Microvascular Free Flap Reconstruction in Pediatric Lower Extremity Trauma: A 10-Year Review

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Background: Limb-threatening wounds of the adult distal lower extremity pose a challenge to the microvascular surgeon and are the subject of a sizable body of literature. The microsurgical management of these injuries in the pediatric population has some unique features but has not previously been the subject of a separate study.

Methods: A review was performed of all pediatric patients (<18 years of age) who received lower extremity free flaps for trauma at the University of Kentucky Medical Center between 1992 and 2002. Charts were reviewed and patients were contacted via telephone and given a standardized questionnaire. Logistic regression was used to identify factors predictive of worse outcome or complications.

Results: Twenty-six patients (28 flaps) met the selection criteria. The most common mechanism of injury was all-terrain vehicle accidents ($n = 6$), followed by motorcycle accidents, lawnmower injuries, and gunshot wounds. The latissimus dorsi muscle flap was chosen in 15 cases, with four other muscle flaps chosen for the remaining 13 cases. There were 12 Gustillo 3B or 3C fractures of the tibia. External fixation was used in 10 cases and internal fixation was used in two. Four patients had a bone gap greater than 4 cm. Three were successfully treated with distraction osteogenesis. The postoperative complication rate was 62 percent, with infection and partial skin graft loss being the most common complications. Three flaps were lost. Growth disturbances were seen in two patients. Patients receiving free flaps within 7 days after injury were seen to have a statistically significant lower rate of complications than those undergoing the procedure beyond the first week. Follow-up ranged from 2 to 11 years, with a mean follow-up of 4.5 years. All limbs were successfully salvaged, and all patients were ambulatory at the time of the survey.

Conclusions: There is a significant role for the microvascular surgeon in the management of limb-threatening injuries in children. If the unique features of this population are taken into consideration, a high rate of limb salvage and good function can be expected. (*Plast. Reconstr. Surg.* 115: 1618, 2005.)

In the last three decades, the advent and refinement of microsurgical techniques have brought about a revolution in the treatment of distal lower extremity trauma. In the adult patient population, the principles of successful treatment of high-energy injuries of the ankle

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and foot are well defined.[1,2] It is unclear, however, how well these principles apply to the pediatric population.

High-energy trauma of the distal lower extremity is fortunately rare in children,[3] and little has been written about the microsurgical management of these injuries. No clinical series has been presented that specifically addresses the microsurgical management of distal lower extremity trauma in the pediatric population. No treatment algorithm has been devised to take into account the unique features and needs of this population, including smaller vessel size, lack of cooperation, social and emotional constraints, and the potential for limb growth abnormalities.

The purpose of the present study is to define the mechanism and patterns of high-energy injuries to the distal lower extremity in the pediatric patient, to identify factors that may predict a higher complication rate or poorer functional outcome, and to propose a rational approach to treatment.

Patients and Methods

A retrospective review was conducted of all pediatric patients (defined as patients younger than 18 years of age) who received lower extremity free flaps at the University of Kentucky Medical Center between 1992 and 2002. Free flaps performed for conditions other than trauma were excluded. Hospital charts were reviewed for demographic data and information regarding mechanism and type of injury, timing of surgery, flap choice, and hospital course, including perioperative complications. Clinic charts were reviewed for data regarding late complications and revisions.

Patients were contacted by telephone and asked a standard battery of questions addressing independence of ambulation, need for orthotic footwear, and participation in physical education, sports, or other avocational physical activities.

A logistic regression analysis was used to assess which factors were predictive of better outcome or lower complication rate. The factors subjected to analysis (independent variables) were sex, age, mechanism of injury, type of injury, and time from injury to free flap. Fisher's exact test was used to further examine the effect of free flap timing on complication rate.

Results

Twenty-six patients (18 male and eight female patients) were identified who fit the selection criteria; 28 free tissue transfers had been performed in these patients. Patients ranged in age from 2 to 17 years of age and had a median age of 13 years.

All patients had sustained a high-energy trauma to the ankle or foot from a motorized vehicle, power machinery, gunshot wound, or a fall from greater than 15 feet. The specific mechanism of injury varied greatly (Table I). Accidents occurring while operating all-terrain vehicles were the most common mechanism, accounting for six cases. There were four lawnmower injuries, four motorcycle accidents, four gunshot injuries, and three falls from heights of 15 to 40 feet. Motor vehicle, pedestrian versus car, and pedestrian versus train accidents accounted for the remaining five patients.

