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Review

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Soft tissue reconstruction of the lower extremity in the pediatric population

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Abstract

Lower extremity defects are a source of significant functional and psychosocial morbidity for pediatric patients and require complex reconstructions to restore form and function. The advent of microsurgical reconstruction along with advances in wound care techniques and technologies have empowered reconstructive surgeons to perform limb salvage surgery in patients that would traditionally require amputation; however, the indications for performing reconstructive surgery for complicated cases are not ironclad. While this is the case, applying the principles of lower extremity reconstruction in adults to the pediatric population is often sufficient to achieve a satisfactory outcome. This overview discusses the evaluation and management of soft tissue defects of the leg in pediatric patients.

Keywords: Plastic surgery, orthoplastic, pediatric, microsurgery, reconstruction, functional reconstruction

INTRODUCTION

Lower extremity defects cause significant functional and psychosocial morbidity in children and are a considerable source of the financial burden for healthcare systems. These defects pose many challenges for reconstructive surgeons given the technical demand required to successfully perform the reconstruction, along with the need to consider functional, psychosocial, and aesthetic factors when developing the reconstructive plan. Furthermore, the wide variety of etiologies responsible for producing the defect in question informs the reconstructive approach in distinctive ways. Compared to adults, restoring form and function in children often poses increased technical challenges and necessitates the reconstructive surgeon account for future growth. In this article, we discuss the evaluation and management of soft tissue defects of the leg in the pediatric population as well as important considerations inherent to this patient demographic.

MULTIDISCIPLINARY APPROACH TO CARE

The management of patients with extensive lower extremity defects is highly complex as patients often require multiple surgical procedures, have prolonged hospitalizations, and frequently experience profound psychosocial impairment. As is true with other forms of reconstructive surgery, multidisciplinary collaboration between the reconstructive surgeon and other surgical and non-surgical specialists is essential to optimize outcomes[1-4]. Of multidisciplinary collaborations, none have had as transformative an impact on patient outcomes as the orthoplastic approach. The orthoplastic approach to lower extremity reconstruction entails extensive collaboration between orthopedic and plastic surgeons when evaluating lower extremity defects and developing the surgical plan[5,6]. Using this approach, the orthopedic surgeons typically perform skeletal reconstruction whilst the plastic surgeons reconstruct the overlying soft tissue; however, the plastic surgery team may become involved in skeletal reconstruction should free transfer of vascularized bone to be incorporated into the reconstructive plan. Over time, this approach has evolved to include the expertise of vascular surgeons, radiologists, infectious disease and pain management doctors, and physical therapists[6]. Several studies have validated the utility of this multidisciplinary approach in the trauma setting, noting shorter time to bony healing, increased rates of free tissue transfer when indicated, decreased rates of bony and soft tissue infections, and healing by secondary intention[7-9]. Additionally, similar beneficial effects have been observed in patients with chronic wounds and oncologic defects managed by a multidisciplinary care team comprised of both orthopedic and plastic surgeons[10,11].

In addition to optimizing reconstructive outcomes, it is important to address the psychological impact that significant insults to the lower extremity can have on children and adolescents. Pediatric patients, in particular, are highly susceptible to developing acute stress disorder and post-traumatic stress disorder secondary to both the cause of lower extremity injury and its associated management[12-15]. As such, the inclusion of psychologists and psychiatrists in the multidisciplinary care team and mindful postoperative management is paramount to minimizing psychological morbidity.

PREOPERATIVE CONSIDERATIONS

Successful lower extremity reconstruction is dependent on meticulous preoperative planning based on a comprehensive history and physical examination. When performing the initial assessment, the reconstructive surgeon must identify risk factors that may preclude the use of some surgical options or complicate wound healing following surgery. Children requiring lower extremity reconstruction typically have fewer comorbidities than adults; however, it is prudent to assess for obesity, diabetes, congenital pulmonary or cardiovascular diseases, coagulopathies, and malnutrition states. In cases of oncoplastic reconstruction, it is imperative to discuss any neoadjuvant and adjuvant chemoradiation plans preoperatively as this will inform the timeline and type of reconstruction performed[16,17].

