements over the past several decades to allow for intricate reconstructive surgical options. A large portion of the research has been dedicated to plastic reconstruction of the head and neck, as well as torso and upper extremity. Very little is written regarding lower extremity reconstruction, and in particular the use of muscular flaps.

There is a lack of knowledge within the Lower Extremity Specialist communities regarding these particular lower limb muscle flaps. The limitations are two fold: there is a lack of exposure, research and training early on in one’s career. But there is also an intimidation factor related to these larger surgical approaches.

Edgardo Rodriguez-Collazo, DPM and Christopher Bibbo, DO have been at the forefront of this lower limb reconstructive era with the debut of the reverse Peroneus Brevis muscle flap in the Journal of Foot and Ankle Surgery in 2013. Dr. Rodriguez has since advanced his surgical skills and perfected several other lower extremity musculocutaneous flaps in the meantime. It has been Dr. Rodriguez’ vision all the while to increase the exposure of this surgical option to all interested surgeons. He has done so through countless cadaveric dissections, lectures, and a yearly hands-on Chicago Lower Extremity Surgical Symposium.

We hope this E-book provides an introduction to a new a powerful technique for lower limb reconstruction.

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Notice:
The information set forth within this E-book is a personal approach used by the principle author. While it has proven to be innovative, and successful in limb salvage, the techniques have been cultivated over several years of surgical practice. The authors do not assume any liability for any injury and/or damages incurred as a result of reading and following protocols within this document. Medical research is also constantly evolving, and it is the reader’s digression to check the most current data available regarding lower extremity advances.
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CLASSIFICATION OF MUSCLE FLAPS

Type I: Tensor fascia lata
Type II: Gracilis
Type III: Gluteus maximus
Type IV: Sartorius
Type V: Latissimus dorsi
MATHES & NAHAI CLASSIFICATION

• Type I – singular vascular pedicle
  – Gastrocnemius

• Type II – dominant vascular pedicle and minor distal vascular pedicles
  – PB, PL, Soleus
  – Survival requires preservation of dominant pedicles

• Type III – 2 dominant pedicles

• Type IV – segmental vascular pedicles
  – EDL, EHL, FHL, TA

• Type V – dominant pedicle and segmental vascular pedicles
MATHES & NAHAI
CLASSIFICATION

PB, PL, SOLEUS
TAYLOR’S CLASSIFICATION

• Type I – single unbranched nerve ending muscle
• Type II – single nerve that branches just before entering muscle
• Type III – multiple branches from same nerve trunk
• Type IV – multiple branches from different nerve trunks
TAYLOR’S CLASSIFICATION
PRE-OPERATIVE PROTOCOL
The most important aspect of a preoperative examination is the determination of any peripheral arterial disease (PAD). As with any surgical procedure, the lack of blood flow can be detrimental to a muscle flap. This is particularly true when discussing REVERSE transposition of muscle grafts. In preparation, each patient must undergo rigorous noninvasive testing. This includes ABIs as well as CT angiography to delineate the extent of distal perforators to the muscle bellies. This allows the surgeon to determine which muscle belly to harvest intra-operatively, and also how distal the perforating branches can be found, determining how distal a transposition can occur. If need be, preoperative vascular intervention is appropriate to increase blood flow and preserve limb salvage.

For neuropathic patients, pre-operative counseling is less concerning regarding pain. However, all patients must be counseled on the need for an external fixation device. This is not negotiable as the muscle flap will perish with any micro-motion!

Nutrition must be optimized for each patient as well. Each patient’s albumin levels are measured, and nutrition counseling is started prior to the date of surgery for all patients and carried through the healing stages. Surgery cannot be performed on any patient that smokes, as it compromises vascular supply to the soft tissues and the harvested muscle flap.
CT ANGIOGRAPHY

Tibialis Posterior

Peroneus

Tibialis Anterior

Lateral Perforators
CT ANGIOGRAPHY

Medial Perforators
INTRA-OPERATIVE PROTOCOLS
INTRA-OPERATIVE PROTOCOLS

Prior to the incision, the CT angiogram is reviewed and the most distal perforators are identified (typically 7cm superior to the tip of the lateral malleolus). A handheld doppler is used to identify the most distal perforators (A), marking the most distal aspect of the incision.

