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Reconstruction of Complex Lower Extremity Defects

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Abstract

Purpose of Review Insults to the lower extremity have the potential to be highly detrimental to patient function and are associated with significant psychological morbidity. Complex defects of the leg, in particular, pose many reconstructive challenges requiring extensive collaboration between reconstructive surgeons and other care teams. This review details the basic principles of managing patients with lower extremity defects and discusses reconstructive options available to surgeons.

Recent Findings Novel reconstructive techniques and wound care technologies have largely improved outcomes in patients undergoing lower extremity reconstruction. Preliminary studies have demonstrated that supermicrosurgery and stem cell therapy both exhibit significant potential in lower extremity reconstruction; however, these modalities are currently in a state of refinement and development, respectively.

Summary Treatment of patients with lower extremity defects is highly complex given the anatomic challenges of the region along with the many pathologies that produce the said defect. Multidisciplinary care, namely the orthoplastic approach, is key to optimizing the processes of evaluating the patient, developing a surgical plan, and ultimately reconstructing the limb. Moving forward, refinement of current techniques along with the advent of novel technologies will pave the way for reconstructive surgeons to optimize patient outcomes in a standardized fashion.

Keywords Plastic surgery · Orthoplastic · Microsurgery · Trauma · Surgical oncology · Wound healing

Introduction

Lower extremity defects are a source of significant psychosocial distress to patients given their deleterious influence on patient's ability to perform day-to-day activities and associated financial burden [1, 2]. The majority of leg defects requiring reconstruction are the consequence of traumatic (including burn), vascular, and neoplastic pathologies, with each subset of patients requiring differing approaches to reconstruction. Despite these differences, the goals of reconstruction remain the same: to restore form and function while minimizing donor site morbidity.

Prior to the advent of microsurgical reconstruction, complex defects of the leg were rarely reconstructed with most patients undergoing amputation with skin grafting; however, advances in microsurgery, multidisciplinary care, and wound healing have made limb reconstruction a viable alternative to amputation [3]. Reconstruction of defects in this region poses many challenges for the reconstructive surgeon given the leg's tight skin envelope and paucity of underlying soft tissue [4]. Herein, we discuss the management of patients with defects of the leg as well as special considerations associated with treating different patient populations.

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Multidisciplinary Care

Multidisciplinary collaboration between plastic surgeons and other care teams has been shown to optimize patient outcomes and to reduce healthcare-related costs for many reconstructive procedures [5–7]. Lower extremity reconstruction necessitates extensive collaboration across multiple care teams (Table 1). Most notably, the increasing collaboration between orthopedic surgery and plastic surgery care teams has greatly improved outcomes in these patients.

The "orthoplastic approach" to lower extremity reconstruction entails both orthopedic surgery and plastic surgery care teams participating in the evaluation and management of patients presenting with both soft tissue and skeletal defects with the goal of optimizing patient outcomes [8, 9]. The efficacy of the orthoplastic approach, particularly in the setting of trauma, has been validated in multiple studies [10, 11, ••12]. In a systematic review comparing outcomes of trauma patients managed by orthoplastic and conventional orthopedic care teams, those managed by an orthoplastic care team experienced decreased time to bone fixation, lower rates of infection of both soft tissue and bone, and decreased reliance on healing by secondary intention [••12]. Furthermore, patients managed by an orthoplastic care team were more likely to undergo free tissue transfer (FTT) for reconstruction of their defect when indicated [••12]. While no formal studies have compared the efficacy of orthoplastic and non-orthoplastic approaches for reconstructing chronic wounds and oncologic defects, multiple retrospective studies have demonstrated favorable outcomes in patients managed using an orthoplastic approach to care in these cases [13, 14].

Preoperative Evaluation

A thorough history and physical examination is central to establishing a patient's candidacy for reconstruction. It is necessary to complete preoperative screening for medical comorbidities and lifestyle practices that may negatively impact reconstructive outcomes such as diabetes, peripheral artery disease, coagulopathies, and smoking [15–18]. When appropriate, the surgeon should also inquire about neoadjuvant and adjuvant chemotherapy and radiotherapy, as these can influence the timing and type of reconstructive procedure performed [19–21]. Prior surgical history should be elicited to assess reconstructive donor site options. Most importantly, the surgeon must evaluate the patients' preoperative functional and ambulatory status, social and economic barriers to healthcare, and desires and expectations as these are essential in guiding reconstructive planning [22].

