M. Klebuc, M.D.

MUSCLE FLAPS AND THEIR ROLE IN LIMB SALVAGE

Michael Klebuc, M.D.;[a,b] Zachary Menn, M.D.[a]
[a]The Methodist Hospital, Houston, Texas; [b]Weill Cornell Medical School, New York, New York

Abstract

Muscle flaps have proved to be a valuable and versatile tool in the surgical treatment of the severely compromised lower extremity. Utilized as both local pedicle flaps and free tissue transfers, muscles have been successfully employed to cover complex wounds, manage osteomyelitis, salvage infected vascular grafts, treat recalcitrant venous stasis ulcers, preserve amputation levels, and restore motion following compartment syndrome. Free flap pedicles have also been used in a flow-through fashion to create a distal arterial bypass. This article explores the multipurpose role of muscle flaps in limb salvage surgery and their beneficial physiologic characteristics in hostile wound environments.

Introduction

Muscle flaps have proven to be a valuable, versatile tool for the limb salvage surgeon. Utilized as both local pedicle flaps and free tissue transfers, muscles have been employed successfully to cover complex wounds, manage osteomyelitis, salvage infected vascular grafts, treat recalcitrant venous stasis ulcers, preserve amputation levels, and restore motion following compartment syndrome. Free flap pedicles also have been used in a flow-through fashion to create a distal arterial bypass.

Versatility

Muscle flaps have demonstrated, both clinically and experimentally, a series of advantages over local skin flaps and fasciocutaneous flaps for the management of complex wounds. The malleability of muscle allows it to effectively obliterate dead space while the dense capillary network facilitates antibiotic deposition. Additionally, muscle flaps are more effective than their counterparts in overcoming varying degrees of bacterial colonization and infection. In a canine model, muscle flaps have demonstrated a rapid, early augmentation of blood flow in response to an inoculum, providing greater degrees of bacterial growth inhibition and bacterial elimination than random skin flaps or fasciocutaneous flaps. Muscle flaps also have demonstrated more rapid collagen deposition and greater tissue ingrowth.[1-3] These advantageous characteristics likely account for their high level of success when used to manage hostile wounds. Regardless of their ability to inhibit bacterial growth, muscle flaps should not be used in an inadequately prepared wound bed. Serial debridement in conjunction with local wound care, antibiotic bead pouches, and negative pressure wound therapy should be employed to decrease contamination and maximize the character of the wound prior to definitive coverage.

Flap Selection

The location of the soft tissue defect plays a pivotal role in flap selection. The lower extremity is frequently subdivided into proximal, middle, and distal thirds in an effort to guide muscle flap selection. The medial and lateral gastrocnemius muscles are supplied proximally by the sural arteries emanating from the popliteal artery. The flap easily covers the tibial plateau region, and the muscle's origin on the distal femur can be released, allowing the reach to be extended to the patella and suprapatellar regions. The soleus muscle flap is the workhorse of the central third of the leg, and its blood supply is derived principally from proximal branches of the posterior tibial artery and peroneal artery. Secondary perfusion is provided by distal branches of the posterior tibial artery. In well-selected patients without significant trauma or vascular disease, it is possible to split the soleus muscle and perform a reverse transposition to cover distal third defects. The great majority of defects in the distal third of the leg, however, are best managed with microsurgical free-tissue transfer (free flaps) (Figure 1), although reverse neuro-fasciocutaneous flaps (reverse sural flaps) can provide a reasonable alternative in select

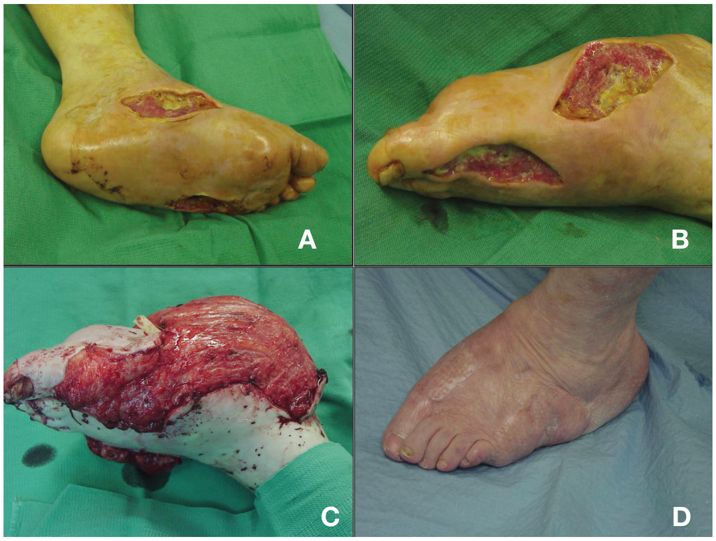

Figure 1. (A, B) Complex plantar and dorsal foot wounds with exposed bone and tendon. (C) Reconstruction with split latissimus dorsi free flap and skin graft. (D) Late postoperative follow-up after free muscle flap reconstruction.