Meticulous hands-free muscular dissection will be discussed in later chapters. All perforators are initially identified and can be tagged with a vessel loops. Several of the most proximal perforating muscular branches are sacrificed using micro clips or suture for closure.

Distal perforating branches are tested using bulldog claps (B) to determine vital vascularity. A clamp is placed upon each perforating vessel, and if the doppler signal is audible distally and bleeding is noted via loupe magnification to the muscle ends proximally, the perforator in question can be sacrificed due to more distal blood flow.
SPECIFIC MUSCLE FLAP DISSECTION
AND
OTHER CONSIDERATIONS
PERONEUS BREVIS MUSCLE FLAP
Incision Placement:
Distal extension - 7 cm proximal to the distal tip of the lateral malleolus (A), common location of the most distal perforator

PERONEUS BREVIS MUSCLE FLAP

Distal extension - 7 cm proximal to the distal tip of the lateral malleolus (A), common location of the most distal perforator
PERONEUS BREVIS MUSCLE FLAP

Incision Placement:
The incision runs parallel and 1cm posterior to the fibula. Proximally, it curves anterior to avoid the Common Peroneal nerve and ends 3cm distal to the fibular head. Distally, it ends 7cm proximal to the lateral malleolar tip as previously discussed.

Landmarks:
A. 1 cm posterior to the midline of the fibula B. Lateral Malleolus C. Anterior Ankle defect
Surgical Incision:
Incision is made using a 10 blade to the level of the subcutaneous tissue (A), exposing the deep fascia of the lateral compartment, and Peroneus Longus Tendon (B)
Surgical Incision:
The incision is deepened through the subcutaneous fat (A), to expose the deep fascia of the lateral compartment (B). Once this is incised sharply, it is important to identify the Peroneus Longus tendon (C) as well as the Superficial Peroneal nerve normally located at the anterior aspect of the deep portion of the fascial layer, along the fibular border.
Surgical Dissection:
Careful separation of the Peroneus Brevis muscle is performed from the fibula medially and anteriorly, and Peroneus Longus muscle and tendon laterally and posteriorly. It is recommended to start at the most proximal aspect and continue distally while carefully preserving the perforators to the Peroneus Brevis muscle. One must be aware of the location of the Superficial Peroneal nerve as it dives proximally into the Peroneus Longus muscle belly (A).
PERONEUS BREVIS MUSCLE FLAP

Identification of vital structures:

A. Peroneus Longus Muscle
B. Superficial Peroneal Nerve
C. Peroneus Brevis Muscle
D. D. Fibula
Surgical Dissection:
The Peroneus Brevis muscle (A) is separated from the underlying fibula and the overlying Peroneus Longus muscle. In the above image one can see the Peroneus Brevis muscle being retracted by the ragnel after preserving the distal perforators and sacrificing the proximal ones.
Surgical Dissection:
The Peroneus Brevis Muscle Flap (A) is separated from the fibular attachment medially and anteriorly (distal attachment intact - R of the image) with patent perforator arterial supply (not visualized in this image). Arterial supply must be verified throughout the entire process using a handheld doppler as it is the most vital step of the procedure.
MEDIAL SOLEUS MUSCLE FLAP
MEDIAL SOLEUS MUSCLE FLAP

Incisional Placement:
The longitudinal incision is made parallel and 3cm posterior to the medial border of the tibia.

Landmarks:
A. Medial tibial border
B. 7cm proximal to the medial malleus
C. Medial tibial notch, at the level of the tibial tuberosity
Surgical Incision:
The incision is made with a 10 blade to the level of subcutaneous tissue, then careful dissection is carried out with metzenbaum scissors to the level of the posterior muscular fascia.