Four of seven injuries in the under-10 age group were the result of lawnmower accidents (57 percent). These injuries were not observed in the over-10 age group. Ten of 19 injuries (53 percent) in the over-10 age group were the result of all-terrain vehicle or motorcycle accidents, and these mechanisms were not seen in the under-10 age group.

Twelve patients sustained Gustillo type 3B or 3C open fractures of the distal tibia and fibula (Fig. 1). These injuries occurred more frequently in the adolescent population (median age, 14 years). Open fractures or partial amputations of the foot with an avulsive component occurred in seven patients. Pure soft-tissue avulsion injuries of the foot or ankle were seen in seven patients. The latter two types of injury were more commonly seen in younger children (median age, 11 years).

The time between injury and free tissue transfer ranged from 3 to 27 days, with a mean

TABLE I
Mechanism of Lower Extremity Injury

Mechanism of Injury	No. of Patients
All-terrain vehicle accident	6
Lawnmower accident	4
Motorcycle accident	4
Gunshot wound	4
Fall from height	3
Passenger in motor vehicle accident	2
Pedestrian struck by automobile	2
Pedestrian struck by train	1
Total	26

FIG. 1. (*Above*) A 15-year-old boy after a moped-versus-automobile accident, with fractures of the left distal tibia and fibula and a large open wound. (*Below*) Appearance 2 years postoperatively after microvascular transfer of a free latissimus dorsi muscle flap. The wound has fully healed with a good contour and the patient is ambulatory.

time of 8 days. Patients underwent 1 to 7 operative débridements (mean, 2.5 débridements) before free flap transfer. Hospital stay ranged from 8 to 38 days, with a mean stay of 15 days.

Free muscle flaps with split-thickness skin grafts were utilized in all cases. The most commonly used flap was the latissimus dorsi muscle, used in 15 cases. In 13 cases the contralateral latissimus dorsi muscle was selected, preserving the ipsilateral muscle for aid in crutch walking and transfers. In one case the ipsilateral side had previously been used as a donor site. In one case of a 3-year-old child (where the child was too young for crutch walking), the ipsilateral muscle was chosen for better geometric design. Serratus anterior, rectus abdominis, gracilis, or iliacus muscle flaps were used in the remaining 13 cases (Table II).

Postoperative complications were seen in 16 of 26 patients (62 percent) (Table III). Serious infections, defined as osteomyelitis, abscess, or cellulitis requiring intravenous antibiotics, were seen in nine patients (35 percent). Partial skin graft loss was seen in five patients (19 percent). Reexploration for venous thrombosis in the early postoperative period (days 1 through 3) was necessary in five patients, and total flap loss occurred in three cases (12 percent). A logistic regression analysis was performed to identify any factors that may be associated with a higher rate of complications. Age, sex, mechanism of injury, and type of injury did not affect complication rate. Using logistic regression analysis, timing of free flap surgery was observed to have a statistically significant effect on complication rate. Patients who underwent free flap transfer within the 7-day "acute" period, as defined by Khouri and Shaw and Byrd et al.,[1,2] had a 27 percent complication rate, as opposed to a 53 percent complication rate in those who underwent free flap surgery longer than 7 days after injury ($p < 0.05$). Considering infectious complications alone, there was a trend toward more frequent complications in the "subacute" group (47 percent versus 18 percent), but this was not found to be statistically significant. The three flap losses occurred in the "subacute" group (Table IV). Fisher's exact test failed to demonstrate a statistically significant relationship between timing and complication rate ($p = 0.18$).

Twelve patients had Gustillo 3B or 3C open fractures of the tibia and fibula. Initial fracture

TABLE II

Choice of Flap

Flap	No. of Flaps
Latissimus dorsi	15
Serratus anterior	5
Rectus abdominis	4
Gracilis	3
Iliacus	1
Total	28

TABLE III

Postoperative Complications

Complications	No. of Patients
Serious infection	9 (35%)
Partial skin graft loss	5 (19%)
Flap loss	3 (12%)
Fracture nonunion	2 (8%)
Limb length discrepancy	1 (4%)
Varous deformity	1 (4%)
Amputation	0 (0%)
Total	26 (100%)

TABLE IV
Correlation of Flap Timing with Infection and Flap Loss

	Free Flap Performed ≤7 Days after Injury (n = 11)	Free Flap Performed >7 Days after Injury (n = 15)
Infection	2 (18%)	7 (47%)
Flap loss	0 (0%)	3 (20%)

fixation was accomplished by external fixation in 10 patients; two patients were managed with an intramedullary rod. There were two cases of fracture nonunion, which successfully united following iliac crest bone grafting. Bony union, as defined by evidence of calcified callous formation on radiograph and resolution of tenderness at the fracture site, was achieved in all patients. The average time to union was 5 months and ranged from 2 to 24 months. Time to bony union was not dependent on the timing of free flap surgery or the type of fracture fixation selected.

