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An Argument for Salvage in Severe Lower Extremity Trauma with Posterior Tibial Nerve Injury: The Ganga Hospital Experience

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Abstract

BACKGROUND—Absence of plantar sensation is a critical factor considered in favor of amputation for patients with lower limb-threatening injuries. This study aims to assess outcomes of limb salvage in a group of patients with severe lower extremity injuries associated with posterior tibial nerve transection.

METHODS—We studied eight cases of limb salvage after traumatic injuries with documented tibial nerve laceration managed at Ganga Hospital, India. Functional and health-related quality of life outcomes were assessed. Outcomes from this case series were compared to outcomes of studies from a systematic literature review on salvage of the severely injured lower extremity.

RESULTS—Patients in this case series reported mild pain (median score 20 on a 100 scale visual analog scale) with some return of plantar sensation in patients with tibial nerve repairs (median score 2/5). Patients demonstrated a decrease in ankle motion (27.5 degrees plantar flexion, 10 degrees extension) and muscle strength (median heel flexor score 3/5). All patients could ambulate independently. Quality of life and function measured by validated instruments revealed minimal disability. We identified 1,767 articles on lower extremity trauma and 14 articles were systematically reviewed. Relative to the case series, published articles reported similarly diminished ankle motion and muscle strength, with reports of mild pain in select studies. Patient reported outcome instruments found variations in the degree of physical disability based on time from the injury.

CONCLUSIONS—Though limited in number, this case series demonstrates the value of limb salvage even for patients with posterior tibial nerve injury.

Keywords

Lower Extremity Salvage; Posterior Tibial Nerve Injury; Severe Lower Extremity Injury; Lower Extremity Trauma; Functional Outcomes; Patient Reported Outcomes

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INTRODUCTION

Severe lower extremity trauma remains a common challenge for the reconstructive surgeon, and debate continues over the choice of amputation and limb salvage (1). Rates of open long bone fractures have been reported at 11.5 per 100,000 persons per year, with the majority of injuries occurring in the lower extremity (2). Based on hospital discharge data, approximately 3500 trauma related lower extremity amputations are performed annually in the United States (3). Only a fraction of these amputees are able to return to the workforce, with many having to change their vocations and/or work part-time (4).

Limb salvage in appropriately selected patients offers advantages over amputation. Healthcare cost associated with amputation can be much higher than the cost associated with salvage. MacKenzie et al (5), estimated projected lifetime costs with amputations to be over three times as much as salvage (\$509,275 vs \$163,282) in the United States. Patients with salvaged extremities have also been shown to benefit from an increase in Quality Adjusted Life Years (QALYs) relative to similar patients with amputations (1).

Though amputations are necessary in some patients with substantial injuries, challenges remain when considering pertinent injury related factors to guide surgical decisions in these patients (6-9). One such critical factor considered preoperatively is the function of the posterior tibial nerve at initial presentation. The absence of plantar sensation at the time of presentation remains an important factor in decisions favoring amputation, even in regions of the world with expertise and available resources for complex reconstructive procedures (10). An anticipation of poor functional outcomes with injury to the posterior tibial nerve, in many cases, triggers a decision for amputation. Some have suggested that the absence of plantar sensation at initial presentation is a poor indication for amputation, primarily because injury to the nerve and loss of sensation may be transient (11). There is, however, limited evidence in the literature to support reconstruction in lower extremity injuries with actual disruption of the posterior tibial nerve.

The aim of this study is to assess outcomes of limb salvage in patients with severe lower extremity trauma with injuries to the posterior tibial nerve. We review the literature to help inform decisions made in this population of patients in a comparative effectiveness strategy. We apply the experiences from an established reconstructive center in India to help other nations in reflecting on their reconstructive philosophy.

METHODS

CASE SERIES

A series of 8 cases of severe lower extremity trauma with injury to the posterior tibial nerve, managed at Ganga Hospital, India were evaluated. Patient and injury characteristics are presented in Table 1. An average of 350 open tibia and fibula fractures are managed annually with an average of 75 below-the-knee amputations performed. Decisions on limb salvage versus amputation in severe distal lower extremity traumatic injuries are primarily based on the ability to achieve bony union in a relatively short time frame. Amputations are performed in the setting of infections that prevent bony union, when stable soft tissue

coverage cannot be provided and when the bony defects are beyond bridging by bone transport or free fibula transfers. These considerations take into account patients goals with a perspective of the timeframe for recovery. Posterior tibial nerve injuries are not a specific consideration in the decision making process.

Six of eight patients sustained crush injuries to the lower extremity, primarily from road traffic accidents (4 of 6 patients) and two patients sustained sharp traumatic lacerations. All patients underwent limb salvage procedures with fracture stabilization as needed; soft tissue reconstruction and posterior tibial nerve repairs were performed in all cases. Quality of life and functional outcomes after salvage including range of motion (ROM) at the ankle, muscle strength, plantar sensation, pain, weight bearing status, gait and work status were evaluated by treating physicians. Assessment measures utilized are presented in Table 2. Outcomes from the case series were then evaluated in comparison to outcomes of studies in the English literature on salvage of the severely injured lower extremity.