* Caution is taken to identify and retract the Greater Saphenous vein as well as the Saphenous nerve.
Surgical Dissection:
Once the superficial posterior fascia is incised using tenotomy scissors, blunt dissection is used to separate the more superficial Gastrocnemius muscle belly (A) from the Medial Soleus muscle belly (B), using the aponeurosis (C) as the landmark to separate the two muscles.
MEDIAL SOLEUS MUSCLE FLAP

Surgical Dissection:
The Medial Soleus is dissected carefully from the fascia separating the superficial compartment (A) from the deep compartment (B) via blunt dissection to the midpoint of the Soleus muscle belly. The fascia overlying the deep compartment is easily visible. Care must be taken not to penetrate this layer.
Surgical Dissection:
The Medial Soleus is mobilized, allowing longitudinal transection of the musculature at the midpoint. A scalpel is only necessary to score the central portion of the Soleal aponeurosis longitudinally. It is important to identify and tie off all bleeding vessels with microvascular clips or hand-ties.
Surgical Dissection:
The Medial Soleus (A) is subsequently harvested as far proximally as possible.
A fully dissected Medial Soleus muscle flap (A) is shown within the superficial compartment of the leg.
Perforating arteries (A) of the muscle belly must be identified intra-operatively.
Perforating arteries (A) of the muscle belly must be identified intra-operatively.
Modification:
The Medial Soleus muscle flap can be modified by performing several strayer type recessions (A) to the fascia in order to increase the length.
The Medial Soleus muscle flap is a very robust and versatile flap that can be used to cover multiple wounds as depicted in the images above:

- Medial arch and cover a Trans-Metatarsal amputation (A).
- Plantar heel ulceration (B).
- Anterior ankle (C).
- Proximal to mid-tibial shaft (D).
MEDIAL vs. LATERAL
SOLEUS MUSCLE FLAP

• Medial
  - More robust muscle belly
  - Poor soft tissue laterally
  - Simpler dissection

• Lateral
  - Added length
  - Poor soft tissue medial
  - Inadequate PB muscle
CONSIDERATIONS FOR REVERSE FLAP TRANSPOSITION
Tunneling:

Once the muscle flap has been mobilized proximally, a technique called tunneling is used to transpose the flap from the distal aspect of the muscle flap incision to the wound bed site. Note: A minimum of 3-4cm skin island is necessary to prevent skin necrosis.

Intra-operatively, a chandler tool (represented here with the posterior aspect of a blade handle) is used to create the tunnel at level of the subcutaneous fascia. This allows minimal soft tissue damage. The subcutaneous fascia, dermis, and epidermis are lifted cohesively to preserve vascularity. Care must be taken to create a tunnel free of constriction to the muscular flap in order to avoid necrosis of the flap and the skin island.
Tunneling:

The proximal aspect of the muscle flap (A) is transposed through the newly created tunnel. This can be accomplished using atraumatic tissue forceps to the proximal most aspect of the muscle. It is important to make sure the tunnel is sufficiently loose enough to avoid tissue necrosis of the muscle flap or skin island.
CONSIDERATIONS FOR REVERSE FLAP TRANSPOSITION

Tunneling:

The wound site must be prepared before the muscle flap is laid down. All nonviable soft tissue is removed. If bone is exposed, fenestration is recommended to incorporate the blood flow from the muscle flap.

Once the muscle flap is pulled through the tunnel, gently pull on the ends of the flap and manipulate the tissue to fill the void. A secondary doppler examination must be performed to ensure the vessels have not been compromised.

Lastly, Integra® Flowable Matrix or Integra® Thin Skin Matrix is placed directly over the wound site to receive the muscle flap.
Reverse Transposition:

After tunneling the muscle flap to the wound site, the edges must be sutured, with 5-0 Vicryl, making sure to keep the Integra product intact underneath.
WOUND CLOSURE CONSIDERATIONS
DELAYED CLOSURE

When completing a delayed closure, the authors prefer to place Integra® Thin Skin Matrix or Integra® Flowable Matrix at the base of the previously prepared wound bed. This provides a nice gliding mechanism for any tendons deep to the muscle flap, and increases the incorporation of the muscle flap. The muscle flap is then placed and sutured using 5-0 Vicryl (as previously shown).

Overlying the reverse transposition muscle flap, a fenestrated Integra® Bi-Layer Wound Matrix is stapled to the skin directly overlying the muscle flap. Make sure the matrix is in complete contact with the muscle flap to allow for granulation tissue to form. A Wound Vacuum is then placed and set at 75mmHg of continuous negative pressure.