patients. The latissimus dorsi, rectus abdominis, gracilis, serratus anterior, and anterolateral thigh with segmental vastus lateralis are frequent donor sites. The flaps can incorporate a skin island or be covered with skin graft as determined by the size and topography of the defect. Blood supply is restored with an arterial and venous microvascular anastomosis, which can be achieved in an end-to-end or end-to-side fashion, typically using 9-0 nylon under the guidance of an operating microscope or high power loupes. Free muscle flaps have proved more resistant to the effects of cigarette smoking than local skin and fasciocutaneous flaps and have been successfully employed in patients with diabetes and peripheral vascular disease.[4]

Illig et al evaluated outcomes and prognostic factors in patients who underwent a combined free tissue transfer and distal vascular bypass to manage otherwise nonreconstructible infrainguinal arterial occlusive disease with associated advanced tissue necrosis.[5] Following wound debridement, ischemia was managed by an infrainguinal bypass with the distal anastomosis achieved below the knee in the majority of patients. The microvascular arterial anastomosis was made to the bypass graft in most patients. The patient group had multiple comorbidities including diabetes mellitus, advanced age, end-stage renal disease (ESRD), and osteomyelitis. All patients would have required a minimum of a below-knee amputation (BKA) if no intervention was initiated. Utilizing debridement in conjunction with arterial bypass and a free muscle flap coverage, a 57% limb salvage rate and 65% rate of meaningful ambulation was achieved during the 5-year follow-up. The study also provides important insight regarding which patients may not benefit from this type of reconstruction. Individuals with diabetes and ESRD requiring dialysis fared poorly, and serious consideration regarding primary amputation should be given to this subpopulation.

Flow-Through Flaps

In the presence of distal vascular disease, select free-tissue transfers can be employed in a flow-through fashion to provide simultaneous soft tissue reconstruction and enhance limb perfusion. The subscapular arterial system can provide an arterial autograft for distal bypass along with associated segments of serratus anterior or latissimus dorsi muscle with or without a skin island.[6] Similarly, the descending branch of the lateral circumflex femoral artery can be combined with skin, fascia, and vastus lateralis muscle segments and employed as a flow-through flap. The radial artery flow-through flap provides a thin skin island and is well suited for defects of the foot and ankle region (Figure 2).[7] An additional benefit of the flow-through flaps is their positive influence on bypass graft flow. Anastomosis of a free flap to a distal bypass produces a decrease in distal resistance, thereby increasing flow. This effect was confirmed in a prospective hemodynamic study conducted by Lorenzetti et al., who demonstrated a 50% increase in flow when free-tissue transfers where connected to infrapopliteal bypass grafts.[8] The enhanced flow bodes well for the long-term patency of the distal bypass.

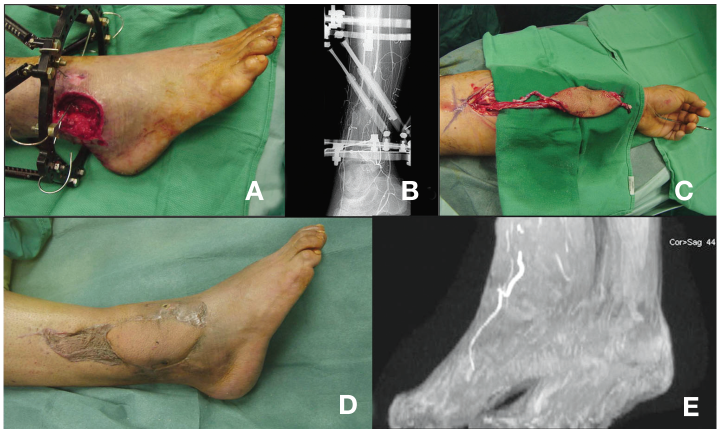

Figure 2. (A) Grade IIIC open ankle fracture with vascular compromise. (B) Arteriogram showing three-vessel injury with limited collateral flow to the foot. (C) Radial forearm free flap in situ. (D) Late postoperative follow up of radial forearm flow through free flap. (E) Late magnetic resonance angiogram (MRA) demonstrating a patent radial artery perfusing the foot via a distal anastomosis to the dorsal pedis artery.