SYSTEMATIC REVIEW OF THE LITERATURE

Search Criteria—Reviewers identified relevant observational studies by a systematic search of two large electronic databases: EMBASE and PubMed (1966 to July 2014). In consultation with a medical librarian, search terms used in EMBASE were: ‘leg injury’ OR ‘leg fracture’ OR ‘tibia fracture’/exp AND (‘limb salvage’/exp OR ‘salvage therapy’/exp OR ‘amputation’/exp). Similarly the search terms used in PubMed were: “lower extremity”[ti] AND (“leg injuries/surgery”[mesh] OR “Fractures, open/surgery”[mesh] OR “fractures, open/classification”[mesh] OR gustilo[tiab]). Multiple authors independently examined the titles and abstracts of citations and generated a list of articles for review. The studies were then assessed against predetermined inclusion and exclusion criteria (Table 3) and disagreements were settled by consensus.

Data Abstraction and Analysis—Reviewers extracted data from each eligible study, including patient demographic data, method of salvage, functional outcomes, post-salvage pain, quality of life and return to work. It was not possible to conduct a meta-analysis model of these studies as the outcomes of interest were not reported with a uniform standard. Significant heterogeneity between studies in terms of design and outcomes estimates made any statistical evaluation of outcomes impossible. A narrative review was thus performed.

RESULTS

Systematic Review Study Retrieval and Characteristics

A total of 1,767 citations were identified from our initial EMBASE and PubMed searches (figure 4). With the application of our predetermined inclusion and exclusion criteria (Table 3), 14 articles were selected for use in the study. A summary of study characteristics is presented in Table 4.

Case Reports

Case 1—A 25-year-old male (patient 5 in the series) with a right lower extremity Gustilo III C fracture of the tibia and fibula sustained from a motor vehicle accident. Three weeks

after the initial injury, the patient was transferred to Ganga Hospital after an initial failed attempt at soft tissue reconstruction with a free anterolateral thigh (ALT) flap, performed at another institution. In addition to his soft tissue defect and fractures, the patient had a disruption of his posterior tibial nerve (figure 1). To address his soft tissue deficit, a cross leg flap was performed and divided 3 weeks later. A corticotomy of the tibia with the application of a limb reconstruction system (LRS) was used to manage the patient's segmental bone loss. In a second stage, a sural nerve cable graft was used to bridge the injured tibial nerve gap. At 56 months postoperatively, the patient had good plantar flexion and was ambulatory without assistance (Video).

Case 2—A 27-year-old male (patient 8 in the series) with a crush injury to the right lower extremity from the fall of a heavy stone. Injuries included soft tissue loss, Gustilo IIIC fracture of the tibia and fibula, posterior tibial nerve transection and loss of perfusion distal to the injury. The right lower extremity was managed by debridement of devitalized tissue with placement of an external fixator for fracture stabilization. The foot was revascularized with use of a saphenous vein graft to bridge the posterior tibial artery. An 8cm posterior tibial nerve gap was bridged using 3 cables of sural nerve graft (figure 3) and soft tissue coverage was achieved with a free gracilis flap. Bone transport was later performed with a LRS device for a bone gap of 6cms. On follow-up at 8 years, the patient has no plantar ulcers, ambulates without assistance, plays cricket and drives a two wheeler. He works as a Lecturer in Mathematics at an Engineering college.

Functional and Patient Reported Outcomes

Plantar Sensation—All 8 patients in our cohort had posterior tibial nerve disruptions; 2 had plantar pin prick sensation rated as normal on evaluation of the MTP, mid heel and mid lateral foot (Table 2). Pin prick sensation was impaired in 5 patients and absent in 1 patient. An assessment of light touch at the 1st MTP, 5th MTP, medial foot, lateral foot and heel revealed impairment in 7 of 8 patients, with an overall median score of 2/5 (range 0/5 to 5/5). Bosse et al. (11) reported similar proportions of normal sensation (approximately 55% of patients) at 2 years after injury in limb salvage patients with an insensate extremity at initial presentation when compared to matched limb salvage patients with intact sensation.

Pain—Patients in the series reported a median pain score of 20, indicating mild pain, on a visual analog scale (VAS) ranging from 0-100. Scores in all patients ranged from 0-35. From the literature review, a majority of eligible studies reported ongoing chronic pain in a significant portion of the limb salvage population. Dahl et al (12) reported that 53% (26/49 patients) of limb salvage patients experienced pain with walking ($p = 0.002$), and 29% (12/41 patients) had pain at rest ($p = 0.19$). Utilizing the VAS to measure pain at 24 months follow-up, Archer et al (13) reported that 55% of salvage patients had mild daily limb pain with scores ranging from 5-44 (OR 1.2; $p = 0.61$), and an additional 25% complained of moderate-severe pain with scores ranging from 45-74 (OR 2.2; $p = 0.06$). Rates of intermittent or activity induced limb pain in smaller studies ranged from 5.3% to 69% (14-17).