When evaluating the lower extremity defect, the orthoplastic care team must determine its size, depth, location along the leg, along with the viability and laxity of surrounding tissue. Additionally, exposed, damaged, and missing vital tissues including bone, neurovascular structures, and tendons, should also be noted on examination. In trauma patients, aggressive debridement of non-viable tissue is needed to fully ascertain the defect's size and extent and decrease the risk of infection following surgery[18,19]. Additionally,

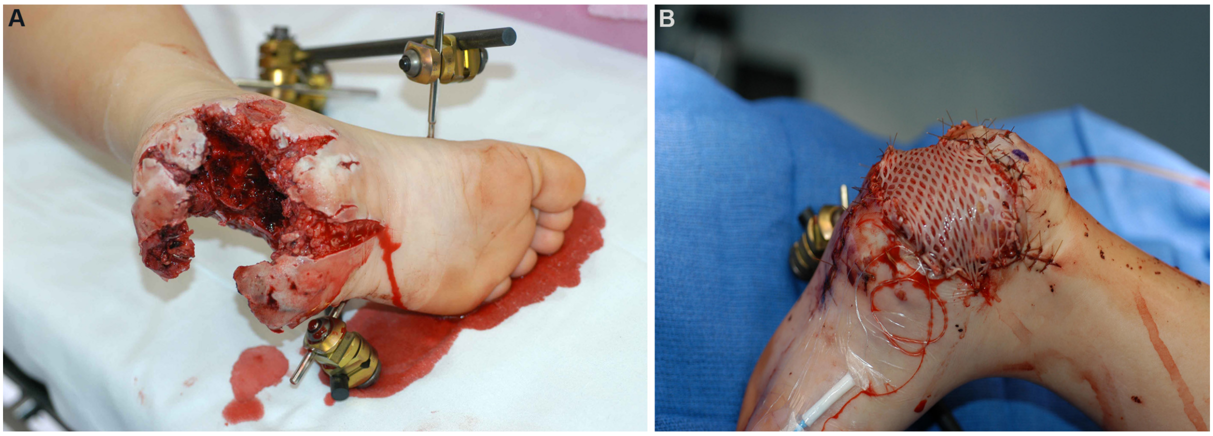

Figure 1. An 8-year-old male with a shotgun wound to his left posterior heel (A). He had intact sensation in the forefoot and toes despite the devastating nature of the bony and soft-tissue injury, and, in discussion with his parents, the team proceeded with a reconstruction of the soft tissue deficit. View after transfer of a latissimus dorsi muscle free flap to the heel (B). He eventually healed and, at six months postoperatively, was running with a custom-made prosthesis despite losing his calcaneus.

evaluating preoperative radiographs and computed tomography scans with the orthopedic surgeon is instrumental in anticipating the operative plan for any existing bony defects or fractures as this will influence the timing and type of reconstruction employed.

When evaluating a patient's neurovascular status, any deficits should be accurately noted. Initial physical examination with dorsalis pedis, and posterior tibial pedal pulses along with a lower extremity Allen test, can be used to screen for any abnormalities and dictate further workup with imaging. We prefer to perform a "dynamic Doppler" exam of the extremity. With this technique, the distal pulses are identified with the Doppler, the vessels are then occluded proximally, and the character of the distal Doppler signal is subsequently evaluated. This can provide more information than simply feeling the pulses or performing an Allen test. When vascular irregularities are noted, arteriography is the preferred modality; however, computed tomography or magnetic resonance angiography can be acceptable alternatives[20-22]. While the utility of routine preoperative vascular imaging with arteriography has been demonstrated in the literature, more judicious use may be indicated in the pediatric population, given the lower incidence of comorbidities that affect the vasculature. Additionally, the associated healthcare-related costs, exposure to radiation, and potential complications in the case of arteriography should be considered in the decision-making process[23,24].