When evaluating defects of the leg, the surgeon must take into consideration its location on the leg, size, and any exposed, damaged, or missing tissues including bone, tendon, and neurovascular structures. Aggressive debridement of nonviable and infected tissue allows for appropriate wound evaluation and is imperative to improve postoperative outcomes by creating a healthy wound bed that promotes healing and decreases the risk of infectious complications [23]. Patients with chronic wounds with exposed bone may be screened for osteomyelitis using bone cultures to guide antibiotic therapy if needed [17, 24]. Neurological assessment must also be performed and should be comprised of both sensory and motor examinations with a focus on sensation of the plantar surface of the foot [25].

Table 1 Specialties involved in management of patients undergoing lower extremity surgery

Specialty	Role
Plastic surgery	Assessment, debridement, reconstruction of soft tissue injury
Orthopedic surgery	Assessment, debridement, fixation of bony injury
Surgical oncology	Surgical resection of neoplastic masses and associated lymph nodes of the lower extremity
Vascular surgery	Revascularization or repair of vessels should limb perfusion become compromised
Critical care	Stabilization of patients upon arrival to the hospital and management of polytraumatic injuries
Medicine	Management of medical comorbidities and coordination of patient care among specialties
Medical and radiation oncology	Management of adjuvant and neoadjuvant chemoradiotherapy
Psychology and psychiatry	Management of psychological comorbidity following trauma or cancer diagnosis
Wound care	Nonsurgical wound management and bedside debridement prior to definitive reconstruction
Specialized flap nurses	Flap examination and management following microsurgical reconstruction
Physical therapy	Rehabilitation to regain strength, function, and increase mobility with postoperative restrictions
Occupational therapy	Rehabilitation for performing activities of daily living after surgery
Nutrition	Ensuring adequate nutrition to optimize wound healing
Orthotists and prosthetists	Fitting of splints, braces, and prosthetic limbs for patients

Assessment of the vasculature is an essential component of the preoperative evaluation, as it plays a significant role in establishing patients' candidacy for reconstruction and identifying viable reconstructive modalities. On physical examination, checking pedal pulses, capillary refill, and color and temperature of the affected limb can screen for signs of vascular compromise. Hard signs of vascular injury, such as pulselessness and pallor, warrant immediate surgical intervention for revascularization by the vascular surgery team [26]. Additionally, patients that lack hard signs of acute vascular injury, but exhibit ankle-brachial index values < 0.90, likely have an insult to the vasculature and require further investigation with computed tomography (CT) angiography [27, 28]. Patients who are scheduled to undergo reconstruction via FTT require further evaluation prior to surgery. A lower extremity Allen test may be used to assess for irregularities of the vasculature though there is debate regarding the value of physical examination for planning microsurgical reconstruction [29–31]. Arteriography, CT angiography, or magnetic resonance imaging angiography may be used for detailed assessment of the vasculature in the instance of an abnormal vascular exam [32, 33]. Recently, some groups have advocated for routine preoperative arteriography in patients undergoing microsurgical reconstruction; however, no comparative studies have been conducted to investigate the cost–benefit ratio for this protocol [34, 35]. Similarly, routine use of venous duplex ultrasonography has also been employed by some groups to assess outflow irregularities or asymptomatic venous thromboses [36, 37]. While preliminary findings are promising, there is still a paucity of data regarding the quantification of venous outflow abnormalities and their influence on flap survival. As such, the added costs associated with the procedure may not outweigh the benefits [38].

Preliminary X-rays of the traumatized limb are very important for the reconstructive surgeon when evaluating the type of fracture (low- versus high-energy) and anticipating the orthopedic approach for bone fixation. Incisions made by the orthopedic surgeon for surgical access should be decided in conjunction with the reconstructive surgeon to facilitate access to a local flap option or recipient vessels for FTT. Extensive collaboration and preoperative planning between the orthopedic and reconstructive teams are imperative to achieving an exemplary outcome in the instance that a patient presents with concomitant severe trauma to the viscera and central nervous system, lift-threatening injuries should be addressed first and take priority over limb salvage. While in the operative room for life-threatening injuries, we try to find an opportunity to expeditiously reduce fractures and stabilize them with splints or external fixation. Should a patient present with life-threatening bleeding from deep structures within the limb, extremity bleeding is promptly controlled with a tourniquet, and the patient is taken emergently to the operative room for hemostasis. Once life-threatening conditions under control, the patient's lower extremity injury may be fully evaluated and plans for definitive reconstruction outlined promptly.