Ankle Range of Motion—Ankle range of motion of salvaged extremities in patients in this case series was limited (Table 3) with a median extension of 0-10 degrees (range 0-20 degrees) and plantar flexion of 0-27.5 degrees (range 0-40 degrees). At 24 months follow-up, Archer et al (13) reported that 53% of salvage patients (n=290) had diminished ankle plantar flexion of < 50 degrees (normal > 50 degrees) and 68% of patients had diminished ankle extension of < 20 degrees (normal > 20 degrees). In smaller studies, Hertel et al (14) and Lin et al (15) also reported ankle ROM limitations in the majority of their salvage patients: 67% and 88%, respectively. Georgiadis et al (16) reported an average total ankle ROM on with salvage to be 24 degrees (range, 10-60 degrees), compared to an average total ankle ROM of 47 degrees (range, 20 to 65 degrees) in uninjured limbs.

Muscle Strength—Using the British Medical Research Council Scale (range 0-5) to assess muscles innervated by the posterior tibial nerve in our 8 reconstructed extremities, heel flexors and the flexor hallucis longus were found to have median scores of 3, indicating reduced muscle strength allowing for movement of the involved joints against gravity but without additional external resistance. The flexor digitorum longus had a median score of 4, with reduced muscle strength but an ability to move joints against resistance. 3 of 8 patients in the series had scores of 4/5 muscle strength for all assessed muscle groups. Ankle strength in salvaged limbs measured by Archer et al (13) using the manual muscle test (MMT, scores range from 0 to 5) found ankle plantar flexion scores of 4 (considered average or good) in 69% of salvaged limbs (160/233) and ankle extension scores 4 in 61% (141/233) of salvaged limbs.

Return to Work—All 8 patients in the series had returned to work at a mean follow up of 56 months (range 9-96 months). Job descriptions reported by patients included engineering, law enforcement, teaching and heavy machinery repairs. MacKenzie et al (18) reported that 43% of lower limb salvage patients first returned to work at 12 months, 55% at 24 months, and 62% at 84 months. The mean time to return to work for all salvage patients (n= 299) was 549 days. Bosse et al (19) reported that 49.4% of limb salvage patients returned to work at 24 months. In much smaller studies Hutchins (20) reported return to work in 63% of salvage patients, Fairhurst et al (17) reported an average of 18 months for return to work and Nieminen et al (21) reported a 35% employment rate after limb salvage with a mean follow up of 32 months.

Quality of Life—Quality of life as measured by the Short Form 36 health survey (SF-36) found that patients in our case series reported minimal disability with average scores of 82 in both the physical and mental health components of the instrument (a score of 0 indicates maximum disability and 100 indicates no disability). The physical health component assessed general health perceptions, bodily pain, physical and physical role functioning, while the mental health component assessed vitality, mental health, social role and emotional role functioning. Physical function evaluated with the American Academy of Orthopaedic Surgeons Lower Limb Form (scores ranging from 0- poor outcome/worse health to 100- best possible outcome/best health) also revealed minimal disability with an average score of 89.

At 12 months follow-up after limb salvage, Bosse et al (19) reported a mean physical function SIP score of 12.8 (Scores range from 0 to 100, with scores greater than 10 representing significant disability). Physical function improved at 24 months follow-up, with a mean physical SIP score of 9.7. Interestingly, MacKenzie et al (22) noted worsening of the physical function SIP scores at 84 months follow-up in salvage patients with a mean score of 13.3, hypothesized to be secondary to aging and the emergence of secondary conditions such as arthritis and chronic pain. Dagum et al (23), using the SF-36 questionnaire reported worse physical component scores in limb salvage patients (38.1) than scores in patients with chronic lung disease or diabetes. Mental functional outcomes in the limb salvage patients were however similar to those found in the general population.

DISCUSSION

In this series of cases from a single institution, we present functional and patient reported outcomes after lower extremity salvage in patients with traumatic injuries with disruptions to the posterior tibial nerve. Our focus on specific outcomes are based on previous work indicating that patient satisfaction with either amputation or limb salvage is largely dependent on higher physical function, faster walking speed, low pain intensity, ability to return to work, and the absence of depression (24). The measures assessed in the group of patients from Ganga Hospital, suggest similar functional results after salvage of extremities with posterior tibial nerve repair in comparison to lower limb salvage in the absence of nerve injury as presented from our literature review. Decreases in ankle range of motion, limb strength and plantar sensation were noted. In spite of these deficiencies all patients were ambulatory without the need for walking aids and there were no reports of trophic ulcers as a result of plantar denervation. Levels of persistent pain were relatively low and critically, patients reported minimal disability with activities of daily living. These findings support the notion that the insensate foot does not portend to poor functional outcomes with salvage. Even further, these findings suggest that in patients with a definite disruption of the tibial nerve, limb salvage with nerve repair is worthwhile.