Amputation

Extensive soft tissue necrosis and irreversible vascular disease will necessitate amputation in some individuals. For these patients, free muscle flaps can play an important role in the preservation of more distal amputation levels (Figure 3). Indirect calorimetry has been used to study oxygen consumption and the energy cost associated with ambulation at different amputation levels. Ambulation with a unilateral BKA requires approximately 9% more oxygen consumption than an unimpaired individual. Oxygen consumption rises to 49% above the base line for individuals with a unilateral above-knee amputation.[9] The extensive metabolic demand contributes to the low prosthetic utilization rates in patients with above-knee versus below-knee amputations. Free-tissue transfers have been successfully used to restore the soft-tissue envelope in short, guillotine-style below-knee amputations, maintaining the more functional amputation level.[10]

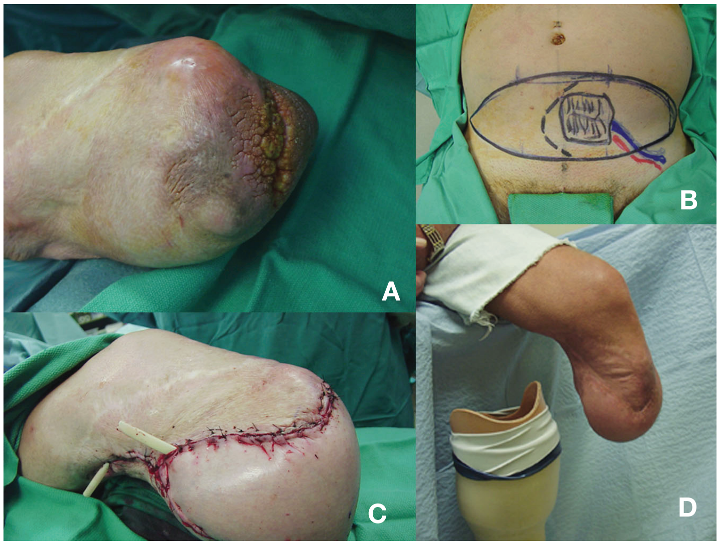

Figure 3. (A) Short below-knee amputation (BKA) stump with unstable soft tissue. (B) Operative markings: muscle-sparing free transverse rectus abdominis myocutaneous (TRAM) flap. (C) Resurfaced BKA stump. (D) Long-term follow-up with preserved BKA level.

Chronic Ulcers

Free muscle flaps have also been used successfully to treat recurrent chronic venous ulcers that have failed conventional therapy. The treatment includes wide local excision of lipodermatosclerotic tissue and replacement with a healthy, well-perfused free-tissue transfer with a vascular pedicle that contains multiple competent microvenous valves. Importing a competent venous segment improves regional venous hemodynamics. This was demonstrated by Dunn et al., who used photoplethysmography to evaluate venous filling times in free-flap reconstructions of chronic venous ulcers.[11] They found significant immediate and long-term increases in flap venous refilling times as compared to the preoperative values. Clinically, no recurrent ulceration or flap breakdown was identified at the 24-month follow-up. Weinzweig et al. also described a 10-year experience using free muscle flaps to reconstruct 24 recalcitrant venous stasis ulcers.[12] After a mean follow-up of 58 months, no recurrent ulcers were identified in the flap territory; however, three patients developed new ulcers on the same leg.

Compartment Syndrome

The benefit of free muscle flaps far exceeds their ability to provide stable soft-tissue coverage. In cases of irreversible compartment syndrome, neurotized free muscle flaps have been successfully used to restore motor function. Lin et al. reported their experience using free-functioning muscle flaps to treat post-traumatic defects in the lower extremity that included cases of neglected compartment syndrome. They utilized the rectus femoris muscle to re-establish ankle plantar flexion and the gracilis to restore ankle dorsi flexion. Acceptable outcomes were achieved in 10 of 15 patients.[13] We have found functional free muscle flaps to be a valuable tool in individuals who have limited options for traditional tendon transfers.

