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Surgical Technique for Below-knee Amputation with Concurrent Targeted Muscle Reinnervation

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Summary: Targeted muscle reinnervation (TMR) is beneficial for decreasing pain following below-knee amputation (BKA). While most current literature describes the principles behind primary TMR, they provide few principles key to the amputation, as the BKA is usually performed by another surgeon. When the BKA and TMR are performed by the same surgeon, it can be performed through the same surgical access as needed for both procedures. The purpose of this article is to describe our anatomically based BKA technique in the setting of planned primary TMR as performed by 3, single, peripheral nerve plastic surgeons at 2 institutions. Advantages of the single-surgeon technique include efficiency in dissection, preservation of donor nerve length, limited proximal dissection, early identification of recipient motor nerves for coaptation, ability to stimulate these while still under tourniquet, and decreased tourniquet and operative time. This technique is quick, reliable, and reproducible to help promote widespread adoption of TMR at the time of BKA. *(Plast Reconstr Surg Glob Open 2020;8:e2990; doi: 10.1097/ GOX.0000000000002990; Published online 16 July 2020.)*

INTRODUCTION

Targeted muscle reinnervation (TMR) has evolved as a treatment for neuroma pain, phantom limb pain, and prevention of symptomatic neuroma formation.[1,2] TMR involves the transfer of transected sensory nerves to a nearby motor nerve, where it enters the muscle at its muscle entry point (MEP), thus providing neurotrophic signals, a pathway for growth, and a target for reinnervation. The surgical technique is described for various levels of amputation in the upper extremity as well as transfemoral and delayed/secondary below-knee amputation (BKA) in the lower extremity.[3–5] Primary, or acute, TMR at the time of BKA has been increasingly used for the prevention of neuromas, and principles have been described following amputation by another surgical service.[6] There are, however, no technical descriptions regarding how to perform the BKA in the setting of planned primary TMR.

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Traditional BKA techniques by orthopedic, vascular, or general surgeons involve proximal transection of the donor nerves and target muscles (anterior, lateral, and deep posterior compartments) near the level of the osteotomy.[7] This can be detrimental when TMR is planned as (1) inadequate length of the donor nerves can eliminate the ability to reach many of the typical MEPs used for TMR; (2) there is difficulty identifying recipient MEPs due to avulsion, dissection, or removal of the recipient muscle; and (3) more proximal dissection is required to find available recipient MEPs. When the BKA and TMR are performed by the same surgeon, it can be performed through the same surgical access and confers several advantages, including preservation of donor nerve length, early identification of recipient motor nerves for coaptation, and prevents the need for proximal dissection or additional incisions. Lack of a reliable, reproducible technique may be limiting the widespread adoption of TMR at the time of BKA.

Successful primary TMR for BKA requires treatment of the major sensory nerves to the leg and foot. In the leg, however, the saphenous and sural nerves lie in a plane superficial to the muscle fascia and require relocation into the muscular compartments to reach available MEPs. There are no descriptions on how to best relocate these nerves for TMR. The aim of this article is to describe our systematic, single-surgeon posterior skin flap

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BKA technique with concurrent TMR as performed by 3 peripheral nerve plastic surgeons at 2 institutions.

Indications

A single-staged BKA and TMR are indicated in any patient who is a good candidate for TMR. Because this technique is faster than the traditional 2-team approach, it is ideal for any patient because prolonged or multiple anesthetic events can increase anesthetic-related complications.

This technique can be used with BKA for failed limb salvage, chronic wounds, trauma, frostbite, or oncologic disease if the tumor is distal and preservation of tissue length and dissection do not risk recurrence. It could be contraindicated in patients whose tissues are unable to tolerate advanced dissection, such as obese, severe vascular disease, or lymphedema.

Technique

The patient is positioned supine with a bump under the ipsilateral hip to internally rotate the leg. A thigh tourniquet is used for all patients without severe calcific disease or vascular stents/bypass. Open wounds are isolated with a stockinette to prevent contamination of the sterile field. Total leg length is measured from the lateral femoral condyle to the lateral malleolus. Hash marks are made at 10% intervals, and marks are made for the anticipated locations of the MEPs.[8] The anterior transverse incision is designed 10–15 cm distal to the tibial tuberosity with length 2/3 the circumference of the leg. The posterior skin flap is designed extending from the lateral extent of the anterior marking; this junction can be curved proximally to prevent dog ears and gain access to the more proximally located MEPs, if necessary (Fig. 1). The beginning of the procedure focuses on identification/preservation of donor nerve length and amputation; MEP identification
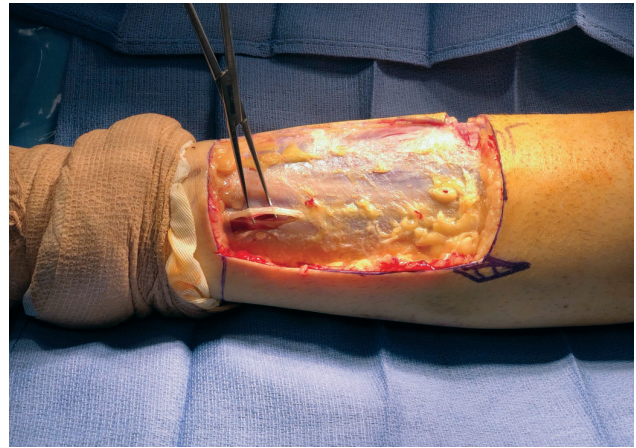