Amputation versus Limb Salvage

Upon completion of the preoperative evaluation, surgical teams are tasked with determining whether the patient is best served undergoing amputation or reconstructive limb salvage surgery. The inclusion criteria for reconstructing defects of the leg is largely based on the etiology of the defect. In the trauma population, contraindications to limb reconstruction include severe crush injuries, complete traumatic disruption of the limb, permanent loss of plantar sensation secondary to irreparable injury to the tibial nerve, a warm limb ischemia time greater than 6 h, and other life-threatening injuries that are prioritized over leg reconstruction [•39]. Significant damage to bone and soft tissue are relative contraindications to limb reconstruction; however, this topic is of considerable debate amongst reconstructive surgeons due to the lack of validated tools available to guide clinical decision-making in this regard. While several groups have attempted to develop surgical algorithms based on injury scoring systems, these efforts have largely been limited by the lack of utility in predicting functional outcomes in patients undergoing limb salvage surgery [40]. Further complicating the matter, both amputation and reconstruction offer patients comparable long-term functional outcomes [41–44]. When comparing both interventions, limb amputation is associated with faster functional recovery, fewer surgeries and postoperative complications, and is more cost-effective in the short-term setting. Despite these benefits, amputation has been shown to predispose patients to more severe psychological morbidity and to increase healthcare-related costs accrued by patients in the long-term setting secondary to serial replacement of leg prostheses throughout their lifetime [41–45, •46, 47].

The indications for limb amputation in patients with chronic leg wounds are more concrete than those with traumatic injuries. Amputation is avoided when possible as it has been shown to reduce 5-year survival rates by as much as 45.4% when compared to FTT in diabetic patients [48]. Additionally, revascularized vessels have been shown to be reliable for supplying free flaps upon anastomosis [49]. Contraindications to reconstruction in this patient population include medical comorbidities that predispose patients to severe intraoperative complications, intractable infection of the bone or soft tissue, and inadequate perfusion in the extremity following revascularization [16, •39]. Additionally, some institutions consider end-stage renal disease to be a contraindication to reconstruction given the increased risk for flap complications [•39]. Lastly, patients with a short life expectancy, regardless of the etiology of their defect, may be best served undergoing amputation rather than limb salvage.

Reconstructive Planning

The reconstructive planning process for defects of the leg can be complex given the myriad of variables the multidisciplinary care team must account for. Optimally timing soft tissue reconstruction can range from simple to highly nuanced based on etiology and the nature of the defect. Chronic wounds have no explicit timeline for reconstruction as definitive reconstruction is largely contingent on preoperative optimization to achieve a healthy wound bed with adequate distal blood supply [17]. Of note, there is no consensus regarding the timing of soft tissue reconstruction in patients with chronic wounds who have a positive result on bone culture. At our center, we provide robust soft tissue coverage once the wound and bone are clean on gross examination (no necrotic tissue, no purulence) – regardless if the wound cultures are positive. We believe it is imperative to bring healthy vascularized tissue to the wound bed to better fight infection and to optimize the environment for healing. Wound cultures play an important role for the selection of an antibiotic regimen, but not the timing of wound coverage. On the other hand, patients undergoing oncologic resection of a tumor almost exclusively undergo immediate reconstruction given the increased risk for surgical complications associated with delayed reconstruction coupled with the need for prompt soft tissue coverage to decrease the risk of complications following radiotherapy [19, 20, 50]. In contrast, there is considerable debate regarding the optimal timing of reconstruction in patients with severe injuries to the leg in the setting of trauma.

