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Traumatic Amputations

There are approximately 2 million people in the United States living with amputations. The majority of amputations are due to non-traumatic reasons, such as diabetes, peripheral artery disease, and cancer. However, trauma is responsible for almost half of the cases of limb loss in the United States.[1] Although traumatic amputations may involve any body part, they typically refer to either the partial or total loss of an extremity. Traumatic amputations can be extremely debilitating injuries that have long-term functional and psychological outcomes. The authors review traumatic amputations, diagnostic evaluation, and management.

— Ann M. Dietrich, MD, FAAP, FACEP, Editor

Introduction

Public awareness of traumatic amputations has increased in the past two decades because of the prevalence of veterans living with amputations. However, traumatic amputations always have been pervasive in the civilian population. In fact, the rate of limb injuries has increased significantly over the decades and is projected to continue increasing as a result of modernization and intensifying violence.[2,3]

Traumatic amputations occur in only 1% of all trauma patients, but they are associated with significant morbidities and a mortality rate of almost 15%.[4,5] The majority of civilian-related traumatic amputations are accidental and associated with motor vehicle collisions (MVCs), machinery, and gun violence. Major amputations, such as those proximal to the hands and feet, often are associated with life-threatening exsanguination. Military experience has demonstrated that immediate treatment and stabilization of patients with traumatic amputations directly correlates with improved survival. Therefore, successful management of traumatic amputations requires rapid and efficient triage, as well as the collaboration of emergency care providers and surgical specialists to effectively manage these patients and associated amputations.

Military Experiences

Uncontrolled hemorrhage due to improvised explosive devices (IEDs) was the most common cause of military deaths during the wars in Iraq and Afghanistan.[3] As time went on, smaller devices, such as anti-personnel land mines, were used more frequently. These devices are activated by trip wires or stepping on them, resulting in smaller explosive charges that produce multiple fragments. The change in device mechanics, in addition to advances in protective equipment and military medicine, has led to a lower mortality rate and an increased number of survivors with traumatic amputations.

The mechanisms of traumatic amputations in the military are often drastically different from those that occur in the civilian population. However, the

EXECUTIVE SUMMARY

- Motor vehicle collisions comprise of 8% of all pediatric amputations and are the leading cause of all adult amputations.
- Firearms are involved in 6.1% of amputations. Unintentional firearm amputations most frequently involved toes, while intentional firearms involvement resulted in above knee, below knee, and finger amputations.
- Guillotine amputations typically occur as a result of machinery such as saws, where the body part is sharply severed from the body. These amputations have well-defined edges with structural injuries occurring at the same level. Therefore, it is the easiest amputation type for replantation.
- Early tourniquet use is associated with a 90% survival rate. Inadequately used tourniquets, such as those misplaced distal to the wound, placed upside down, or placed incorrectly, all are associated with increased morbidity and mortality.
- Optimally, the ischemia time should be minimized to less than six hours to maximize limb salvage.

increasing incidence of terrorist events worldwide highlights the need to translate military medicine to civilian populations. This was well demonstrated in the Boston Marathon bombing of 2013, which was the first modern mass-casualty event that mirrored the damage caused by IEDs on the battlefield. There were 152 patients who presented to the ED within 24 hours of the explosions, and 66 of those patients had an extremity injury. Twenty-nine patients had life-threatening exsanguination due to an extremity injury, and 17 patients had traumatic amputations. This event demonstrated how critical it is to translate the advancements in military medicine and apply them to civilian medicine.[6,7]

Civilian Experiences

Despite the increase in terrorist attacks and other mass casualty events, traumatic amputations in the civilian population still most commonly are due to non-explosive mechanisms. In the adult population, the most common causes of traumatic amputations are blunt injury. Almost half are related to MVCs, followed by machinery-involved industrial accidents, motorcycle accidents, and other mechanisms such as railway accidents.[5,8] Most patients are males and are between the ages of 15-40 years. Between 60-80% of amputations involve digits, and lower extremities are the second most common sites of amputations.[1,5] Upper extremity amputations are significantly more common after penetrating trauma, most likely because high-velocity injuries are associated with concomitant vascular injuries. Lower extremity amputations tend to occur through bone shafts instead of joints, and the most common site is the upper third of the tibia.[2,9] The need for multiple limb amputations has been demonstrated to be an independent risk factor for death; one study demonstrated a mortality of 23.2% with multiple amputations, compared with an overall amputation mortality of 15%.[5]

The workplace is a common environment for traumatic amputations, which therefore affect a younger male population. Thousands of occupational amputations occur each year and result in significantly more serious consequences compared to hobby-related accidents. The annual cost of work-associated amputations is estimated to be in the billions of dollars, likely due to longer hospital stays, increased work stoppage, and delayed resumption of work.[10-12] The highest rates of work-related amputations typically occur in paper and wood product manufacturing, usually involving loggers or carpenters.[11,12] Other situations in which amputations occur more frequently include food manufacturers, employment service companies, and heavy manufacturing.[10] Most amputations occur during the use of machinery, such as power hand tools, or as a result of extremities being caught in or between objects. One study found that the hand was injured in the majority of cases, and that 63% of injuries tended to occur on the left side. It was usually on the radial side of the hand when only one finger was injured, while the middle digits were involved primarily when multiple fingers were injured.[12]

Similar digit amputation injuries are seen in non-occupational wood-working injuries, such as those involving table saws. There are approximately 30,000 table saw injuries treated in the emergency department (ED) annually, and more than half of these injuries occur at home.[12] Hobby-related injuries tend to occur in an older (> 40 years of age) population compared to work-related injuries. Most of these injuries are due to direct contact with the blade, resulting in the severing of tendons, nerves, and vessels in a guillotine-like manner. They are associated with a 10-15% amputation rate of fingers and thumbs and can have significant long-term morbidity including functional and sensory deficits.