Four patients had tibial bone gaps greater than 3 cm after débridement of nonviable tissues. These patients were all managed with initial external fixation followed by provision of high quality soft-tissue coverage with a free muscle flap. In three patients the resultant bone gaps were treated by bone transport and successfully healed without significant limb length discrepancy. One patient was managed with corticocancellous iliac crest bone grafting. This patient developed a nonunion but healed following a second bone grafting procedure.

Twenty-four of 26 patients were successfully contacted via telephone. Follow-up ranged from 2 to 11 years, with a mean follow-up of 4.5 years. At the time of follow-up, all patients were ambulatory. Three of the 24 patients (12.5 percent) were ambulating with the aid of a crutch or cane. Nine patients (37.5 percent) were fully ambulating but were unable to participate in physical education or sports. Twelve patients (50 percent) were participating in physical education, sports, or other avocational physical activities. Four patients (17 percent) were routinely wearing orthotic footwear at the time of our survey (Table V). No statistically significant relationship could be demonstrated between final functional outcome and sex, age, mechanism or type of injury, or timing of free flap surgery.

Adverse effects on growth were observed in two patients. One patient with a severe circumferential avulsion injury at the ankle developed a varus deformity requiring surgical correction. One patient with an extensive avulsion injury of the ankle and foot developed a limb-length discrepancy of 3 cm at 11 years postoperatively, which was treated with orthotic footwear.

TABLE V
Long-Term Functional Results after Extremity Salvage

Functional Result	No. of Patients
Not ambulatory	0 (0%)
Ambulatory with crutch/cane	3 (12.5%)
Fully ambulatory (no sports/PE)	9 (37.5%)
Participating in sports or PE	12 (50%)
Total	24 (100%)

PE, physical education.

DISCUSSION

In 1986 Godina published his series of 532 patients who had received microsurgical reconstruction of the lower extremity after trauma.[4] The following year Khouri and Shaw presented their series of 304 cases performed at Bellevue Hospital during the preceding 10 years.[1] The basic principles delineated in those large early series are universally accepted and applied today: wide débridement, external fixation, early coverage with well vascularized tissue, and delayed bone grafting. Although it is well established that free tissue transfer in children can be accomplished safely and successfully,[5–7] no series to date has specifically addressed the microsurgical management of pediatric lower extremity trauma.

By far the most common indication for free tissue transfer in the adult lower extremity is the Gustillo 3B open fracture of the tibia and fibula, accounting for more than 90 percent of cases in many of the large published series.[1,4] This type of injury accounts for only 46 percent of the cases in the present series. In the seven patients younger than 10 years of age, Gustillo-type ankle fractures were present in only two. This can be attributable in part to the more compliant long bones of small children and the higher incidence of avulsion injuries, especially lawnmower injuries, in this population.

The most common mechanism of injury in our series was accidents arising from the use of recreational all-terrain vehicles, accounting for six of 26 cases. This type of accident appears to be increasingly frequent. According to the all-terrain vehicle industry, there were 7 million all-terrain vehicles in use in 2001, twice the number that were in use in 1997.[9] During that same time period, emergency room visits as a result of all-terrain vehicle accidents doubled to 111,700. Injuries in children younger than 6 years of age increased by 233 percent![9] Making matters worse, many states have no licensing restrictions, age restrictions, or helmet laws applicable to these vehicles. In our state we have seen serious all-terrain vehicle–related injuries in children as young as 2 years.

Flap choice in our series was largely determined by the demands of the defect, but there are some considerations germane to the pediatric patient. The latissimus dorsi muscle was the flap of choice in the majority of cases, as it has a consistent vascular anatomy and a vascular pedicle of sufficient caliber, even in very small children. The rectus abdominis muscle was used in four patients, but in our experience this muscle and its vascular pedicle are often quite small in younger patients. When possible, it was harvested through a Pfannenstiel incision to minimize the visible scar.