Fig. 2. Lateral view of left leg undergoing below-knee amputation with targeted muscle reinnervation; the foot is toward the left. The superficial perineal nerve is identified after avulsion of the discarded skin from the anterior crural fascia. It exits between the anterior and lateral compartments.

is delayed until after completion of the amputation, allowing for faster dissection and improved exposure.

The leg is exsanguinated, and the tourniquet inflated to 300 mm Hg. All incisions are made through the skin. (**See Video [online],** which displays surgical technique of a BKA with TMR.) Immediately through the medial aspect of the transverse incision, the saphenous nerve is identified; this is dissected distally to provide length for the nerve transfer and transected. The remainder of the incisions can then be carried down to the anterior crural fascia. The skin is then removed from the anterior crural fascia (Fig. 2). While doing this, the sensory portion of the superficial peroneal nerve is found to exit the crural fascia between the extensor digitorum longus and peroneus longus. The fascia between these compartments is opened proximally, and the superficial peroneal nerve is transected distally.

Fig. 1. Preoperative skin markings for below-knee amputation with primary targeted muscle reinnervation for frostbite of the foot. The anterior, transverse skin incision is shown 12 cm from the tibial tuberosity with the posterior myocutaneous flap incision extending from the lateral extent along the borders of the Sol. Estimated locations for commonly used recipient MEPs are marked by measuring leg length (lateral femoral condyle to lateral malleolus; circled), and hash marks are drawn at every 10% interval. MEPs to TA are located at 10%–40% leg length, PL at 20%–40%, Sol at 20%–60%, and FDL at 30%–60%.[8] FDL indicates flexor digitorum longus; PL, peroneus longus; Sol, soleus; TA, tibialis anterior.

Fig. 3. Anteroposterior view of left leg undergoing below-knee amputation with targeted muscle reinnervation; the foot is toward the left. The deep peroneal nerve is shown under the blue background; this is identified on the floor at the interval between tibialis anterior and extensor digitorum longus.

Table 1. Recommended Nerve Coaptations for Primary TMR

Donor Nerve	Recipient MEP	Exposure
Superficial peroneal	PL PB	Within lateral compartment. Open fascia longitudinally along course of SPN. Retract PL/PB laterally from septum. Motor nerve is along deep and medial surface of PL/PB.
Deep peroneal	TA EDL	Within anterior compartment. Dissect between TA and EDL. Motor nerve is along medial surface of EDL muscle belly.
Tibial	FDL TP	Between deep and superficial posterior compartment. Develop interval between soleus and deep compartment. Motor nerves accompany tibial nerve as separate, distinct fascicles.
Saphenous	Soleus TP FDL	In subcutaneous tissue on anteromedial aspect of leg. Deliver from the superficial to deep plane (below muscle fascia) by creation of a 2-cm musculofascial trough proximal to the transverse skin incision
Sural	Soleus	In subcutaneous tissue of posterior myocutaneous flap. At roughly 50% leg length, create a window with blunt dissection in the midline raphe of the soleus, continuing down between the heads of the gastrocnemius muscle into the subcutaneous tissue where the nerve lies. Identified proximally by palpating through this window and simultaneously tugging on the distal end with a hemostat. Once identified, looped the nerve with a hemostat and deliver through the window into the deeper plane.

EDL, extensor digitorum longus; FDL, flexor digitorum longus; PB, peroneus brevis; PL, peroneus longus; SPN, superficial peroneal nerve; TA, tibialis anterior; TP, tibialis posterior.

Anterior compartment muscles are dissected from the tibia and transected distally; muscle length is preserved at this point for later MEP identification. The deep peroneal nerve is identified between tibialis anterior and extensor digitorum longus (Fig. 3). The adjacent anterior tibial vessels are suture ligated distally at the level of muscle transection; proximal ligation will be performed later once the level of final muscle transection occurs. The tibial osteotomy is performed at the level of the skin incision with an oscillating saw while protecting the neurovascular bundles and adjacent muscles. The distal anterior angle of the tibia is rounded with a rasp.