Despite the revision of safety standards for table saws in 2005, such as new requirements for modular blade guards and other features to reduce kickback, there are still a stable number of saw-related injuries. Interestingly, one study demonstrated that education has little effect on the risk of injury. For example, 51% of injured workers had taken a wood-working class, while 5% had taken a table saw-specific course. Furthermore, of those injured by machinery, 68% of workers were wearing safety gear compared to 31% of hobbyists. This illustrates the importance of vigilance in addition to the use of protective equipment and safety mechanisms when using wood-working tools.[13]

Traumatic amputations also are commonly seen in the pediatric population. The occurrence of traumatic amputations in this population has a bimodal distribution. The injuries often occur in the youngest (5 years of age or younger) and the oldest (15-17 years). Males are involved three times more often than females.[14] The mechanisms of traumatic amputations are similar to those for adults and include MVCs, machinery, firearms, and other methods such as

Table 1. Causes of Traumatic Amputations, by Age Group[5,14,16]

Pediatric	Adult	Geriatric
• Caught-between mechanisms, doors (16.3%) • Machinery (15.6%) • Motor vehicle collisions (8%) • Firearms (6.1%) • Off-road vehicles (6.1%)	• Motor vehicle collisions (43%) • Industrial (26%) • Motorcycle accidents (21%) • Other (10%)	• Saws (45%, table > power saws) • Other products, food processors (32%) • Caught-between mechanisms, doors (10%) • Lawn mower (10%) • Snowblower (3%)

off-road vehicles and caught-between mechanisms. The most frequently amputated body parts are the fingers, followed by the toes.

The most common mechanism of pediatric amputations is caught-between injuries, such as those involving doors. There are approximately 140,000 door-related injuries per year, and they tend to occur in children 5 years of age or younger, with an average of one injury every four minutes. These injuries have an associated overall amputation rate of 6.1%.[15] Machinery is the second most common cause (15.6%) and occurs throughout all pediatric ages. Powered lawn mowers cause most machinery-related injuries and involve lower extremity amputations, especially in younger children. Children younger than 5 years of age are six times more likely to sustain a severe lower extremity amputation compared with those older than 6 years. This is most likely because of lower skeletal mass and skeletal immaturity.[14] Table saws pose a risk for the pediatric population as well. One study found that injuries in the pediatric population occurred in school woodshop courses. Improper equipment was cited as a cause in 38% of cases.[13]

MVCs comprise 8% of all pediatric amputations and are the leading cause of all adult amputations. The majority occur in driving-age patients and are associated with significant amputations. One study demonstrated that MVCs were the cause of a majority of upper extremity amputations, frequently resulting in amputations at the level of the shoulder/upper arm (61%), followed by forearm/elbow (31%), and hand/wrist (13.8%). The majority of lower extremity amputations occurred proximal to the toes and often were associated with concomitant open fractures, vascular injuries, and compartment syndrome.[14] Firearms are involved in 6.1% of amputations. Unintentional firearm amputations most frequently involved toes, while intentional firearm injuries resulted in above knee, below knee, and finger amputations. Off-road vehicles comprise 6.1% of amputations and occur in all age groups.

The elderly are another under-recognized, yet significantly at-risk population for traumatic amputations. They are at increased risk because of age-related changes in vision and coordination, as well as decreased gray matter in the prefrontal and parietal cortex, which primarily is responsible for motor control.[16] One study demonstrated that 42% of traumatic amputations occurred in patients 65 years of age or older, and approximately 12% of ED visits by the elderly in 2001 were due to traumatic amputations.[1] The most frequently amputated body part was the finger (95%), and the most common mechanism was powered saws (45%), followed by other consumer products (such as food processors), caught-between mechanisms (such as doors), lawn mowers, and other machines. The majority of elderly patients are treated and released from the ED because replantation is rarely performed in the elderly. Studies have demonstrated higher replantation failure rates in those older than 50 years of age.[16] Table 1 lists the most common mechanisms of injury based on age group.

Pathophysiology

Understanding the mechanism of injury is important in the evaluation and treatment of traumatic amputations. The type of mechanism determines the extent of skeletal, soft tissue, vascular, and nerve damage as well as the possibility for replantation. Guillotine amputations typically occur as a result of machinery, such as saws, where the body part is sharply severed from the body. These amputations have well-defined edges with structural injuries occurring at the same level. Therefore, it is the easiest amputation type for replantation.