The importance of adequate débridement and early coverage with high-quality soft tissue for lower extremity injuries was recognized by Converse during World War II.[8] It is well established in the adult population that early definitive soft-tissue coverage reduces the risk of complications in the adult patient population.[1,2,4] Our findings in the pediatric population mirror this experience. Using a logistic regression analysis, the complication rate in our series was significantly lower for free flaps performed within 7 days of injury than for those performed after 7 days (27 percent versus 54 percent). A delay in definitive coverage may be a result of the severity of the patient's overall condition, however, as in multiple traumas, which may also predispose the patient for postoperative complication. In addition, the accuracy of logistic regression analysis may be negatively affected by small sample size; however, this is controversial.[10]

Mirroring the experience of May and Rohrich,[11] plantar defects were managed with muscle flaps and split-thickness skin grafts without subsequent problems resulting from cutaneous breakdown. These patients maintained protective sensibility.

All patients had social work and child psychology consultations early in the hospital course to help with the child's adjustment to a long hospital stay and address their psychological and emotional needs. Every attempt was made to reduce physical discomfort. Indwelling epidural catheters were extremely helpful in this patient group, providing analgesia while reducing narcotic requirements, and they were used in 15 of 26 cases in this series. Postoperative protection of the extremity was of paramount importance, usually involving circumferential casting with a window for flap monitoring and suspension from a traction trapeze. Even so, there was a high incidence of partial skin graft loss from shear, requiring secondary grafting in five patients.

There were three instances of flap loss in the series. In all three cases venous congestion was noted in the first 72 hours of the postoperative period. In each case an attempt at salvage was unsuccessful. The flap success rate of 88 percent is lower than most published series of adult free flaps but is within the range of other reported series of pediatric free tissue transfer. Published success rates for pediatric microsurgery range from 67 percent to 100 percent.[5,6,12–18] This is likely attributable, at least in part, to smaller vessel size but may also relate to the increased susceptibility to vascular spasm that we have observed in children and young adults.

Four patients in our series had a tibial bone gap of greater than 4 cm after débridement. The largest gap was 6 cm. In three of four cases the bone gap was successfully managed by distraction osteogenesis. In our experience distraction lengthening is an extremely valuable technique in this patient population, as pediatric long bones exhibit a strong regenerative response to distraction with a low rate of nonunion. In addition, pediatric patients are typically more compliant with the frequent office visits necessitated by this technique than are their adult counterparts (Fig. 2).

In the three patients who underwent distraction osteogenesis in the present study, there were no cases of limb length discrepancy, and the limbs continued to exhibit normal growth. The one patient who developed a clinically significant limb length discrepancy was a 5-year-old who sustained a severe lawnmower avulsion injury at the ankle joint, involving the perichondral ring. This type of injury is well known to cause growth disturbances, as it permits a callus bridge to form between the epiphysis and metaphysis.[19,20] When a subtotal injury to the physeal plate occurs, an angular deformity results, most commonly a varus deformity, which was observed in one patient in the series.

In the few studies of long-term results after microsurgical salvage of the adult lower ex-

FIG. 2. (*Above, left*) A 6-year-old girl with a Gustillo 3B open right distal tibia fracture sustained in a motor vehicle accident. (*Above, right*) Radiograph showing a large, displaced diaphyseal fragment of tibia. (*Below, left*) After external fixation, limb shortening, and coverage with a free rectus abdominis flap. (*Below, right*) Appearance 3 weeks postoperatively, with several small patches of skin graft loss. The patient subsequently underwent distraction osteogenesis of the tibia, and at 2 years postoperatively she was ambulating and participating in physical education.

tremity, persistent limitation of function was present in as many as 80 percent of patients.[21] A significant limitation of the present study is the lack of objective functional testing. The results of our questionnaire, however, suggest a much higher level of long-term function than what is typically achieved in the adult population. Fully 50 percent of patients contacted were able to participate in physical education, sports, or other activities such as cycling, dance, or cheerleading. Outcomes such as these would seem to justify an aggressive approach toward microsurgical lower extremity salvage in the pediatric patient.

The potential for growth disturbance and limb-length discrepancy is of particular concern in the child with a severely injured extremity, but in our experience these complications can be avoided with judicious application of free tissue transfer followed by distraction osteogenesis. There is clearly a significant role for the microvascular surgeon in the management of limb-threatening injuries in children, and if the unique features of this population are taken into consideration a high rate of limb salvage and good function can be expected.

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