One of the better studies to date on the subject of posterior tibial nerve injuries in patients with severe lower extremity injuries was done through the Lower Extremity Assessment Project (LEAP) (11). Patients with severe lower extremity injuries with absent plantar sensation at presentation were compared to patients with similar injuries but intact plantar sensation. At 2 years after limb salvage there were no differences in functional and quality of life outcomes; an equal proportion of patients (55%) in both groups had normal plantar sensation. Though not specifically assessed, it is likely that nerve injuries in the patients with absent plantar sensation in the LEAP study were from neuropraxia and not frank disruption, thus explaining the return of sensation at 2 years of follow-up. In the LEAP series, no patient with an insensate foot underwent posterior tibial nerve exploration and repair. Our case series focuses specifically on a population of patients with documented tibial nerve disruptions which were all repaired. Though plantar sensation to pin prick was impaired in 6 of 8 patients, 2 patients reported normal sensation to pin prick at an average of 56 months follow-up. Sensation to light touch was consistent with these findings, with a median score of 2 of 5 in the salvaged extremities. These findings support the return of some protective plantar sensation after tibial nerve repairs in all but one case.

On a global scale, the World Health Organization estimated approximately 30 million amputees living in low-income countries in 2010 (25). Only 5-15% of patients have access to necessary prosthetic devices (26). A prominent reason for the lack of access is the prohibitively expensive cost of these devices. Patients who undergo lower limb amputations without appropriate access to prostheses are placed at a disadvantage for securing employment in addition to the associated social stigma present in many cultures (27-29). This is especially problematic in developing nations where people walk long distances to get to work and where jobs are less sedentary and require standing and physical labor. One approach to this problem would be to improve on access to and affordability of prostheses. Alternatively, in the arena of severe traumatic lower extremity injuries, efforts can be made to attempt salvage in patients who at present time would undergo amputations, such as patients with posterior tibial nerve disruptions. This aggressive reconstructive approach makes sense in the developing world and also makes sense in developed nations with limited resources. Of note, the absence of programs similar to the Worker's Compensation and disability systems likely plays a role in providing an incentive to return to work in the study population.

Our findings highlight the value of mutual learning in today's global health system. Information and ideas are traditionally transferred from developed nations to developing nations; however, there is a growing appreciation for the potential for learning from developing nations in a process termed reverse or frugal innovation (30). Reverse innovation takes advantage of progress made from developing novel or creative solutions to problems that typically arise from necessity present in lower income countries. Ignoring this reverse flow of innovation places developed nations at risk of forgoing ideas from over half the world and in addition to missing out on potential lessons that could be learned from people without an infrastructure that limits their ability to innovate (31). The approach to management of severe lower extremity trauma provides one avenue for such learning, as based on a lack of viable prosthetic options in a developing nation, reconstructive efforts for limb salvage in patients with transected posterior nerves are maximized, challenging the traditionally accepted paradigm. This is particularly important with potential cost savings from salvage (1, 5) alongside the reality of limited resources in many nations of the world, including the United States.

This study has limitations, some related to the study design. Data on a small number of cases are presented, limiting our ability to make firm recommendations about salvage in this patient population. Our findings do lay the foundation for further studies on this and suggest exciting clinical possibilities for salvage in this patient population. All patients presented were treated in India, thus limiting the generalizability of the results to other populations. Review of the literature on limb salvage was also limited by the strength of the available evidence in the literature. There were no randomized control trials evaluating limb salvage or amputations as patient randomization in this setting would be impossible for clinical and ethical reasons.

CONCLUSIONS

Functional outcomes and quality of life after limb salvage with tibial nerve repair appears to be similar to outcomes after salvage in patients without nerve involvement. Though limited in number, this case series demonstrates the value of limb salvage in a population of patients who in many parts of the world would receive an amputation in anticipation of poor functional outcomes. With a higher utility value and lower cost of limb salvage relative to amputations, consideration should be given for limb salvage in severe lower extremity traumatic injuries with posterior tibial nerve compromise.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1. Attrition Diagram

Case 1. A patient with a right tibia Gustilo III C fracture, prior to reconstruction (above left) and after division cross leg flap (above right). The posterior tibial nerve defect (middle left) defined in a subsequent operation and reconstructed with a sural nerve cable graft (middle right). Patient standing in neutral position (lower left) and on toes (lower right) at 56 months follow up.

Figure 2.

Case 1. A patient with right tibia Gustilo III C fracture, prior to reconstruction (above left) and after division cross leg flap (above right). The tibial nerve defect (middle left) defined in a subsequent operation and reconstructed with a sural nerve cable graft (middle right). Patient standing in neutral position (lower left) at 56 months follow-up.