There are various reasons to allow for a delayed closure. Most notably one would withhold placing a split thickness skin graft (STSG) into an unhealthy wound site. If the wound bed looks unhealthy post-debridement, the authors prefer to allow incorporation of the muscle flap before introducing a more fragile graft such as a STSG to the area. Additionally, if the muscle graft is not bleeding adequately, the STSG will be delayed and the muscle flap will be allowed to incorporate prior to skin graft placement.
Delayed Closure:
Application of Integra® Bi-layer Wound Matrix over the muscle flap, and sutured using 5-0 Vicryl or staples.
SINGLE STAGE CLOSURE

Similar to the delayed closure, the authors again prefer to place Integra® Thin Skin Matrix or Integra® Flowable Matrix at the base of the previously prepared wound bed. This provides a nice gliding mechanism for any tendons deep to the muscle flap, and increases the incorporation of the muscle flap. The muscle flap is then placed and sutured using 5-0 Vicryl (as previously shown).

Though optional, the authors have found increased incorporation of the STSG when first placing a layer of Integra® Meshed Wound Matrix, suturing it to the wound edges with 5-0 Vicryl. Next, the STSG is harvested from the ipsilateral lower limb. The thickness is 0.018”, for a more robust graft, with a 2” plate. The graft is meshed at a 1.5:1 ratio and sutured overlying the muscle flap or matrix with 5-0 Vicryl. The STSG can also be stapled in place. A Wound Vacuum is then placed and set at 75mmHg of continuous negative pressure.

Once the muscle flap is harvested, transposed and sutured into place, it must be critically evaluated. Should the muscle be noted to have good bleeding with a healthy wound base free of underlying soft tissue or bony infections, this is a perfect opportunity to incorporate a split thickness skin graft. This decreases the risk of returning to the operating room and therefore any inconvenience and morbidity associated. However, the environment must be optimal for STSG placement.
SINGLE STAGE CLOSURE
PRODUCTS

There are several products necessary to allow for such intricate procedures, without which these limb salvage options would not be possible. Below are merely the authors’ preferences, however other options may work similarly in different surgeons’ hands.

Integra® wound products are used throughout the procedure and their uses are explained in other chapters.

At the beginning of each procedure, 60cc of whole blood from the patient’s IV and 60cc of bone marrow aspirate (BMA) from the patient’s Tibial Tuberosity or Lateral Calcaneus are harvested. This is then taken off the surgical field and harvested into concentrated BMA (BMAc), platelet rich plasma (PRP), and platelet poor plasma (PPP).

The BMAc is concentrated into a 10:1 ratio and utilized in combination with calcium chloride/thrombin solution at the site of the muscle flap transposition. PRP is also injected into the transposition site in a similar fashion. The CaCl/thrombin allows the product to remain where the product is injected, giving it a more viscous consistency than its natural state. Growth factors that are injected into the needed area in a large concentration.

The PPP is obtained from the remainder of the harvested blood and is used throughout the muscle harvest site to promote hemostasis. Some growth factors within these cells are also instilled into the area. Additionally, BioComposite RapidCure® beads are inserted into harvest site to decrease inflammation, and infection rate.

An external fixation device is placed on the affected limb of each patient post operatively; and it is the authors’ preference to use Orthofix® circular fixation devices. However any external fixation device that will eliminate motion to the lower limb will work.
PRODUCTS

Top - PPP injected into the harvest site of a lateral soleus muscle flap.

Left – BMAc/PRP inserted into newly transposed site prior to Integra® Bilayer Wound Matrix application.
COMPLEX WOUND CLOSURE

The incisions created for harvest are large, ranging from 20-25cm. With large incisions comes the increased propensity for complications, namely hematomas, wound dehiscence, and infections. Care is taken to decrease the risk of any adverse complications with a systematic complex wound closure.

Hematomas can form very easily with a large void at the site of the incision. Placing 1-2 JP drains from distal to proximal will decrease this complication, as well as any post-op compartment syndrome. These are usually pulled 24-48 hrs post-operatively.

As previously discussed, PPP and BioComposite RapidCure® beads are inserted into harvest site to decrease inflammation and infection.