The preoperative evaluation along with the expected functional recovery following surgery should inform the decision to opt for amputation over limb salvage surgery. Generally, reconstruction, when feasible, is preferred in the pediatric population, given that multiple studies have confirmed the viability of limb salvage surgery despite serious injury in this patient demographic [Figure 1][25-28]. Nonetheless, the exclusion criteria for limb salvage surgery, which are largely derived from the adult trauma population, can still be used as a guide to ascertain a patient's candidacy for reconstruction on a case-by-case basis. Settings in which limb salvage surgery is contraindicated include: a warm limb with ischemia time greater than 6 h, severe crush injury, complete traumatic disruption of the limb, and the presence of other life-threatening injuries[25,29]. Controversial relative contraindications to reconstruction include loss of plantar sensation, and severe soft tissue and bony injury. The short- and long-term relative advantages and disadvantages of amputation and limb salvage must be discussed with the patient and parents. In the adult population, both interventions have similar long-term functional outcomes[30-33]. When compared to reconstructive surgery, amputation is associated with a faster return to day-to-day activities, fewer surgeries, and decreased immediate healthcare-related costs[30-36]. In contrast, limb salvage is associated with decreased rates of psychological morbidity and is more cost-effective in the long term, given the significant expenses associated with serial prosthetic replacement throughout an individual's lifetime.

When opting for limb salvage, the timing of definitive reconstruction remains a controversial topic; however, most centers agree that early definitive wound coverage, as proposed by Godina[37], is preferable. With the addition of negative pressure wound therapy as an adjunct for managing lower extremity wounds, numerous studies have demonstrated that definitive coverage can be performed past the initial 72 h period with similar outcomes[38-42]. Specifically, in children, Rinker *et al.*[42] noted that patients who underwent soft tissue coverage within 7 days of injury exhibited decreased complication rates following surgery than those whose defect was covered after one-week post-injury. In contrast, Lee *et al.*[40] noted no difference in flap failure or other complications in adults when wound coverage was performed in the acute, subacute, and chronic periods. While adequate debridement, prevention of infection, and diligent wound care can extend the timeline of reconstruction, definitive coverage should still be completed as early as possible to allow patients to resume ambulation. Finally, the patient's and family's expectations, along with the various reconstructive options and their expected outcomes and postoperative rehabilitation protocols, should be discussed frankly prior to surgery.

SOFT TISSUE RECONSTRUCTIVE OPTIONS

The goals of lower extremity soft tissue reconstruction are to restore form and function by providing durable coverage with minimal donor site morbidity. Generally, we minimize the use of non-surgical wound care modalities in order to minimize the psychological morbidity associated with dressing changes. Both locoregional and free tissue transfer are employed for reconstruction, with technical selection being determined by the location and size of the defect as well as the availability of donor tissues. The leg, particularly at its distal aspect, is challenging to reconstruct because of the limited tissue laxity, thin skin envelope, and high prevalence of superficial vital structures in the region; as such, reconstructive surgeons typically divide the leg into thirds to guide reconstructive efforts [Figure 2][43].

Locoregional tissue transfer

Local and regional flaps are viable reconstructive options when used in patients with small- and middle-sized defects with sufficient surrounding soft tissue. When employed under appropriate conditions, locoregional flaps are associated with decreased hospital length-of-stay, shorter operations, and reduced short-term healthcare-related costs compared to free tissue transfer[44,45]. Locoregional tissue transfer is primarily employed to treat soft tissue defects in the upper and middle one-third of the leg, given the paucity of tissue available in the distal one-third. In the upper one-third, permutations of the gastrocnemius flap with overlying skin grafting allow the surgeon to reconstruct many defects with minimal impairment to the patient's ability to perform plantarflexion of the foot[46,47]. Similarly, the soleus flap is another muscle flap that can be used in conjunction with skin grafting to repair defects of the middle one-third with minimal functional morbidity[48,49]. While free tissue transfer is preferred for defects of the distal one-third, a distally-based reverse sural artery flap along with several muscle flaps, such as the peroneus brevis and hemisoleus muscle flaps, are alternatives to free tissue transfer for patients who are not candidates for microsurgical reconstruction[50-52].

Free tissue transfer

Free tissue transfer is the gold-standard reconstructive modality in medically-fit patients who require reconstruction of large, composite defects not amenable to reconstruction with local or regional flaps[53].