Case 2. A patient with a crush injury to the right lower extremity (Gustilo IIIC tibia and fibula fracture) with neurovascular compromise to the foot (above left). The lower extremity revascularized with a vein graft, the nerve was repaired with a sural nerve cable graft (above right) and soft tissue coverage established with a free gracilis flap (below left). At 8 years of follow up, the patient weight bearing without assistance (below right).

Figure 3. Attrition Diagram

Case 2. A patient with a crush injury to the right lower extremity (Gustilo grade IIIc tibia and fibula fracture) with neurovascular compromise to the foot.

Fig. 4.
the lower extremity vascularized with a vein graft; the nerve was repaired with a sural nerve cable graft

Fig. 5.
Soft tissue coverage was established with a free gracilis flap

Fig. 6.
At 8-year follow-up, the patient was weight bearing without assistance

Table 1

Patient Injury Characteristics and Functional Outcomes

Patient Number	Age (Years)	Gender	Gustilo Classification	Injuries/Nerve Repair	Number of Operative Interventions	Follow-Up (Months)	Functional Outcomes
1	23	M	Grade III C	Tib-fib fractures EHL, EDL Posterior tibial vessels Posterior tibial nerve Mechanism: Crush Level of nerve injury: Distal third Type of nerve repair: Primary	2	63	Plantar sensation (Light Touch): 2/5 Plantar Sensation (Pin Prick): Impaired Pain (VAS): 30 Ankle ROM: 15 degrees flexion, 10 degrees extension Limb Strength: Heel flexors- 4/5, FDL-4/5, FHL- 4/5 Walking Speed: 1.54 m/s Ambulatory without assistance Follow-up from time of Nerve Repair (months): 63
2	45	M	N/A	Tibialis posterior, Soleus, Peroneal muscle Posterior tibial nerve Mechanism: Crush Level of nerve injury: Middle-lower third Type of nerve repair: Primary	2	83	Plantar sensation (Light Touch): 5/5 Plantar Sensation (Pin Prick): Impaired Pain (VAS): 20 Ankle ROM: 30 degrees flexion, 20 degrees extension Limb Strength: Heel flexors- 4/5, FDL-4/5, FHL- 3/5 Walking Speed: 1.95 m/s Ambulatory without assistance Follow-up from time of Nerve Repair (months): 83
3	37	M	Grade III B	Tib-fib fractures, Posterior tibial nerve Mechanism: Sharp Laceration Level of nerve injury: Distal third Type of nerve repair: Primary	4	91	Plantar sensation (Light Touch): 0/5 Plantar Sensation (Pin Prick): Absent Pain (VAS): 10 Ankle ROM: 0 degrees flexion, 0 degrees extension Limb Strength: Heel flexors- 1/5, FDL-0/5, FHL- 0/5 Walking Speed: 1.71 m/s Ambulatory without assistance Follow-up from time of Nerve Repair (months): 91
4	25	M	Grade II B	Tibia, FHL, FDL, Tibialis Posterior, Posterior tibial vessels, Posterior tibial nerve Mechanism: Crush Level of nerve injury: Distal third Type of nerve repair: Sural nerve cable graft (7cm gap)	2	9	Plantar sensation (Light Touch): 1/5 Plantar Sensation (Pin Prick): Normal Pain (VAS): 20 Ankle ROM: 5 degrees flexion, 20 degrees extension Limb Strength: Heel flexors- 1/5, FDL-1/5, FHL- 1/5 Walking Speed: 0.91 m/s Ambulatory without assistance Follow-up from time of Nerve Repair (months): 9