An avulsion amputation occurs when there is forced stretching and tearing of tissue, resulting in degloving injuries. The skin and soft tissue can be pulled off, and the nerves and vascular supply can be destroyed at levels different from the original site of separation. This makes limb salvage less likely to be successful. A common example is a ring avulsion, which occurs when a patient's ring is caught on an object during fast movement, such as a fall or a jump. The abrupt tug can cause a tearing of the finger from the ring, sometimes resulting in amputations. Crush injuries, such as those occurring in MVCs, also are associated with more extensive soft tissue damage, which either can be localized or extend from the wound edges, depending on the force of injury. These injuries often require debridement to healthy tissue, and also are less likely to be successfully reattached.[17]

The most catastrophic mechanism of traumatic amputations is explosive devices, which result in complex injuries with global structural damage. (*See Figure 1.*) The mechanism of explosions occurs in two major steps. Gases are produced rapidly under high pressure, causing detonation to occur quickly from the initial site of explosion. The initial shock wave affects the bone first and causes bony fractures. The subsequent blast wind causes detonation products and nearby debris to contact the limb, causing soft tissue destruction and further stress to the already damaged bone, resulting in limb avulsion and/or amputation. This two-wave

Figure 1. Explosive Upper Extremity Injury

phenomenon results in injuries that affect all tissues and result in extensive soft tissue loss, and nerve and vascular damage that often is several levels proximal to the bone injury.[3,18]

The effect of blast injuries on extremities can be classified into three distinct zones. Zone 1 involves the area closest to the site of injury, where there is widespread destruction of the skin, tendon, muscles, and neurovascular structures. Soft tissue injuries are extensively contaminated, making it difficult to salvage. Zone 2 involves focal areas of injury most often localized by the major neurovascular bundles. Lacerated blood vessels and endo- and epineural hemorrhage causes subsequent vasospasm, impaired blood flow, and nerve edema. Zone 3 refers to the injured area most distal from the site of injury. This area involves avulsed small arterioles off the main vessels, impaired venous return, and demyelination of peripheral nerves.[18] These zones of injury highlight the catastrophic and widespread effects of explosions on extremities, which makes replantation nearly impossible.

The various mechanisms of amputations can result in either partial or complete amputations. In a complete amputation, the body part is entirely separated from the body. The transected vasculature has the tendency to retract into the stump and to vasospasm, which results in decreased hemorrhage. A partial amputation occurs when the distal body part is still connected in some way, whether it is the bone, vessels, soft tissue, or even a small bridge of skin. If vessels are severed only partially, they are unable to retract and therefore are associated with continued hemorrhage and an increased risk of life-threatening exsanguination.[19]

Prehospital Considerations

The initial assessment and management of patients with traumatic amputations remains the same as for any other trauma patient and should follow standard Advanced Trauma Life Support (ATLS) principles. It is important to note, however, that hemorrhage control of traumatic amputations is directly correlated with improved survival. As a result, the mnemonic ABC (airway, breathing, circulation) was revised in the military population to CAB to ensure that life-threatening hemorrhage was stopped as soon as possible.[3,20]

Bleeding should be controlled by direct pressure or through the use of commercially available tourniquets. Tourniquets traditionally have been used to control extremity bleeding after amputations. However, historical use was associated with life-threatening complications, so it often was condemned and used only as a last resort. This opinion is changing gradually with the increasing use of tourniquets in recent wars, and the efficacy is well-documented in modern military literature. Purpose-designed tourniquets have been shown in several studies to have superior hemostatic results and to reduce mortality from extremity wound exsanguination with minimal complication rates.[6] However, the efficacy of tourniquets depends on appropriate and early use. One study evaluating tourniquet use in situations in which the patient bled to death, lost vital signs, or was in shock found that the tourniquet typically had been applied too late and was associated with a 90% mortality rate. On the other hand, early tourniquet use was associated with a 90% survival rate. Inadequately used tourniquets, such as those misplaced distal to the wound, placed upside down, or placed incorrectly, all are associated with increased morbidity and mortality.[20]

Improvised tourniquets also are unsuitable and should be avoided. An appropriate tourniquet must be wide enough to compress both arterial and venous vasculature without creating pressure necrosis of the skin or causing neuropraxia. This makes improvised tourniquets, such as rubber tubing, ineffective. Tourniquets also must be placed snugly around the extremity proximal to the wound and should have an attached device, such as a windlass, to generate adequate circumferential pressure. Improvised tourniquets lack the necessary characteristics for successful tourniquet use and therfore are rarely effective and often more harmful than helpful.

Complications of improper tourniquet application include pressure necrosis, neuropraxia, and paradoxical bleeding. Nerve palsy at the level of the tourniquet usually resolves within three days. Tourniquet duration is not associated with nerve palsy. Paradoxical bleeding is a devastating complication that often is seen in venous tourniquets that do not adequately provide arterial control. While these tourniquets may create initial adequate hemorrhage control, the continued distal arterial flow in the absence of venous return results in distal venous engorgement, blood pooling, and edema. There is increasing limb girth that can cause compartment syndrome, as well as expanding hematoma formation. This will result in the loss of hemorrhage control and subsequent hypovolemic shock. It occurs quickly and is worse than if no tourniquet had been used at all.[6,20]

The Boston Marathon bombing highlighted the deficiency in translating the advances in military medicine to civilian medicine, particularly with respect to traumatic amputations and the use of tourniquets. Twenty-seven tourniquets were applied in the aftermath of the bombing: 16 of 17 traumatic amputations, five of 12 lower extremities with major vascular injuries, and six with soft tissue injuries. All of the devices used were improvised tourniquets, including those placed by prehospital medical providers. The lack of consistent optimal tourniquet use in the prehospital environment resulted in the creation of a taskforce called the Joint Committee to Create a National Policy to Enhance Survivability from Intentional Mass Casualty and Active Shooter Events (also known as the Hartford Consensus) to improve the prehospital management of mass casualties and to highlight the importance of expeditious control of bleeding in the prehospital setting.[6,21]