Chronic Osteomyelitis

The beneficial physiologic characteristics of muscle flaps have been previously discussed; however, in few situations are they more advantageous than for the treatment of chronic osteomyelitis. Customary treatment protocols include bony sequestrectomy and serial debridement with application of an antibiotic bead pouch along with a 6-week course of culture-specific intravenous antibiotics. Once a clean wound with visible punctate bony bleeding is achieved, local or free muscle flaps are used to obliterate dead space and improve the local wound environment. Utilizing a similar treatment protocol, Anthony et al. reported a 96% success rate in 34 patients with a mean follow-up of 7.4 years.[14] While the above treatment strategy can prove very effective, patients should be cautioned that chronic osteomyelitis is better thought of as being managed or suppressed and not eradicated, as late recurrences are not infrequent.

Graft Infections

Vascular surgeons may find that muscle flaps have the greatest utility when used for managing periprosthetic graft infections. Although the number of graft infections is generally low (1-6%), they are associated with significant rates of limb loss (30-50%) and mortality (25-75%).[15] Debridement, graft preservation, and muscle flap coverage have been used as an alternative to graft removal and extra-anatomic bypass. Meland and Arnold, in their classic paper, describe the role of muscle flaps in the management of 24 periprosthetic graft infections.[15] The infected grafts were treated with extensive debridement followed by muscle flap coverage and postoperative wound irrigation with a povidone-iodine solution delivered through implanted catheters. Systemic intravenous antibiotics were also employed. Frequently used donor sites include the sartorius, rectus femoris, and rectus abdominis. Although not advocated in this study, the gracilis and omentum are additional sources of well-vascularized soft tissue. Utilizing this treatment strategy, a 66% limb salvage rate was achieved over a mean follow-up of 41 months.

In our reconstructive surgery institute at The Methodist Hospital, this protocol has been modified, yielding even higher rates of graft preservation and limb salvage. The closed-suction irrigation system has been abandoned in favor of antibiotic-impregnated beads. Polymethyl methacrylate bone cement is combined with powdered vancomycin and tobramycin and fashioned into small beads secured on a heavy nonabsorable suture. When implanted within the wound, the beads offload their antibiotic payload, achieving local concentrations exceeding 100 times the mean inhibitory concentration. These supraphysiologic antibiotic concentrations have proved active against biofilms while being associated with limited systemic absorption, avoiding potential ototoxicity and nephrotoxicity.[16] Serial debridement and antibiotic bead exchange is undertaken until a clean culture-negative wound has been obtained (Figure 4A). The antibiotic beads are removed and the graft covered with a local muscle flap (Figure 4B-D). Utilizing this treatment protocol in conjunction with 6 weeks of culture-specific intravenous antibiotics, we have achieved a 96% long-term limb salvage rate.[17]

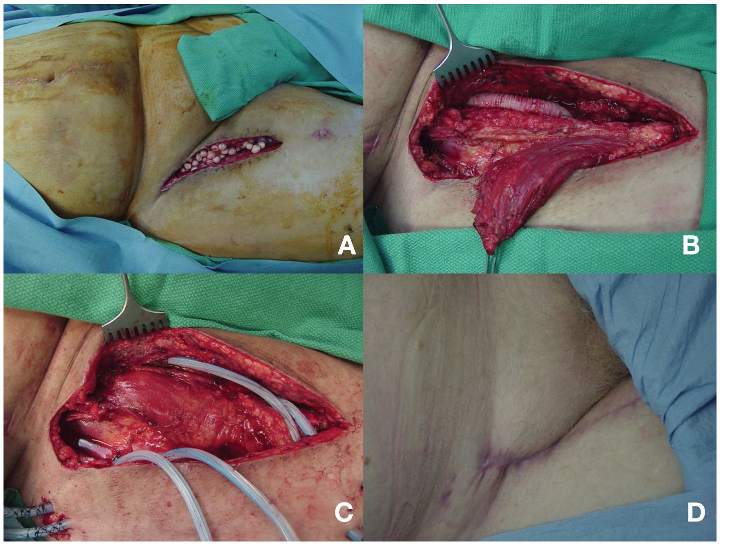

Figure 4. (A) Infected prosthetic vascular graft treated with antibiotic impregnated beads. (B) Elevated sartorius muscle flap. (C) Vascular graft enshrouded by muscle flap. (D) Long-term follow-up with graft preservation.