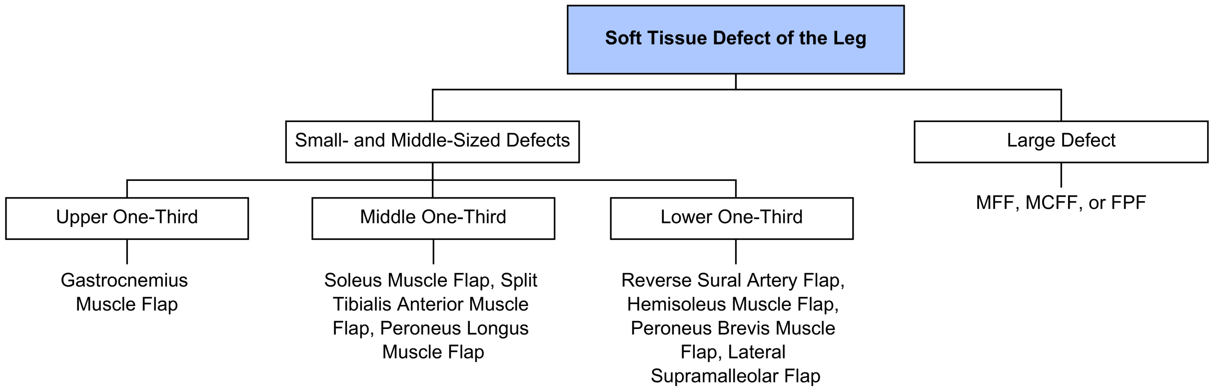

Figure 2. Reconstructive algorithm for soft tissue defects of the leg. MFF: Muscle free flap; MCFF: myocutaneous free flap; FPF: free perforator flap.

Microsurgical reconstruction in children comes with its own set of challenges and special considerations relative to adults. As previously mentioned, children and adolescents typically exhibit increased vessel patency given the decreased incidence of vasculopathic processes, such as diabetes and atherosclerosis, observed in this patient demographic[54,55]. Despite this, the decreased size of the vascular pedicle of flaps compared to adults increases the technical challenge of successfully performing the anastomosis[56,57]. When employing flaps with large and reliable pedicles, reconstructive surgeons can often achieve comparable success rates to those observed in adults[58].

Free perforator flaps and muscle free flaps are both frequently employed to reconstruct soft tissue defects, with both producing similar outcomes[59-61]. Muscle free flaps are able to provide more bulk to reconstruct defects at the expense of mild donor site morbidity with the added benefit that the flap will shrink over time. Free perforator flaps have minimal associated donor site morbidity and may not be as bulky initially; however, these flaps will not shrink and can grow if the child gains weight over time[62]. The primary advantage of perforator flaps is that they are more easily reelevated in patients who require access for bony, tendon, or nerve reconstruction at a later date[53]. The senior author favors muscle flaps in children, particularly the latissimus dorsi, due to its reliable anatomy, ease of harvest, large surface area available for coverage of defects, and appropriate pedicle caliber - even in the pediatric population.

Generally, the posterior tibial artery and vein are the recipient vessels of choice for microvascular anastomosis, given that they are usually uninjured in the trauma setting and are readily accessible [Figure 3]. Another benefit of employing the posterior tibial vessels is that the reconstructive surgeon may access the greater saphenous vein and use it as an alternative vessel for venous drainage via the same approach. In contrast, the anterior tibial artery, which travels along the interosseous membrane, is more likely to be injured when there are concomitant fractures; as such, it is a secondary option when used as a recipient's vessel. In patients who require limb salvage in the setting of trauma, microvascular anastomosis is preferably performed outside the zone of injury as complications may arise secondary to structural injury to the recipient vessels or vasospasm[63,64]. Should a patient have no viable vessels within or surrounding the zone of injury, the reconstructive surgeon may use vein grafts to supply the flap at the recipient site. In terms of anastomosis, both end-to-end and end-to-side anastomoses produce comparable outcomes; however, the end-to-side anastomosis may be necessary should there be a size mismatch between the flaps pedicle and recipient's vessels or in cases of single-vessel runoff to the foot[53,65]. Single vessel runoff can be directly visualized using conventional arteriography, computed tomography, or magnetic resonance angiography; however, it may also be identified intraoperatively by performing an intraoperative dynamic