A survey performed by the Hartford Consensus in 2015 demonstrated that a majority of the public (94%) would be very likely or somewhat likely to try to stop bleeding if they were able to provide first aid. The majority also were interested in having bleeding control kits made available in public places and were interested in taking a class on bleeding control and other first-aid techniques. Consequently, the Hartford Consensus, along with the Department of Homeland Security (through the National Security Council) and the National Association of Emergency Medical Technicians (through the Bleeding Control [B-Con] course), have developed the "Stop the Bleed Campaign" throughout the United States.[21,22] This campaign focuses on the education of nonmedical providers, including law-enforcement officers and bystanders, on how to perform external hemorrhage control before professional first responders arrive on scene.[21]

Once hemorrhage is controlled and the patient is stabilized as much as possible, the patient should be transported rapidly to a trauma center. In cases of complete amputation, the amputated body part should be recovered if possible. To protect the body part, gross debris should be removed and the part should be wrapped in either a clean, damp cloth or sterile, saline-soaked gauze. The body part then should be placed in a water-tight container, such as a plastic bag, and stored in an ice-filled container such as a cooler. The purpose of this is to maintain cold ischemia time and increase the success of replantation. However, it is important that the amputated part not come in direct contact with ice or water and that it is not inadvertently frozen. Dry ice should never be used as a cooling agent because it can precipitate crystal formation and further tissue damage.

If body parts are partially amputated, any gross debris should be removed and the ends should be re-aligned as much as possible. The parts then should be protected and wrapped together with gauze and/or a splint to prevent further injuries to the proximal and distal ends. These patients should be sent to Level I trauma centers.[4,17,23]

Hospital Management

Once the patient arrives at the hospital, it is important to remember that the principles of assessing these patients remain the same as those for any other trauma patient. A thorough primary and secondary evaluation must be performed to exclude other more life-threatening concomitant injuries. Patients who present with lower extremity amputations are more likely to be severely injured with higher injury severity scores and a mortality rate of 18%.[4] This is likely because the force required to cause lower extremity amputations is much higher than that for upper extremity amputations. Consequently, a higher suspicion for concomitant injury is required for patients who present with lower extremity amputation(s). They are more like to have hypotension and a Glasgow Coma Score (GCS) of less than 8 in the setting of concomitant intracranial, intra-abdominal, and intrapelvic injuries.[5]

Tourniquets should be placed in those who are experiencing life-threatening hemorrhage. Avoid exceeding 30-40 mmHg above the patient's systolic blood pressure. It is also important to note the time when tourniquets are applied in either the prehospital or hospital setting so that the ischemia time can be noted appropriately. Vessels should not be tied off or clamped in an attempt to control bleeding because it decreases the amount of viable vasculature, making it more difficult for successful reconstruction and potential replantation.

In major traumatic amputations involving injuries proximal to the digits and toes, the patient should be taken to the operating room as soon as possible. This usually occurs once the patient has been completely assessed and all other potential causes for life-threatening injuries have been triaged and/or treated appropriately. Surgical treatment consists of hemorrhage control and surgical debridement to excise all necrotic and foreign material of the residual limb.[3] Viable vascular and nerve structures should be identified and preserved if possible. The wound cannot be closed primarily because of the usual extensive contamination and often requires multiple operative debridements.[2] In cases of replantation, the amputated limb is treated in the same manner with surgical debridement and identification of remaining vital vascular and nervous structures.

A decision also must be made regarding whether to perform a primary completion amputation or possible replantation. Primary or early amputations refers to the limbs that are amputated as a primary treatment modality (less than 12 hours from admission). Historically, the decision to perform primary amputations was dependent on various scoring systems that were used to classify extremity injuries. The most well-known scoring systems are the Mangled Extremity Severity Score (MESS), which is used to classify mangled extremities, and the Gustilo-Anderson Classification, which is used to classify open fractures.[2] Typically, MESS scores of greater than 7 were associated with amputation rates of up to 41%.[5] However, these scoring systems were developed more than 15 years ago. Since that time period, significant advances in medicine, such as resuscitative techniques, surgical techniques involving reconstruction methods, and available devices, have made these scoring systems near obsolete. Several recent studies have demonstrated that these scoring systems have a relatively low sensitivity and specificity and are not predictive of short- or long-term functional outcome. Therefore, the clinical utility of these scores has not been demonstrated and should not be used as the sole determinant of extremity amputation.[2,3,24]

Current Eastern Association for the Surgery of Trauma (EAST) guidelines recommend primary amputation in specific scenarios, including complex combined arterial and skeletal injuries in the setting of penetrating injury, tibial or sciatic nerve transections, prolonged ischemia, massive soft tissue injuries, severe contamination, open comminuted tibial-fibular fractures (Gustilo III), or life-threatening associated injuries.[24] However, many studies have demonstrated that mangled extremities have an unpredictable prognosis, and the decision to amputate or salvage should be assessed carefully.[2] The decision does not need to be made at the initial operation. Although a majority of amputations are primary, there is a subset of patients who undergo secondary or late amputations. This refers to amputations performed in a delayed fashion (more than 12 hours after admission).