Lateral compartment muscles are then dissected from the fibula, transected distally, and reflected proximally. The fibula is circumferentially dissected, and osteotomy is performed 1–2 cm superior to the tibial osteotomy. The distal bones are reflected forward, and electrocautery or amputation knife is used to disoriginate the deep posterior compartment muscles from the bones, completing the amputation. The peroneal vessels are suture ligated distally.

The tibial nerve is identified at the end of the posterior flap in the interval between the superficial and deep posterior compartments. The deep posterior compartment muscles are elevated in a distal to proximal direction. Care is taken to preserve the MEPs to the flexor digitorum longus and soleus, which are typically present in the proximal 50% of leg length.[7] The remainder of the deep posterior compartment muscles are removed unless there are identifiable MEPs. Identified MEPs are stimulated and tagged for later use. The posterior tibial vessels are suture ligated distally.

The sural nerve is identified in the midline of the subcutaneous tissue at the end of the posterior flap. Some surgeons do not routinely perform TMR for this nerve as subcutaneous dissection at the end of the flap has potential to compromise vascularity.[8] To avoid vascular compromise, the nerve is delivered to the deep plane by creation of a window through the deep surface of the posterior myocutaneous flap at a distance approximately 50% of the leg length. The window is created with blunt dissection in the midline raphe of the soleus, continuing down between the heads of the gastrocnemius into the subcutaneous tissue. The sural nerve is identified proximally by tugging on the distal end with a hemostat and palpating through this window. It can then be looped with a hemostat and delivered through the window into the deeper plane. This technique requires no distal subcutaneous dissection, thus preserving blood supply to the posterior skin flap.

MEPs are then identified to the anterior and lateral compartments using a nerve stimulator. Target muscles for reinnervation in the anterior, lateral, and deep compartments are then transected distal to the segment of muscle contraction. Nontarget muscles are transected at the level of the osteotomy and removed. The 3 major vessels are then ligated at the level of target muscle division to ensure preservation of segmental blood supply. The superficial posterior compartment is left intact as the posterior myocutaneous flap. Finally, the saphenous nerve is delivered from the superficial plane to below muscle fascia by creation of a 2-cm musculofascial trough proximal to the transverse skin incision. The tourniquet is deflated, and hemostasis is achieved.

Finally, TMR is performed. Any MEP can serve as a recipient if the donor nerve has sufficient length to reach; however, preferred nerve coaptations are shown in Table 1. Recipient MEPs are transected within a few millimeters of where they enter the muscle. The donor sensory nerves are shortened to an appropriate level to prevent tension and coapted to the MEPs using 2 interrupted epineurial 8-0 nylon sutures. Due to the donor:recipient nerve size mismatch, following coaptation, a longitudinal epimysiotomy is made to bury the coaptation in the adjacent denervated muscle; this is closed over the coaptation with suture or fibrin glue.

Muscle from the anterior or lateral compartment is closed over the end of the tibia. Closure of the posterior flap is performed by securing the Achilles tendon to the tibial periosteum followed by a layered skin closure. A posterior splint is placed to prevent knee flexion. A stump shrinker and protector is placed when the dressings are removed on the second postoperative day.

RESULTS

Using this technique, identification of donor and recipient nerves is efficient, adding an average of 20

minutes to the BKA operative time. The identified MEPs can reliably be stimulated under tourniquet for 30 minutes, but a stimulus is often achieved up to 45–60 minutes.

Since 2018, this technique has been used on 10 primary BKAs. There has been one incidence of dehiscence requiring revision. There have been no cases of vascular compromise to the posterior skin flap. Pain outcomes are consistent with previously published studies.[1]

DISCUSSION

TMR, both in the acute and in the delayed setting, has potential to significantly improve the quality of life and functional recovery for patients undergoing amputation.[1] TMR should be performed in most patients with BKA— ideally at the time of initial BKA, as the undissected tissue planes allow for easier dissection. This may stop the chronic pain cycle before it begins by preventing neuroma formation. Amputations, now more than ever, have potential to be a reconstructive surgery providing patients a functional, painless residual limb, rather than an ablative surgery performed with little consideration for the long-term outcome.

It is advantageous for a single surgeon to perform the BKA and TMR to allow for efficient dissection, preservation of donor nerve length, ability to stimulate recipient nerves, and decrease tourniquet and operative time. In contrast, when TMR is performed following BKA by another surgeon, anatomic landmarks are no longer present, making donor and recipient nerve identification more difficult.

SUMMARY

This single-surgeon technique for BKA with TMR provides a clear anatomic approach that is reproducible. Benefits of this technique include efficient dissection, preservation of donor nerve length, ability to stimulate recipient nerves under a single tourniquet time, and decreased tourniquet and operative time. Single-surgeon BKA with TMR should be considered for patients who are at risk for chronic pain, phantom limb pain, or symptomatic neuroma formation.

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