The first study investigating the impact of timing on lower extremity reconstruction using FTT was published by Marko Godina in 1986 [••51]. In his study of 532 patients, Godina observed that patients who underwent soft tissue coverage within 72 h of injury experienced reduced rates of flap failure and osteomyelitis compared to patients who underwent reconstruction after the 72-h mark [••51]. This landmark study, however, was published before the advent of advanced wound care technologies – including negative pressure wound therapy. This limitation, along with the limited feasibility of performing soft tissue reconstruction within 72 h upon injury, led other groups to conduct further studies [52–55]. Lee et al. observed FTT could be delayed to 9 days post-injury without increasing major complications such as take-backs, partial flap failures, or total flap failures [52]. This study, however, reinforced the notion that delayed FTT, in this case occurring between 10 to 90 days after injury, would result in increased complications when compared to patients who underwent FTT promptly following their injury. Conversely, Starnes-Roubaud et al. observed no differences in flap complications, osteomyelitis, bone union, or ability to ambulate in patients who underwent FTT before and after 15 days post-injury [53].

Soft Tissue Reconstruction

Soft tissue reconstruction of the leg can be performed using a wide variety of techniques. The primary goals of soft tissue reconstruction are to restore form and function and to provide durable coverage for underlying bone, tendon, and neurovascular structures should they be exposed [••51, 52]. Locoregional tissue transfer and FTT are both frequently employed to treat defects of the leg with each having their own indications. Reconstructive surgeons divide the leg into thirds based on the arsenal of local reconstructive options available for soft tissue reconstruction.

Locoregional Tissue Transfer

Locoregional flaps are frequently used to reconstruct defects of the leg in standalone fashion or, in the case of muscle flaps, in conjunction with overlying skin grafting or, rarely, fasciocutaneous free flaps. When compared to FTT, locoregional flaps result in lower operative times, shorter length of stay postoperatively, and reduced healthcare-related costs in the short term [56, 57]. Contraindications to locoregional tissue transfer include large composite tissue injuries and instances where tissue injury and vascular disease limits the viability of locoregional flaps. Our center does not employ local flaps that have been previously exposed to radiotherapy as they are particularly susceptible to postoperative complications given the deleterious effects that it can have on the flap's vasculature [58]. In these cases, a regional flap or a free flap can be used to bring non-radiated, vascularized tissue to the defect.

Soft tissue defects of the upper one-third of the leg are often reconstructed using gastrocnemius muscle flaps. These muscle flaps may be designed to include the medial, lateral, or both muscle heads, giving the flap excellent maneuverability to fill dead space within a defect [59, 60]. The medial gastrocnemius flap is typically preferred over lateral flaps given its increased size and greater ability to move; however, soft tissue defects in the lateral aspect of the upper one-third of the extremity may require reconstruction using lateral gastrocnemius flaps [61, 62]. Combined flaps may be used to reconstruct large defects; however, this can result in weakened plantarflexion of the foot [59].

A pedicled soleus flap is often used to reconstruct defects of the middle one-third of the leg [63, 64]. While the flap may be used to reconstruct defects at the distal aspect of the leg, its use in this region is limited given the flap's high complication rate in this setting [63, 65]. When compared to the conventional soleus muscle flap, the hemisoleus muscle flap provides greater arc of rotation and produces reduced donor site morbidity; however, dividing the muscle may result in impaired perfusion and increase postoperative flaps complications following surgery.

The reverse sural artery flap is a fasciocutaneous flap frequently employed to reconstruct soft tissue defects of the lower one-third of the leg or as a lifeboat flap. The flap is supplied by retrograde flow from the septocutaneous perforators of the peroneal artery with the lesser saphenous vein serving as the primary means of outflow. Flap complications are high in patients, with 17% and 19% of patients demonstrating partial and complete flap necrosis, respectively [66]. Recent evidence demonstrated increasing the width of the pedicle can reduce the risk of developing venous congestion; however, more studies with larger sample sizes are necessary to definitively confirm these findings. Another strategy is to perform a "delay procedure" of the flap for a more reliable performance [67].

Pedicled perforator propeller flaps (PPPFs) have become an increasingly popular reconstructive modality for correcting small- and medium-sized soft tissue defects of the leg. PPPFs are designed based on a single perforator and can be axially rotated along the perforator by up to 180° to provide soft tissue coverage [68]. When compared to patients treated with FTT, PPPFs have been demonstrated to produce comparable success rates with the added benefits of providing aesthetically similar tissue with minimal donor site morbidity [69, 70]. Despite these benefits, elevation, rotation, and inset of the PPPF is technically challenging which may limit widespread use of the technique. Local fasciocutaneous flaps based on one or more perforators, such as a keystone flap, may also be used to reconstruct soft tissue defects with minimal donor site morbidity (Fig. 1).