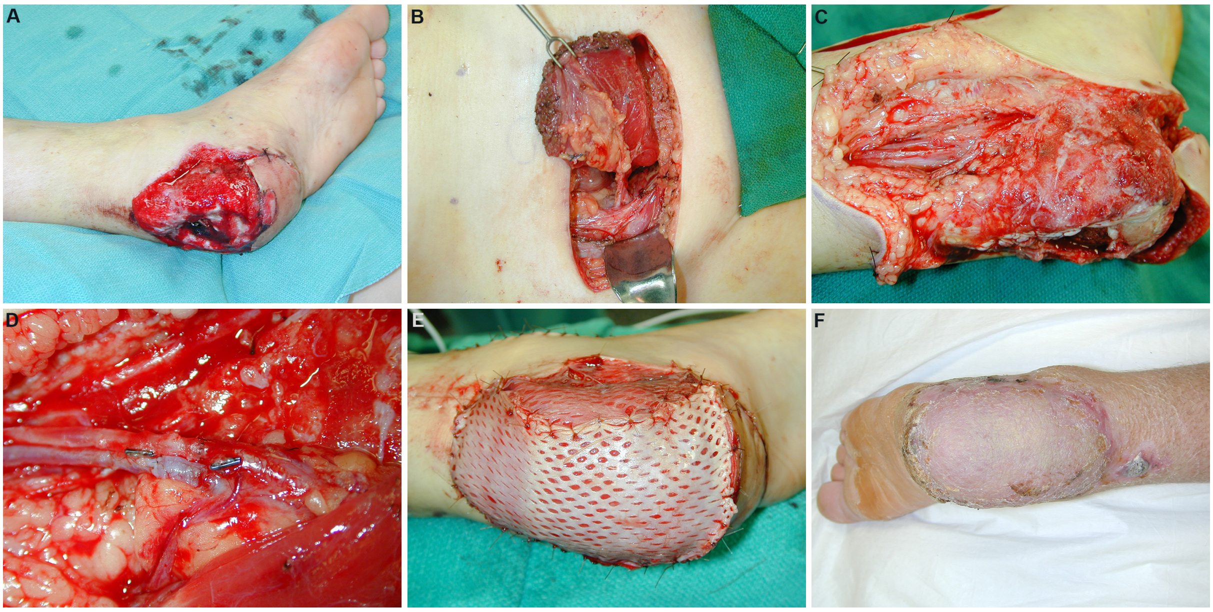

Figure 3. A 7-year-old male with a foot injury six days after a lawnmower accident (A). A portion of the rectus abdominus was harvested for coverage as a free flap (B). View of the foot after debridement and exposure of the posterior tibial vessels for flap anastomosis (left side of the photograph) (C). View after muscle insetting and end-to-end vascular anastomosis of the deep inferior epigastric vessels to the posterior tibial vessels (D). Flap after split-thickness skin graft was placed (E). Patient at one month following surgery showing a well-healed flap (F). He went on to return to full activity at three months postoperatively.

Doppler examination. In the absence of absolute or relative contraindications, the senior author, like many microsurgeons, employs end-to-end anastomosis as it poses less of a technical challenge for the surgeon.

FUNCTIONAL RECONSTRUCTION

Large defects of the anterior compartment of the leg can impair a patient's ability to perform dorsiflexion of the ankle, necessitating patients wearing an ankle orthosis to ambulate effectively. One manner in which the reconstructive surgeon can restore dorsiflexion is by transferring the posterior tibial tendon through the interosseous membrane to the distal segment of the injured anterior tibial tendon (Bridle Procedure)[66]. While effective for restoring patients' ability to perform dorsiflexion of the foot, many patients require microsurgical reconstruction for soft tissue coverage; as such, innervated muscle transfer can be used to provide coverage while restoring function simultaneously. For this intervention to be considered, patients must have intact recipient vessels, a peroneal nerve, and a distal anterior tibial tendon segment to allow the flap to survive and to function appropriately [Figure 4]. Innervated gracilis muscle flaps are most frequently employed when reconstructing anterior compartment defects; however, innervated rectus femoris myocutaneous flaps have also been shown to be efficacious in adults but suffer from limited excursion[67].