Patient Number	Age (Years)	Gender	Gustilo Classification	Injuries/Nerve Repair	Number of Operative Interventions	Follow-Up (Months)	Functional Outcomes
5	25	M	Grade III C	Tib-fib fracture, Tibialis anterior, Anterior and posterior tibial vessels, Posterior tibial nerve Mechanism: Crush Level of nerve injury: Middle third Type of nerve repair: Sural nerve cable graft (10cm gap)	8	56	Plantar sensation (Light Touch): 2/5 Plantar Sensation (Pin Prick): Impaired Pain (VAS): 0 Ankle ROM: 30 degrees flexion, 10 degrees extension Limb Strength: Heel flexors- 5/5, FDL-5/5, FHL- 5/5 Walking Speed: 0.78 m/s Ambulatory without assistance Follow-up from time of Nerve Repair (months): 38
6	54	M	N/A	FHL Posterior tibial vessels Posterior tibial nerve Mechanism: Crush Level of nerve injury: Distal third Type of nerve repair: Primary	1	39	Plantar sensation (Light Touch): 2/5 Plantar Sensation (Pin Prick): Impaired Pain (VAS): 5 Ankle ROM: 40 degrees flexion, 20 degrees extension Limb Strength: Heel flexors- 4/5, FDL-4/5, FHL- 4/5 Walking Speed: 1.36 m/s Ambulatory without assistance Follow-up from time of Nerve Repair (months): 39
7	27	M	Grade III C	Tib-fib fracture, Anterior and posterior tibial vessels, Posterior tibial nerve Mechanism: Sharp Laceration Level of nerve injury: Middle-lower third Type of nerve repair: Primary	6	17	Plantar sensation (Light Touch): 0/5 Plantar Sensation (Pin Prick): Normal Pain (VAS): 35 Ankle ROM: 30 degrees flexion, 10 degrees extension Limb Strength: Heel flexors- 3/5, FDL-4/5, FHL- 4/5 Walking Speed: 0.84 m/s Ambulatory without assistance Follow-up from time of Nerve Repair (months): 17
8	27	M	Grade III C	Tib-Fib (segmental), Crush injury to anteromedial and anterolateral compartments, Anterior tibial vessels, Posterior tibial nerve Mechanism: Crush Level of nerve injury: Distal third Type of nerve repair: Sural nerve cable graft (8cm gap)	4	96	Plantar sensation (Light Touch): 3/5 Plantar Sensation (Pin Prick): Impaired Pain (VAS): 5 Ankle ROM: 25 degrees flexion, 10 degrees extension Limb Strength: Heel flexors- 3/5, FDL-2/5, FHL- 2/5 Walking Speed: 0.77 m/s Ambulatory without assistance Follow-up from time of Nerve Repair (months): 96

Tib-fib fracture- tibia and fibula fractures, EHL- extensor hallucis longus muscle, EDL- extensor digitorum longus muscle, FHL- flexor hallucis longus muscle, FDL- flexor digitorum longus muscle. VAS- Visual Analog Scale, ROM- Range of Motion.

Table 2**Measures Utilized in Limb Salvage Patient Assessment**

Outcome Measure	Method of Assessment
Range of Motion	Ankle extension and flexion with standard goniometric technique. Norms determined based on the American Academy of Orthopaedic Surgeons (AAOS). <20 degrees of ankle extension and 50 degrees of ankle flexion considered restricted.
Limb Strength	British Medical Research Council Scale (Grade 5: Muscle contracts normally against full resistance. Grade 4: Muscle strength is reduced but muscle contraction can still move joint against resistance. Grade 3: Muscle strength is further reduced such that the joint can be moved only against gravity with the examiner's resistance completely removed. As an example, the elbow can be moved from full extension to full flexion starting with the arm hanging down at the side. Grade 2: Muscle can move only if the resistance of gravity is removed. As an example, the elbow can be fully flexed only if the arm is maintained in a horizontal plane. Grade 1: Only a trace or flicker of movement is seen or felt in the muscle or fasciculations are observed in the muscle. Grade 0: No movement is observed)
Plantar Sensation	Reconstructed extremities evaluated with an assessment of their sensitivity to pin prick at 1 st MTP, mid heel and mid lateral foot. Sensation rated as normal, impaired or absent. In patients with variable sensation at the 3 areas examined, the foot classified as impaired. Monofilament sensation with Semmes-Weinstein 5.07 monofilament at the following plantar sites- 1 st MTP, 5 th MTP, medial foot, lateral foot and heel. A two-choice forced algorithm used: plantar site is touched during one of two time periods, counting "one, two", and the patients are asked to state the time period (1 or 2) when they felt the stimulus. Correct or incorrect responses recorded and scored (</5).
Pain	Visual analog scale using a 0 – 100mm horizontal line. (5-44mm mild pain, 45-74mm moderate pain and 75-100mm severe pain).
Quality of Life	Short Form 36 (SF-36) American Academy of Orthopaedic Surgeons Lower Limb Form

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Table 3

Functional Outcomes of Lower Extremities after Salvage

Functional Activity	Median	Range
Plantar Sensation		
Light Touch	2/5	0/5-5/5
Pain		
Visual Pain Score	20	0-35
Ankle Range of Motion		
Flexion (degrees)	27.5	0-40
Extension (degrees)	10	0-20
Muscle Strength		
Heel flexors	3	1/5-5/5
FDL	4	0/5-5/5
FHL	4	0/5-5/5
Ambulation		
Walking speed (m/s)	1.14	0.77-1.95

FDL- flexor digitorum longus muscle, FHL- flexor hallucis longus muscle

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Table 4

Predetermined Inclusion and Exclusion Criteria for Systematic Review

Inclusion Criteria
Primary data from prospective and retrospective observational studies
English language
Human Studies
Studies that include severe lower limb threatening injuries managed with salvage
Studies that stratify specific outcomes of interest with limb salvage
Minimum of 1 year patient follow up
Exclusion Criteria
Review, technique or case report articles
Studies with fewer than 10 total patients with salvaged lower extremities
Studies focused on amputations
Studies with no relevant extractable outcomes
Studies not published in English