Conclusion

In conclusion, both pedicle and free muscle flaps enjoy intrinsic biologic advantages over local skin and fasciocutaneous flaps, making them a powerful, multipurpose tool in the armamentarium of the limb salvage surgeon.

Conflict of Interest Disclosure: All authors have completed and submitted the *Methodist DeBakey Cardiovascular Journal* Conflict of Interest Statement and none were reported.

Funding/Support: The authors have no funding disclosures.

Keywords: muscle flaps, limb salvage

References

1. Gosain A, Chang N, Mathes S, Hunt TK, Vasconez L. A study of the relationship between blood flow and bacterial inoculation in musculocutaneous and fasciocutaneous flaps. Plast Reconstr Surg. 1990 Dec;86(6):1152-62; discussion 1163.
2. Chang N, Mathes SJ. Comparison of the effect of bacterial inoculation in musculocutaneous and random-pattern flaps. Plast Reconstr Surg. 1982 Jul;70(1):1-10.

3. Calderon W, Chang N, Mathes SJ. Comparison of the effect of bacterial inoculation in musculocutaneous and fasciocutaneous flaps. Plast Reconstr Surg. 1986 May;77(5):785-94.
4. Herold C, Gohritz A, Meyer-Marcotty M, Steiert A, Jokuszies A, Vaske B, et al. Is there an association between comorbidities and the outcome of microvascular free tissue transfer? J Reconstr Microsurg. 2011 Feb;27(2):127-32.
5. Illig K, Moran S, Serletti J, Ouriel K, Orlando G, Smith A, et al. Combined free tissue transfer and infrainguinal bypass graft: an alternative to major amputation in select patients. J Vasc Surg. 2001 Jan;33(1):17-23.
6. Malikov S, Magnan PE, Champsaur P, Casanova D, Branchereau A. Subscapular artery Y-shaped flow-through muscle flap: a novel one-stage limb salvage procedure. J Vasc Surg. 2008 Jul;48(1):159-66.
7. Bullocks J, Naik BM, Lee E, Hollier L Jr. Flow-through flaps: A review of current knowledge and a novel classification system. Microsurgery. 2006;26(6):439-49.
8. Lorenzetti F, Tukiainen E, Albäck A, Kallio M, Asko-Seljavaara S, Lepäntalo M. Blood flow in a pedal bypass combined with a free muscle flap. Eur J Vasc Endovasc Surg. 2001 Aug;22(2):161-4.
9. Huang CT, Jackson JR, Moore BA, Fine PR, Kuhlemeier KV, Traugh GH, et al. Amputation: energy cost of ambulation. Arch Phys Med Rehabil. 1979 Jan;60(1):18-24.
10. Shenaq S, Krouskop T, Stal S, Spira M. Salvage of amputation stumps by secondary reconstruction utilizing microsurgical free-tissue transfer. Plast Reconstr Surg. 1987 Jun;79(6):861-70.
11. Dunn RM, Fudem GM, Walton RL, Anderson FA Jr, Malhotra R. Free flap valvular transplantation for refractory venous ulceration. J Vasc Surg. 1994 Mar;19(3):525-31.
12. Kumins NH, Weinzweig N, Schuler JJ. Free tissue transfer provides durable treatment for large nonhealing venous ulcers. J Vasc Surg. 2000 Nov;32(5):848-54.
13. Lin CH, Lin YT, Yeh JT, Chen CT. Free functioning muscle transfer for lower extremity posttraumatic composite structure and functional defect. Plast Reconstr Surg. 2007 Jun;119(7):2118-26.
14. Anthony JP, Mathes SJ, Alpert BS. The muscle flap in the treatment of chronic lower extremity osteomyelitis: results in patients over 5 years after treatment. Plast Reconstr Surg. 1991 Aug;88(2):311-8.
15. Meland B, Arnold PG, Pairolero PC, Lovich, SF. Muscle-flap coverage for infected peripheral vascular prostheses. Plast Reconstr Surg. 1994 Apr;93(5):1005-11.
16. Wininger DA, Fass RJ. Antibiotic-impregnated cement and beads for orthopedic infections. Antimicrob Agents Chemother. 1996 Dec;40(12):2675-79.
17. Klebuc MJ, Salazar H, Peden E. Salvage of infected vascular grafts with antibiotic impregnated beads. Paper presented at: Society for Clinical Vascular Surgery 36th Annual Symposium; 2008 Mar 5-8; Las Vegas, Nevada.