The decision to replant an amputated body part requires the collaboration between different surgical subspecialties, including trauma, orthopedic, vascular, and plastic surgery. It depends on several factors, including the mechanism and extent of injury, the patient's overall status, and the hospital/surgeon's status. Microvascular limb reconstruction is technically demanding, time-consuming, and has significant associated complications such as infection, bone non-union, and osteomyelitis. Failed attempts at limb salvage are associated with prolonged hospitalization, multiple surgical procedures, pain, and psychological trauma. Even if limb salvage is successful, these procedures still are associated with complications such as pain, infection, and the need for further procedures. They do not guarantee functionality, a pain-free extremity, or a normal life.[2,25]

The mechanism and type of traumatic amputation determines the success of replantation. As previously mentioned, guillotine amputations are more likely than crush or avulsion amputations to be replanted because of the differences in involved levels of tissue injury. Wounds that are deeply contaminated are prone to significant complications related to infection and ischemia and are less likely to be successfully replanted. The ischemia time should be minimized to less than six hours to maximize limb salvage. Restoration of blood flow always takes priority over the management of skeletal injury. Based on these factors, one study proposed that criteria for replantation should include: 1) cold ischemia time of less than six hours; 2) no deep contamination; 3) total segmental bone and soft tissue loss with a composite defect of less than 15-20 cm.[24,26]

Replantation requires prolonged operative time, so the patient's hemodynamic status and concomitant injuries may be a contraindication to replantation. Replantation usually requires multiple surgical interventions and long periods of recovery, so it requires motivated patients who are willing to undergo and able to tolerate aggressive rehabilitation.[26] A patient's pre-injury functional status also may play a role in the decision-making process. Successful replantation also depends on the available resources of the hospital, including available orthopedic and plastic surgeons. Factors to consider for replantation are listed in Table 2.

In cases in which replantation is not possible, the goals of completing amputation surgery include the creation of a healthy soft tissue envelope with adequate padding and durability to tolerate socket load transmission and prolonged prosthetic wear.[27] When this is not possible, atypical flaps and free-tissue transfer can be performed in a delayed fashion to provide durable solutions. The availability of free-tissue transfers has significantly increased the ability to reconstruct limbs successfully. However, free-flaps placed in weight-bearing areas can have complications, such as altered prosthetic fit and functional outcomes, because of insensate tissue pads. Too much bulk in soft tissue flaps also may affect prosthetic wear and comfort.[28] Complications of traumatic amputations occur in approximately one-quarter of all amputations. This is usually because of delayed wound healing, retained foreign bodies, and infection. This is seen more frequently in lower extremity amputations compared to upper extremity amputations.[5]

Lower Extremity Amputations

Lower extremity injuries are one of the leading causes of hospital admissions for patients between 18-54 years of age, accounting for nearly 250,000 hospitalizations a year. Military survivals in addition to workplace injuries tend to occur in a younger population, resulting in chronic long-term consequences.[5,29] Lower extremity amputations are the second most common amputations after digit amputations. Below knee amputations are more likely to undergo delayed surgical interventions. This likely is related to the high incidence of concomitant injuries that must be managed and stabilized prior to interventions for the involved extremity.[5]

There are complex reconstruction protocols in place for severe lower extremity injuries such as partial amputations and/or mangled extremities. However, the decision to perform reconstruction vs. primary amputation is complex and controversial. Reconstruction is associated with secondary amputations, nonunion, and flap failure, while amputations may require multiple secondary revisions. Revision procedures for both amputations and reconstructions include debridements, temporary placement of antibiotic beads, fusion, soft-tissue coverage, and free vascular flap tissue transfers.[30] Both options are associated with many other complications, including infection, osteomyelitis, and prolonged hospitalization, in addition to long-term disability, chronic pain, and psychosocial consequences. Even with successful limb salvage, many patients are still non-ambulatory after two years because of persistent pain and disability. There are numerous studies comparing primary amputation and reconstruction in mangled lower extremities, but the data continue to be conflicting. Many available studies have failed to demonstrated consistent superiority of either reconstruction or amputation with respect to clinical outcomes.[25,28,29,31]

The Lower Extremity Assessment Project (LEAP) was a multicenter, prospective, longitudinal study published in 2002 evaluating functional outcomes of severe lower extremity injuries. It was one of the largest studies performed across eight Level I U.S. trauma centers between 1994 and 1997. The outcomes are presented in Table 3. Amputations were more common

Table 2. Factors to Consider for Replantation

Factor	Positive Factors
Patient's general health status	No comorbidities, younger age, no tobacco use
Ischemia time	Cold ischemia time < 6 hours
Level/type/extent of tissue damage	Absence of deep contamination Total segmental tissue loss of < 15-20 cm
Future functionality	Upper extremity > lower extremity amputations
Available recovery programs	Available acute rehabilitation programs
Available surgeon's skill/expertise	Plastic, orthopedic, vascular surgery
Patient's demeanor	Motivation, high level of self-efficacy
Other social factors	Excellent social support network

in patients with more severe injuries and greater frequencies of bone and soft tissue damage/loss. Other factors included initial pulse deficits and lack of plantar sensation. However, both reconstruction and amputation groups were similar in that they had not fully recovered by their two-year follow-up. The reconstruction group was associated with a higher number of complications, rehospitalizations, and need for further surgery. However, there were no significant differences in scores for the Sickness Impact Profile (SIP). After adjusting for injury severity and patient characteristics, the study concluded that patients undergoing reconstruction had comparable two-year outcomes to those undergoing amputation.[31]