A cross vessel loop retention suture closure is performed overlying the entirety of the incision to prevent wound dehiscence (left). This decreases tension on the edges, and is further helped with the placement of an incisional wound vacuum.
EXTERNAL FIXATION

Any motion to the lower extremity will decrease success of the muscle flap transposition due to the interruption of the microvasculature leading to graft necrosis and subsequent failure.

Typically, two olive wires are placed in the calcaneus (A), and two smooth wires or 1-2 half pins into the tibia (B). This allows for adequate exposure of the graft and incision sites for wound vacuum changes every 5-7 days. Please make sure to avoid the muscle flap site when placing wires! The external fixation is for skeletal stabilization and the patient is non weight-bearing on the involved extremity for 4-6 weeks until complete incorporation of the flap, during which time the fixator is removed and the patient is allowed to slowly start weight bearing.
EXTERNAL FIXATION

Application of PRP under the transposed muscle flap.

Application of the Integra® BI-layer Wound Matrix
POST OPERATIVE PROTOCOLS

The first dressing change is scheduled for 7 days post operatively to allow for the Integra® Bi-Layer Matrix or STSG to incorporate beneath the wound vacuum. At this point, the KCI® Wound Vacuum is changed every 5-7 days, with the settings always remaining at 75mmHg of continuous negative pressure.

JP drains are typically pulled 24-48 hrs post operatively. However this could vary depending on the amount of fluid collection. The drains are removed once <10ml is collected within a 24 hr period. This will decrease the risk of a hematoma formation, as well as any post-operative compartment syndrome.

The incisional Wound Vacuum, placed upon the harvest site, is discontinued 7-10 days post operatively. The staples and vessel loops are removed at week 3-4 to ensure prevention of wound dehiscence.

The patient is followed very closely post operatively, with visits at post-operative day #7, #14, #28. The third post-operative visit is when a decision is made regarding the viability of the muscle. With adequate incorporation, the external fixation device is removed at week 4-6. Primary or secondary STSGs are scheduled at this point in time as well.

With the removal of the external fixation device, the patient is placed in a CAM boot and is usually slowly transitioned into a weight bearing status based on surgeon’s preferences, the location of the wound, and the patient’s compliance. The patient is seen every 2-4 weeks until the wound is closed.
CASE STUDY
CASE STUDY

BACKGROUND:

This is a 42 year old male with a PMH significant for DM2, morbid obesity, Charcot neuroarthropathy, and hypertension. Physical exam was significant for left tibial varus deformity and chronic ulceration of the left 5th metatarsal base with underlying osteomyelitis that had been treated for 18 weeks.

Prior conservative and surgical interventions have included IV antibiotics, and debridement of the ulceration with minimal alleviation of symptoms. Given the severe biomechanical deformities, along with the neuropathic decrease in sensation, this patient was determined to be a good candidate for a reverse Peroneus Brevis muscle flap, along with a tibial osteotomy for a complete limb salvage procedure.

PRE DEBRIDEMENT
Chronic non-healing ulcer to the lateral aspect of the 5th metatarsal base with subsequent debridement of all nonviable soft tissue and bone
MUSCLE HARVEST:
Peroneus Brevis muscle with intact distal perforator vascular supply prepared for transposition
MUSCLE FLAP TRANSPOSITION:
Peroneus Brevis muscle flap, after harvest has been tunneled under the skin and placed overlying the previously debrided ulceration site. The muscle is sutured using 5-0 vicryl along the wound edges (arrow).
Application of an external fixation device is essential for all muscle flaps to decrease the motion of the transposed muscle and decrease the risk of necrosis.

The Integra® Bi-Layer Wound Matrix is fenestrated and stapled over the muscle flap.
A. 1 week post op: Integration of the wound graft
B. Re-application of Integra® Bi-Layer graft.
C. Harvest of STSG and application overlying the newly incorporated muscle flap.
A. 2 months post-transposition of the muscle flap
B. 4 months post-transposition of the muscle flap
* Two more rounds of STSG were needed
CASE STUDY

WOUND CLOSURE:
5 months post transposition of the muscle flap
REFERENCES