Free Tissue Transfer

FTT is often employed to treat large soft tissue defects that cannot be reconstructed with locoregional tissue transfer. Soft tissue defects located at the distal one-third of the leg, in particular, frequently require reconstruction using free flaps given the paucity of viable soft tissue and high complication rates associated with locoregional tissue transfer in this area. Furthermore, FTT has been demonstrated to offer superior functional outcomes when compared to local fasciocutaneous flaps in patients with open tibial fractures undergoing soft tissue reconstruction [71].

Muscle or fasciocutaneous free flaps may be used to reconstruct leg defects with both demonstrating similar performance and complication rates (Fig. 2) [72–74]. When comparing the two, fasciocutaneous flaps, in non-obese patients, often offer improved aesthetic outcomes at the recipient site as some patients may find the skin graft used to cover muscle flaps, and its associated donor site, to be aesthetically displeasing [72]. In regard to donor site morbidity, muscle flaps may produce variable levels of functional impairment depending on the donor site used whereas fasciocutaneous flaps have minimal impact on patient function. Fasciocutaneous free flaps are generally preferred in patients that require staged skeletal reconstruction as they are more easily reelevated than muscle flaps [75]. Lastly, our center favors fasciocutaneous free flaps when reconstructing soft tissue defects overlying joints because they are more supple than muscle flaps thereby allowing increased range of motion along the joint.

Vessel selection for flap anastomosis is determined by a multitude of factors. Many surgeons prefer to use the posterior tibial artery as the recipient vessel given its ease of access and decreased susceptibility to injury when compared to the peroneal and anterior tibial arteries; however, this may not always be practical in cases where the patient has irregular vascular anatomy or a damaged vessel distally that may have a viable proximal stump to perform a microvascular anastomosis. In trauma patients, vessels located within the zone of injury should be avoided, as their use predisposes patients to complications owing to structural changes secondary to the traumatic insult and increased tendency for vasospasm [76]. Even so, this is not always feasible and may complicate anastomosis of the flap. Several studies have demonstrated that microvascular anastomosis can safely be performed in mildly damaged vessels provided that microsurgeons are mindful of potential complications [77]. Alternatively, if no viable vessels are present in or near the zone of injury, vein grafts or arteriovenous loops can be used or created to allow a distant microvascular anastomosis, respectively [78].

In regard to technical selection for vessel anastomoses, both end-to-end and end-to-side approaches are employed by microsurgeons with both producing comparable outcomes [79]. Many surgeons find end-to-end anastomoses to be less technically challenging; however, end-to-side anastomoses may be necessary should distal perfusion be highly reliant on the recipient vessel in question. Additionally, end-to-side anastomosis is warranted in the instance that a significant size mismatch exists between flap and recipient vessels. It is a good habit to clamp the selected recipient vessel and to assess the distal perfusion of the limb before transecting the vessel and performing an