Although this study demonstrated no difference in long-term functional outcomes between reconstruction and amputation, other studies have shown better long-term outcomes with specific lower extremity injuries. Sanders et al evaluated lower extremity open grade IIIB ankle and talus fracture salvage procedures and found a 100% fusion rate and muscle flap success rates. However, salvaged limbs were associated with a minimum of three hospitalizations, an average length of stay of 62 days, and an average of eight surgeries. They also were associated with significant functional and psychosocial disabilities. Therefore, the researchers concluded that patients with open grade IIIB tibiotalar injuries likely would benefit from early amputation.[30]

A follow-up LEAP study analyzed a subset of patients with mangled foot and severe ankle injuries. It was similar to the original LEAP study in that there were no statistically significant differences between the groups in terms of pain at two years, walking speed, or return to work. However, the salvage patients requiring free flaps and/or ankle arthrodesis had significantly worse outcomes compared to primary standard below-knee amputations with regard to these factors. The salvage patients had a greater overall disability and a higher number of hospitalizations. This study also suggested that early below-knee amputations may provide better long-term functional outcomes than limb salvage for severe distal tibia and hind-foot injuries.[28]

Conversely, other studies have demonstrated a better quality of life and overall lower healthcare cost in those undergoing salvage instead of primary amputations. One study performed a cost analysis of LEAP study participants and determined the total lifetime cost for reconstructed patients was $163,282 compared to a lifetime cost of $509,275 in amputated patients. The increased cost of amputations was independent of ongoing prosthetic needs and years of life remaining. They concluded that salvage is less expensive and associated with a higher functionality and therefore should be performed aggressively unless amputation is absolutely necessary.[25]

Given the abundance of controversial studies, limb salvage rates are extremely variable. One study noted a salvage rate of 93% in patients with a MESS score greater than 7, while another study had a salvage rate of 9% in patients with similar injuries.[2]

However, regardless of amputation vs. reconstruction, early mobility is important after any operative interventions. It is associated with improved and decreased time to functional mobility, while delayed rehabilitation results in longer times to initial ambulation. However, even with early weight-bearing activity and aggressive rehabilitation, studies have demonstrated bone mineral density loss in 40% of combat-related lower extremity amputees, with severely low bone densities in 15% of patients. Bone mineral density loss is the result of several factors, such as more proximal amputation levels, bilateral amputations, and delayed rehabilitation.[27]

Upper Extremity Amputations

Trauma is the most common cause of upper extremity amputations. Upper extremity amputations account for approximately 30% of all traumatic extremity amputations and tend to occur in a young, predominantly male population. Major amputations that occur through or proximal to the radiocarpal joint tend to occur from blunt crush injuries such as MVCs or penetrating injuries such as gunshot wounds. Minor amputations that involve the fingers tend to occur from machinery (41%) and powered hand tools (17%), followed by caught-between mechanisms and piercing objects. The functionality of upper extremities is essential in activities of daily living (ADLs). Therefore, upper extremity amputations have devastating physical and psychosocial consequences. Some studies have demonstrated the highest disability ratings in upper extremity amputations.[5,23,32-34]

Major upper extremity injuries are three times more likely to undergo surgical evaluation and reconstruction compared to lower extremity amputations. However, the decision to undergo replantation vs. primary amputation in the upper extremity is similar to that for lower extremity injuries. Primary

Table 3. LEAP Study: Clinical and Functional Status 24 Months After Injury

	Amputation	Reconstruction	*P* Value
Fracture not healed	N/A	10.9%	N/A
Soft tissue not healed	9.1%	3.9%	0.10
Additional surgery	5.0%	19.1%	< 0.001
≥ 1 re-hospitalization			
Any complication	33.9%	47.6%	0.002
Osteomyelitis	3.1%	9.4%	0.02
Other infection	15.4%	13.9%	0.69
Non-union	N/A	20.9%	N/A
Sickness Impact Profile (>10 = severe disability)	12.6 ± 11.8	11.8 ± 11.6	0.53
Return to work	53%	49.4%	0.48

Data from: Bosse M, et al. An analysis of outcomes of reconstruction or amputation of leg-threatening injuries. *N Engl J Med* 2002;347:1924-1931.

amputations are more likely to occur in cases of avulsion amputations, severe contamination, and multilevel injury. Upper extremity injuries from penetrating mechanisms are more likely to be treated with attempted replantation.[33]

One study demonstrated an upper extremity replantation rate of 32.3% and found that patients who presented with a more distal level of amputation (i.e., wrist, forearm) were significantly more likely to undergo replantation. Patients undergoing replantation had significantly increased hospital lengths of stay, more postoperative complications, and more secondary revisions compared to primary amputations. Complications of upper extremity revisions and amputations were similar to lower extremity reconstructions, including wound breakdown and infections. All patients required at least one secondary surgical revision, including proximal revision amputations, further debridements, and split-thickness skin grafts. The overall success rate in this study for replantation was 70%.[32]

If the decision is made to perform primary amputation, the level of amputation is crucial. The upper extremity requires a great deal of range of motion to properly position the hand for ADLs. The level of amputation can determine the range of forearm pronosupination, the motion at the shoulder or elbow, and available functional prosthetic options. Therefore, the length of the amputation stump should be maximized as much as possible. Soft tissue coverage to preserve upper extremity length can be challenging and may require free-tissue transfers or flaps. Indications for free-tissue transfer are to preserve shoulder and elbow function, retain pinch function in the hand, and to maintain skeletal length of at least 7 cm. Studies have demonstrated an improved function as a result of preserving major joints and a better prosthetic fit.[34]

The management of minor upper extremity amputations is significantly different compared to major amputations. The recommended maximum warm ischemia time for digits is 12 hours, and cold ischemia time is less than 24 hours, which is double the time compared to proximal extremity replantations. The decision to replant also is determined by the functionality of the digit. Currently, the five key indications for digit replantation include: any amputation in a child, thumb amputations, multiple digit amputations, midpalm amputations, and single digit distal to the flexor digitorum superficialis insertion.[23] Other single digit traumatic amputations do not have long-term functional consequences and therefore rarely are replanted.