Table 5

Summary of Study Characteristics

Authors	Year	Study Design	Limb Salvage Patient No.	Mean Age (Years)	Follow Up (Range)	Outcomes Measured	Results	Conclusions
Ly et al (7)	2008	Prospective	407	36	24 mo (N/A)	Functional outcome (SIP)	-Median SIP scores were 15.2 and 6.0 at 6mo and 24mo, respectively. -No scoring system was predictive of SIP outcomes at 6mo or 24mo.	Current injury severity scores are not predictive of the functional recovery of patients who undergo successful limb reconstruction.
Lin et al (15)	2007	Retrospective	19	32.4	12 mo (N/A)	Pain Need for orthosis Functional outcome Muscle power Foot posture	-Minimal chronic pain post-salvage. -Majority of patients did not require orthoses. -Muscle power varied widely. -Majority of patients with ROM limitations post-salvage.	Functioning muscle transfers post-trauma result in acceptable functional outcomes and reliable limb salvage.
Mackenzie et al (18)	2006	Prospective	299	N/A	84 mo (N/A)	Return to work	-Median time to RTW was 1.6yrs post-injury. -Patients working at 84mo were limited in their abilities 20-25% of the time. -Factors associated with high rates of RTW ($p < 0.05$): younger age, Caucasian, higher education, nonsmoker, high self-efficacy, pre-injury job tenure, higher job involvement, no litigation.	RTW after severe lower extremity trauma remains challenging. Several factors that influence RTW that suggest strategies for intervention were identified, namely pain and self-efficacy.
Archer et al (13)	2006	Prospective	381	35.6	24 mo (N/A)	Range of motion Manual muscle test Walking speed Gait deviation Pain Balance Strength Muscle atrophy	-At 24mo post-salvage, over half of patients had decreased ankle ROM, but average to good ankle strength -At 24mo, 55% of salvage patients had mild daily limb pain (OR 1.2; $p = 0.61$); 25% complained of moderate-severe pain (OR 2.2; $p = 0.06$).	The most significant clinical factors associated with gait asymmetry and decreased walking speed post-salvage include decreased ankle ROM, decreased knee and hip strength, a non-reciprocal stair-climbing pattern, and poor single-leg standing balance.
Bosse et al (11)	2005	Prospective	55	N/A	24 mo (N/A)	Pain Range of motion Walking aid Reciprocal stair climbing Sensation Functional outcome (SIP)	-Insensate salvage group patients did not report or demonstrate significantly worse outcomes at 12- or 24mo post-injury compared to subjects in the insensate amputation or sensate control groups	Insensate foot at time of presentation did not adversely affect limb salvage outcome. More than half of patients presenting with an insensate foot treated with limb salvage regained

Authors	Year	Study Design	Limb Salvage Patient No.	Mean Age (Years)	Follow Up (Range)	Outcomes Measured	Results	Conclusions
							<ul style="list-style-type: none"> -55% of patients in the insensate salvage group and sensate control groups had normal plantar sensation at 2yrs post-injury -No significant difference noted in overall, physical, or psychosocial scores amongst the 3 subject groups. 	sensation at 2 years. Initial plantar sensation is not prognostic of long-term plantar sensory status or functional outcomes and should not be a component of a limb-salvage decision algorithm.
Mackenzie et al (22)	2005	Prospective	252	N/A	84 mo (N/A)	Functional outcome (SIP)	<ul style="list-style-type: none"> -Physical and psychosocial functioning deteriorated between 24- and 84mo post-injury. -At 84mo post-injury, half of all had a physical SIP > 10, showing substantial disability -No significant difference in the psychosocial outcomes according to treatment group -Except for age, predictors of poor outcome were similar at 24- and 84mo post-injury. 	Limb salvage results in functional outcomes equivalent to those of amputation. Regardless of treatment option, long-term functional outcomes are poor. Priority should be given to efforts to improve post-acute-care services that address secondary conditions compromising optimal recovery.
Bosse et al (19)	2002	Prospective	330	35.8	24 mo (N/A)	Functional outcome (SIP) Return to Work Complications	<ul style="list-style-type: none"> -No significant difference in SIP scores between limb salvage versus amputation (11.8 vs. 12.6, $p = 0.53$). -Similar proportion of patients who underwent amputation and salvage RTW at 2 years (53% vs 49.4%). -Predictors of a poor SIP score included: rehospitalization, low education level, non-white race, poverty, lack of private health insurance, low self-efficacy, smoking, litigation. 	Two-year outcomes for limb salvage versus amputation are equivalent.
Dagum et al (25)	1999	Retrospective	40	37	71 mo (7-147 mo)	SF-36 scoring WOMAC scoring Patient preference Return to work	<ul style="list-style-type: none"> -Limb salvage patients had worse SF-36 physical component scores than patients with chronic lung disease or diabetes. -SF-36 mental component score was comparable to that of a healthy population. -92% of patients preferred their salvaged leg to an amputation at any stage of their injury. 	Patients not meeting the standard indications for a primary amputation should undergo limb salvage, because a successful salvage will have a better functional outcome compared to amputation. Patients overwhelmingly preferred their salvaged leg to an amputation.