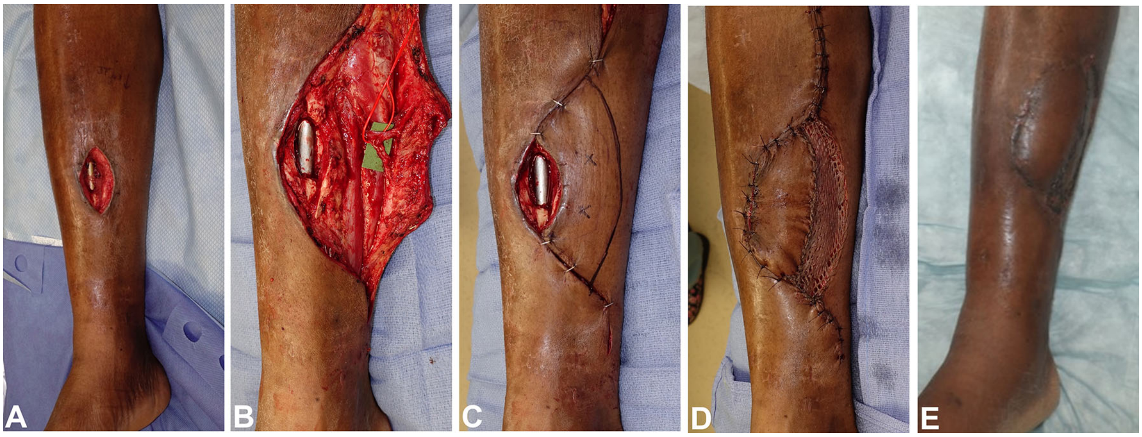

Fig. 1 A 43-year-old male smoker with wound breakdown at the middle one-third of his right leg two months following intramedullary nailing of the tibia (**A**). The patient was initially scheduled to have his soft tissue defect reconstructed with a soleus muscle flap; however, the team elected to reconstruct the defect with a fasciocutaneous keystone flap following the discovery of two robust posterior tibial perforators (**B**, **C**, **D**). The patient demonstrated an excellent postoperative result at follow-up and had no complications associated with his procedure (**E**)

end-to-end microvascular anastomosis. Should any concerns for impaired distal limb perfusion arise during the intraoperative clamping test, end-to-side or a flow-through microvascular anastomosis should be performed instead.

Skeletal Reconstruction

Reconstruction of skeletal defects in the lower leg is highly challenging given the weight the skeleton is forced to bear, high incidence of concomitant soft tissue defects, and need to preserve limb length [80]. When performing skeletal reconstruction in children, surgeons are also tasked with accounting for future skeletal growth [80]. Reconstructive efforts are primarily undertaken to correct intercalary defects of the tibia as the bone bears the majority of body weight as opposed to the fibula [81]. Skeletal reconstruction is largely dependent on the nature of the defect, the quality of the wound bed, and patient desires with each technique having their own unique benefits and limitations.

Autogenous non-vascularized bone grafts (NVBGs) may be used to repair small, segmental defects in select patients. Autograft can be harvested from several bones; however, most surgeons prefer to source the graft from the iliac crest given its ease of access, abundance of cortical and cancellous bone, and minimal associated donor site morbidity. Fat embolism and thermal injury-induced osteonecrosis, while rare, are potential complications associated with traditional harvesting methods for intramedullary bone graft. The Reamer-Irrigator-Aspirator system© (DePuy-Synthes, Cork, Ireland) may be used to aspirate cortico-cancellous bone graft along with mesenchymal stem cells (MSCs) with decreased risk for both complications; however, clinicians should be mindful when using the system as overzealous harvest is not uncommon [82, 83]. NVBGs are traditionally indicated to reconstruct intercalary defects less than 6 cm in length in patients with well-vascularized and non-irradiated wound beds [84]. Additionally, NVBGs are relatively susceptible to infection and osteoradionecrosis when compared to vascularized bone. Intercalary defects greater than 6 cm in length can be reconstructed with NVBGs using the Masquelet technique. This two-stage technique entails the use of polymethyl methacrylate cement with or without antibiotic spacers to induce the development of a pseudo-synovial membrane in the intercalary defect over a period of 4–5 weeks before replacement of the cement with cancellous autograft within the membrane [85]. The pseudo-synovial membrane is well-vascularized and produces growth factors for the bone thereby increasing its viability.

Vascularized bone grafts (VBGs) are often preferred over NVBGs given that they offer superior resistance to infection and radiotherapy, exhibit lower rates of bone non-union, and can survive independent of the wound bed's quality at the recipient site [84, 86]. Furthermore, VBGs are highly dynamic and are able to hypertrophy in response to weight bearing stress. While a wide variety of vascularized bone grafts may be used for tibial reconstruction, fibular VBGs are preferred given that they are most anatomically compatible with the tibia, can reliably repair very large intercalary defects, and are harvestable in multi-segment fashion. Additionally, a skin paddle or muscle flap can be harvested to perform single-stage skeletal and soft tissue reconstruction.