The thumb is the most critical appendage and provides 40% of all hand function. Traumatic thumb amputations result in significant functional defects and therefore should be replanted if possible. Thumb replantation currently is associated with excellent success rates of 80-90%. Despite this, digital replantation rates are low, ranging from 7-27%. One study evaluating thumb replantations demonstrated that hospitals treating more than 20 patients per year with thumb amputations had the highest replantation rate (22.9%) and success rate (87.5%). Teaching hospitals were more likely to attempt thumb replantations compared to nonteaching hospitals (77.6%), although the success rates were similar. The difference in replantation attempts varied depending on mechanism of injury and injury severity score. Increased age and comorbidities were not associated with decreased success rates, and a history of smoking was the only factor found to significantly decrease replantation success rates.[7]

Early complications are common and include arterial or venous insufficiency in nearly 80% during the first two postoperative days, which declines to 10% after three days. Arterial insufficiency is manifested as pale color, loss of turgor, slow capillary refill, low temperature, and absent pulse. It typically is due to platelet aggregation and requires immediate anastomotic revision. Venous insufficiency is manifested by a purple hue, engorged vessels, brisk capillary refill, low temperature, and intact pulses. It typically is due to fibrin clots and can be treated with medicinal leeches and revision of the venous anastomosis. Late complications include cold intolerance, tendon adhesions requiring tenolysis surgery or tendon grafting, neuromas, and altered sensation.[23]

Replantation results in significantly increased quality of life, particularly with respect to functional and psychological outcomes. Long-term studies evaluating upper extremity replantation found that patients regained 34% of grip strength compared with their contralateral side, and all patients regained protective sensation.[3] Functional results were better when the injury was at the level of the forearm, suggesting that the distance of re-innervation is directly related to functional results. Consequently, replantation of the upper extremity is usually attempted unless the patient's status proposes a contraindication.[4,5,26,35] However, it requires the availability of surgeons, such as hand surgeons, who specialize in upper extremity reconstruction.

Consequences of Traumatic Amputations

Dramatic improvements in the field of medicine for both the civilian and military population have resulted in improved survival rates and an increased prevalence of survivors living with traumatic amputations.[3] Subsequently, there has been an increasing amount of studies evaluating the long-term effects of traumatic amputations, primarily with respect to functional, societal, and psychological outcomes.

Functional outcomes often are determined based on the level of injury and the number of limbs amputated. Upper extremity amputations are associated with a significantly decreased quality of life compared to lower extremity amputations because of substantial functional defects. Isolated trans-tibial (below knee) amputations typically are associated with a "normal life," while unilateral trans-femoral (above knee) amputations have comparatively decreased function. Functionality is further decreased with bilateral above-knee amputations, although the life expectancy is comparable to unilateral below-knee amputations. Prosthetics often are abandoned after an average of seven years of use. The most common reason is because of residual limbs that are too short for prosthetics (33%). Other reasons include pain (25%) or prosthetics that are too heavy (17%) or too much hassle (17%).[3] Despite advancements in prosthetics, socket-related problems frequently limit function. Some problems include ill-fitting sockets resulting in weight-bearing pressure issues, sweating, and venous outflow obstruction in too-snug sockets.[36]

A significant percentage of patients will suffer from chronic pain, with incidences ranging from 50-95%.[37,38] One study demonstrated that only 9% of unilateral limb amputees were pain-free four weeks after initial injury. Causes of chronic pain include phantom limb pain, residual limb pain, contralateral limb pain, and back pain. Phantom limb pain is described as pain in a limb that is no longer present and can occur with a prevalence as high as 85%.[38] There are no statistically significant differences in the prevalence of phantom pain based on etiology, patient age, or level of amputation, although increased comorbidities, a depressed mood, and a younger age are associated with the intensity to which phantom pain bothers patients. The prevalence also did not vary significantly by the time since amputation; 74% of amputees who were more than 10 years since their amputation reported phantom pain. There are also conflicting data on whether phantom limb pain is increased in lower vs. upper extremity amputations.

Approximately 55% of those with phantom pain also suffer from residual limb or stump pain. Residual limb pain varies from 10-13% at two years post-amputation to 55-76% in long-standing amputees.[38] A quarter of these patients described residual limb pain to be "extremely bothersome." Age, etiology, amputation level, the presence of pre-amputation pain, prosthetic fit, and comorbidities were significant predictors of residual limb pain. The extent of residual limb pain also was dependent on sensitized neuromas (49%), somatic pain (41%), and complex regional pain syndrome (20%).