COMPLEX RECONSTRUCTION IN CHILDREN

Children with severe, complex injuries involving soft tissue, bone, tendons, and nerves are usually excellent candidates for the one-stage reconstruction of all tissues if this is feasible[68]. Obviously, with a combination of significant bone and soft tissue loss, it is usually better to get soft tissue coverage and then perform bony reconstruction [Figure 5]. There are young patients, however, who will benefit from reconstruction of the soft tissue defect and function, as noted in Figure 3, and this can be done over the repair of injured nerves. We feel that there is no reason to delay nerve grafting in complex reconstruction in children as nerve grafts do very well under the newly transferred vascularized tissue. This approach also potentially saves the child

Figure 4. View of a 13-year-old girl's left leg after high tibial fracture and subsequent anterior compartment syndrome (A). An innervated gracilis muscle with a skin paddle was placed to reconstruct defect and function (B). View one year following reconstructive surgery (after excision of monitoring skin paddle) with the foot in plantar flexion (C). View one-year following reconstructive surgery showing dorsiflexion via a re-innervated gracilis muscle flap (D).

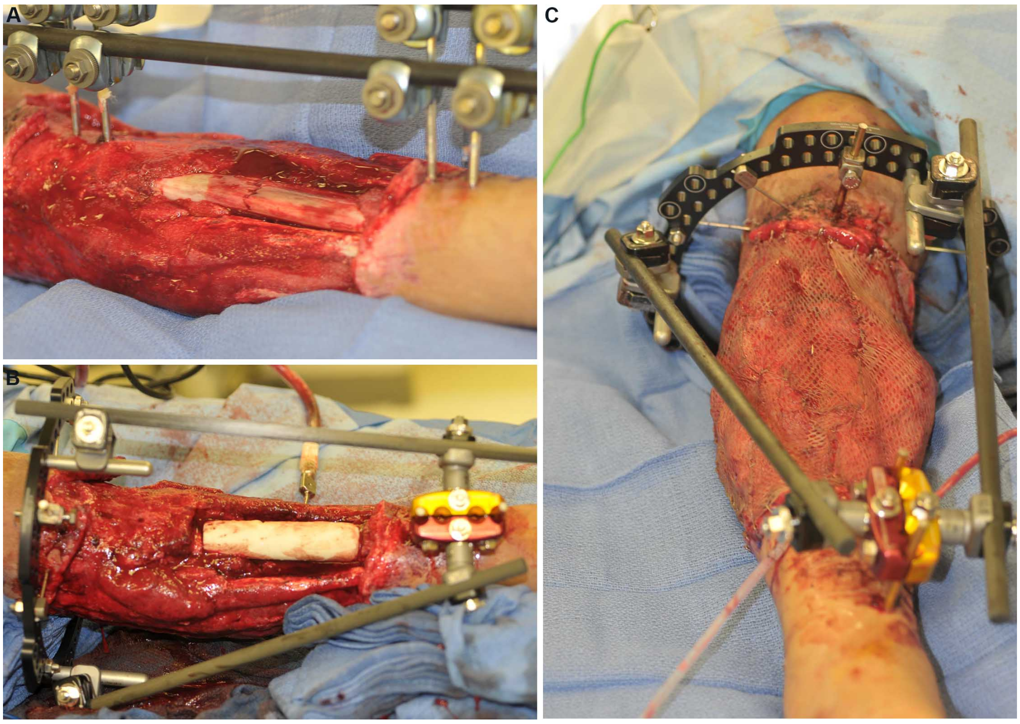

Figure 5. View of a 13-year-old male's leg after transfer from outside hospital 10 days after ATV rollover and tibia fracture (A). The tibia was degloved and has been exposed during this time. The orthopedic service debrided the clearly nonviable tibia near the fracture site and placed a large antibiotic spacer (B). This was covered with a latissimus dorsi muscle flap and split-thickness skin graft (C). He eventually had bony union after many months of bone transport.

from undergoing multiple operations and expedites their overall recovery time [Figure 6].