Vascularized fibula can be transferred to tibial defects in both pedicled and free-tissue fashion though FTT offers greater freedom for positioning the vascularized bone. Of note, up to 5% of the general population's distal lower

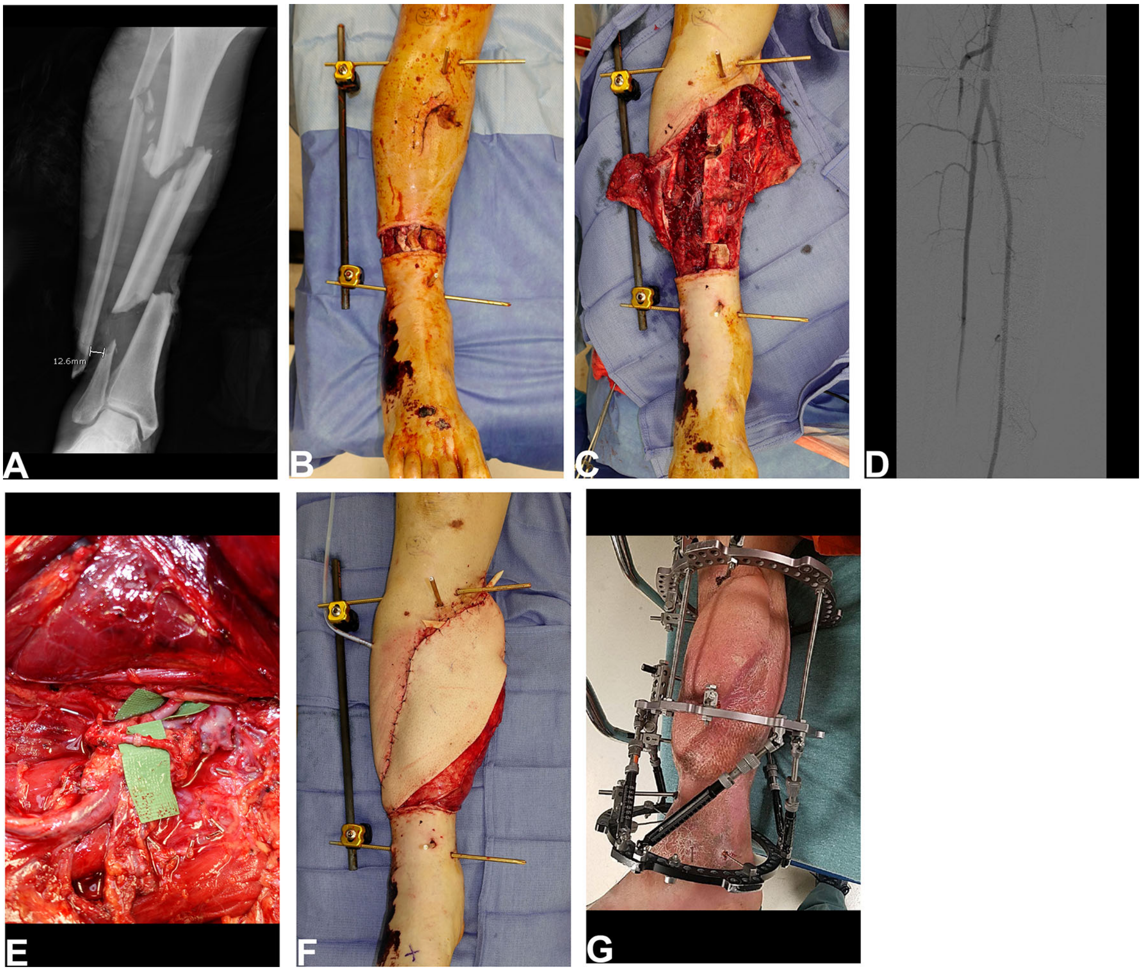

Fig. 2 A 46-year-old male with lower extremity injury after being hit by an automobile. Radiographs revealed significantly displaced, multilevel tibia-fibula fractures (**A**). He underwent reduction with external fixation and aggressive debridement that produced a large soft tissue defect (**B**, **C**). Arteriography revealed a single-vessel leg (posterior tibial); however, a decision was made to proceed with limb salvage rather than amputation (**D**). The soft tissue defect was reconstructed using an anterolateral fasciocutaneous-vastus lateralis muscle free flap and split-thickness skin grafting end-to-side on the proximal posterior tibial vessels (**E**, **F**). Our patient is currently undergoing uncomplicated skeletal reconstruction with a robust vascularized soft tissue envelope (**G**)

extremity has the peroneal artery serving as its primary blood supply; however, our clinical experiences suggest that the prevalence of this vascular phenotype may be lower than previously described [87]. Failure to screen for this anomaly, a strict contraindication for fibula FTT, will either result in unnecessary costs associated with aborting surgery or devitalization of the foot should the surgeon fail to identify it intraoperatively. While use of fibular FTT offers many benefits over other forms of reconstruction, it requires 6 months of healing before weight bearing can be achieved on the recipient limb [75].