Authors	Year	Study Design	Limb Salvage Patient No.	Mean Age (Years)	Follow Up (Range)	Outcomes Measured	Results	Conclusions
Nieminen et al (21)	1999	Retrospective	58	38	32 mo (6-177 mo)	Complications Use of orthoses Employment rate	<ul style="list-style-type: none"> - Failure rate among free flap transfer salvage patients was 2% with amputation rate of 5%. - 13 patients required long-term use of orthoses - At 32mo follow-up, 35% of salvage patients were employed. 	Free flap transfers add a well-vascularized muscular cover that is beneficial for healing of the fracture and prevention of infection. Complicated leg injuries should be centralized to hospitals with microsurgical facilities available.
Hertel et al (14)	1996	Retrospective	21	22	86 mo (23-143 mo)	Walking ability Pain Muscle atrophy Range of motion Return to work Cost	<ul style="list-style-type: none"> -Ankle ROM limitations in 67% of salvage patients -Total rehab time was 12mo for amputation and 30mo for salvage ($p < 0.009$). -36% of the amputees and 19% of salvaged patients were retrained to a different profession ($p < 0.025$). -Median pain score (0-5) for salvaged patients was 0.9 ($p < 0.05$). -Median walking distance was 5.25km for the amputees and 12km for the reconstructed patients ($p < 0.018$). 	For potentially salvageable legs, reconstruction is advisable because the functional outcome was better than for amputation and there was no permanent social disintegration due to the long treatment. Total costs for reconstruction were far lower than for amputation.
Dahl et al (12)	1995	Retrospective	53	28	9 yrs (2.5-13.6 yrs)	Pain and leg swelling Use of cane Change in sports activities Employment Patient preference	<ul style="list-style-type: none"> -53% of limb salvage patients experienced pain with walking ($p = 0.002$), while 29% had pain at rest ($p = 0.19$). -59% of salvage patients complained of leg swelling, compared to 7% of amputees ($p < 0.00005$). -63% of salvage patients noted a decrease in daily activity, compared to 50 of amputees ($p = 0.59$). - 14% of salvage patients required use of a cane, compared to 17% of amputees ($p = 1.0$). 	The long-term functional and social results after free tissue transfer are almost the same as those achieved after primary amputation. Patients selected for salvage should be thoroughly informed about the risk of long-term hospitalization, pain and edema; however, the benefits include lack of prosthesis and limb salvage.
Fairhurst (17)	1993	Retrospective	12	25	Minimum of 12 months after treatment (N/A)	Quality of Life Pain Function score Return to work Return to sport	<ul style="list-style-type: none"> -58% of salvaged patients had mild to moderate pain intermittently. -Ankle ROM limited in 50% of salvaged limbs. -Amputees and salvaged tibial scores were not statistically significant. 	The study concurs with the belief among many Orthopaedic surgeons that function of a patient with a below-knee amputation and a well-fitting modern prosthesis is superior to

Authors	Year	Study Design	Limb Salvage Patient No.	Mean Age (Years)	Follow Up (Range)	Outcomes Measured	Results	Conclusions
							-Quality of life was similar and not statistically significant between amputees and salvage patients. -Average of 18mo for RTW in salvage patients.	that of the salvaged Grade III tibial fracture.
Georgiadis et al (16)	1993	Retrospective	29	33	35 mo (20-96 mo)	General well-being Time to full weight-bearing Function Life satisfaction Hospital length of stay	-Average hospital length of stay for salvage was 71 days. -69% of salvage patients experienced limitations in walking due to pain or swelling. -73% of salvage patients required crutches or a cane. -Only 6% of salvage patients could climb stairs without difficulty. -Average total ankle ROM with salvage of 24 degrees (range, 10 to 60 degrees), compared to an average total ankle ROM of 47 degrees (range, 20 to 65 degrees) in uninjured limbs.	Patients who had had a successful limb-salvage procedure took significantly more time to achieve full weight-bearing ($p < 0.05$), were less willing or able to work ($p < 0.01$), and had higher hospital charges ($p < 0.006$) than the patients who had been managed with an early below-the-knee amputation.
Hutchins (20)	1981	Retrospective	23	47.2	56 mo (N/A)	Return to work Length of hospital stay	- Return to work in 63% of salvage patients. - Mean hospital stay in salvage patients 14.8 weeks. - Factors associated with poor outcome following limb salvage included: elderly patients, proximal and distal third fractures, extensive soft tissue injury, and accompanying multiple injuries.	The disability resulting from amputation is high and does not justify recommending earlier amputation.

Mo – month, Yrs – years, SIP- Sickness Impact Profile, SF-36- Short Form 36 Health Survey, WOMAC- Western Ontario and McMaster Universities Arthritis Index, ROM- range of motion, RTW – return to work, N/A- Not Available