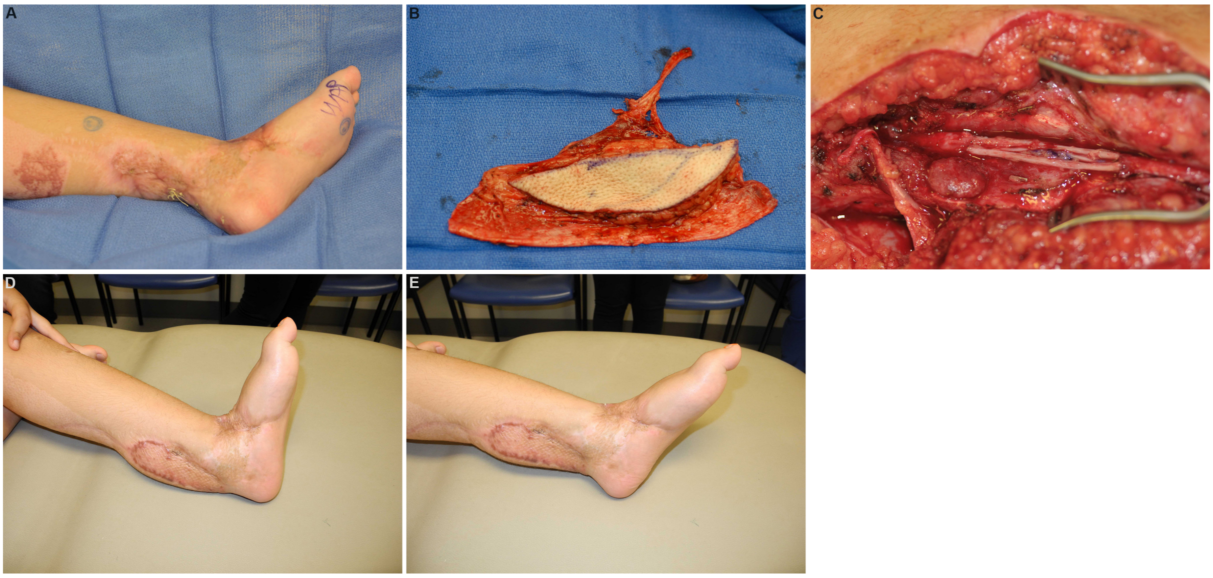

Figure 6. A 7-year-old female three months after suffering a propeller injury to the ankle in a boating accident (A). Her tibial nerve and Achilles tendon were divided, and she had a severely plantar-flexed foot with extreme sensitivity of the foot and ankle. An anterolateral thigh flap was raised with a large portion of facia lata to reconstruct the Achilles tendon (B). The tibial nerve was repaired with a cable sural nerve graft (C). Ankle extension (D) and flexion (E) at 14-month postoperatively. She had a return of good sensation to her plantar foot and can now run without difficulty.

CONCLUSION

Lower extremity soft tissue defects in children pose many challenges for the reconstructive surgeon. In addition to accounting for anatomical differences between children and adults, the surgeon must be mindful of the patient's condition's impact on their psychosocial outcomes when developing the reconstructive plan. Advances in formal multidisciplinary collaboration, wound care, and microsurgical free tissue transfer have empowered care teams to profoundly improve reconstructive outcomes in this patient demographic. Despite these strides, further investigation is needed to develop ironclad reconstructive algorithms to optimize patient care across limb salvage centers.

DECLARATIONS

Authors' contributions

Conceptual design of manuscript: Gimenez AR
Drafting of manuscript: Gimenez AR, Ferry AM
Critical review and editing of manuscript: Gimenez AR, Pederson WC

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Conflicts of interest

All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

Not applicable.

Consent for publication

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