Allogeneic NVBGs come in many forms ranging from malleable demineralized bone matrix to rigid cortical bone grafts with the latter having unique applications for reconstruction [80, 88, 89]. Unlike vascularized bone transfer, structural cortical allografts provide prompt resumption of weight-bearing activity on the recipient limb. Despite this, the long-term efficacy of allogeneic NVBGs is limited by high rates of bone non-union along with their susceptibility to infection and osteoradionecrosis. Rodolfo Capanna developed a technique that combined the short-term and long-term benefits of cadaveric allografts and vascularized bone transfer by placing a vascularized fibula within the medullary cavity of the cadaveric allograft [90]. The load-bearing function of the cadaveric allograft offer patients prompt functional recovery while the fibula integrates thereby sustaining patient function in the long-term setting. This technique is best indicated on oncological defects and clean surgical sites [80].

Lastly, intercalary defects of the tibia can be repaired using the Ilizarov technique. This reconstructive modality, also known as bone transport and distraction osteogenesis, induces the formation of a bone callous by applying tensile forces on osteotomized proximal and distal bone segments.

In contrast to other reconstructive modalities, the Ilizarov technique does not require harvest of autogenous tissue and is able to provide lasting structural stability unlike bone allograft. Given the mechanism of the procedure, the duration of bony reconstruction is directly correlated with the size of the defect. The Ilizarov technique is used to reliably reconstruct large tibial defects up to 12 cm in length; however, bony defects greater than 33 cm in length have been successfully reconstructed. Reconstruction of long bone defects with bone transport; however, may take many months to several years and can pose many challenges and potential complications for the patient [91–93].

Future Directions

The advent of supermicrosurgery has revolutionized many aspects of reconstructive surgery and is most well-known for its contributions to treating lymphedema. In the context of lower extremity reconstruction, supermicrosurgery has been employed to perform FTT in regions with nonviable or poorly accessible axial vessels via perforator-to-perforator anastomosis [94]. When compared to standard microsurgical techniques, supermicrosurgery offers comparable success rates in patients undergoing limb reconstruction with thin fasciocutaneous and cutaneous flaps [95]. While promising, supermicrosurgery has yet to be widely employed for limb salvage given its novelty and steep learning curve.

MSCs have been studied for the purposes of reconstruction because of their innate ability to secrete cytokines and growth factors that facilitate wound healing. Animal studies have demonstrated that MSCs are capable of inducing healing of both bone and soft tissue; however, clinical research in human subjects is still in its infancy [96]. Of note, one clinical study demonstrated biologic scaffolding enriched with bone marrow-derived MSCs resulted in improved osteogenesis and faster functional recovery when compared to conventional bone grafting techniques in patients following resection of benign neoplasms [97].

Conclusion

Lower extremity reconstruction is a highly complex process necessitating collaboration between plastic surgeons and other care teams in order to provide patients the best possible outcome. Despite the myriad of etiologies that cause defects of the leg, the basic principles of reconstruction remain the same. Thorough wound preparation, meticulous reconstructive planning, and precise technical execution are all key factors that influence the final result. Moving forward, refinement of current techniques along with the advent of novel technologies will pave the way for reconstructive surgeons to optimize patient outcomes in standardized fashion.

Author Contributions AMF: Primary drafting of manuscript, revision of manuscript, preparation of tables and figures. ARG: Primary drafting of manuscript, revision of manuscript. AA-G: Critical review of manuscript, revision of manuscript. EYX: Critical review of manuscript, preparation of tables and figures. WCP: Critical review of manuscript, revision of manuscript. DÁAL: Critical review of manuscript, revision of manuscript. MM: Conceptual design of manuscript, critical review of manuscript, revision of manuscript.

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Recently published papers of particular importance are noted as:

- • Of importance;
- •• Of major importance

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