Neuromas are benign but abnormal growths of nerve tissue that occur at the end of injured nerve fibers and can be very painful. These commonly are associated with military blast-related amputations.[3,37] Other causes of neuropathic pain include displaced bone fragments, heterotopic ossification (HO), and scar tissue that can envelop and constrict nerves. Significant nerve pain that is limiting functional mobility can result in delayed amputations. One study demonstrated that late amputations (> 12 weeks after injury) occurred in 15.2% of traumatic lower extremity amputations as a result of unbearable neuropathic pain.[3]

HO is the abnormal formation of mature lamellar bone in soft tissue, and occurs as a result of osteogenic precursor cell activation in response to humeral, neural, and local factors that cause dysregulations in skeletogenesis.[39,40] Studies have demonstrated an HO prevalence of 23% in the civilian population regardless of amputation etiology, although there was no association found between HO and traumatic amputations. Conversely, traumatic amputations in the military population are highly associated with HO (64%). This suggests that explosive mechanisms may be an independent risk factor for the development of HO. Prevalence varies in the pediatric population from 5-86%, but it is seen less commonly in patients older than 12 years.[27,39,40] In the lower extremities, HO often is associated with post-amputation pain, overlying skin and muscle breakdown, and poor prosthetic fit and function, which can require surgical excision and lead to delayed rehabilitation. More than 25% will fail non-operative management and ultimately require surgical excision.

Half of all unilateral amputees reported pain in their non-amputated limb. Women are 40% more likely to report non-amputated limb pain compared to men. Other risk factors include patient age, etiology of amputation, time since amputation, comorbidities, and lower extremity amputations. Lower-limb amputees are eight times more likely than upper-limb amputees to report pain in their non-amputated limb. Back pain also affects 52-71% of amputees in the United States. The prevalence of back pain is affected by sex, younger age, and poverty status. Amputees who were 65 years of age or older were half as likely to report back pain compared to those between the ages of 18-44 years. Household poverty was associated with a doubled increase in back pain.[38] Among lower-limb amputees, there was no difference in the prevalence of back pain between those with above-knee vs. below-knee amputations.

Treatment of persistent residual or phantom limb pain with analgesics alone is ineffective. Rather, the most important method to treat chronic pain associated with traumatic amputations is to identify and treat the underlying cause. For example, excising neuroma or heterotopic ossification can improve the prosthetic fitting, thereby decreasing pain and increasing functional mobility. Treating chronic pain effectively is critical because the presence of chronic pain can result in further psychological and functional limitations. It is negatively correlated with employment rates and psychological adjustment. For example, clinically significant neuropathic residual limb pain has been associated with symptoms of post-traumatic stress disorder and depression.[37]

Depression in the traumatic amputation population varies from 35-51%, which is three to five times more than the general population. The LEAP study demonstrated that predictors of poor psychosocial outcomes (for both amputations and reconstructed patients) included re-hospitalization(s) for major complications, or patient characteristics such as less than high school education, poverty, nonwhite, lack of insurance, poor social-support network, smoking, and involving the legal system in injury compensation.[31] Other factors affecting psychological adjustment include limitations in activity, time since amputation, and age.[38] The development of anxiety and depressive disorders can lead to other chronic issues, such as unemployment, alcohol dependence, and drug abuse. Therefore, timely identification and management of these disorders is essential.

Public Health Education

As demonstrated by several studies, a significant number of amputee burdens are due to trauma and can have devastating consequences. The risk of amputations is approximately two to three times higher in minorities, which may be due to poverty and differences in access to primary care and preventive services. Therefore, public health education to reduce the prevalence of limb loss is crucial and includes primary, secondary, and tertiary prevention strategies.[1,9]

Primary preventive methods include methods to prevent injury before it even occurs and to educate the public on reducing and removing the risk factors for injury. For example, most injuries with wood-working tools are associated with the failure to use properly installed safeguards.[12,16] Machinery, such as powered lawn mowers, should be used only by children older than 12 years of age. Falling was the third most common cause of injury associated with lawn mowers, so education should be focused on the use of lawn mowers while wearing close-toed shoes and only when the grass is dry to minimize slipping and/or falling. Riding lawn mowers should be used only by those older than 16 years of age.[14,16] Door-related injuries can be minimized with passive methods, such as pinch-free doors, improved doorstops, and the use of glazed safety glass. This type of glass is safer than ordinary glass doors because it breaks into small harmless fragments and does not shatter.[15]

Secondary prevention aims to reduce the effect of an injury that already has occurred. An excellent example is improving disaster preparedness nationwide and worldwide, such as the "Stop the Bleed" campaign. Increased public health education on how to respond to mass casualty events has been demonstrated to reduce mortality.

Finally, tertiary prevention involves taking measures to decrease the impact of an injury that has lasting effects. This includes the management and rehabilitation of patients with traumatic amputation to ensure improved functional and psychological outcomes. It involves identifying those who are suffering from associated anxiety and depression and treating them appropriately and adequately to prevent the other chronic sequelae of traumatic amputations. Tertiary prevention is extremely important to help improve the quality of life of millions of traumatic amputees in the United States.

Conclusions

Traumatic amputations are devastating injuries with life-long consequences, including multiple physical and psychological sequelae. The prevalence of traumatic amputations is quite significant across all age groups and is projected to continue increasing. Therefore, public health education to reduce the prevalence of limb loss is crucial. This involves educating the public on injury-prevention strategies. The treatment of traumatic amputations also requires timely interventions, especially with regard to hemorrhage control, and the public should be educated about how to assist others in the event of life-threatening exsanguination. Once patients are stabilized, consideration for replantation requires an efficient and well-thought-out approach, as well as the collaboration between various surgical subspecialties so that satisfactory outcomes can be achieved. These patients also need to be followed closely postoperatively to help minimize the effect these amputations may have on psychological and functional outcomes.

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CME/CE Questions

1. Traumatic amputations occur across all age groups.
   a. True
   b. False
2. The most common body part that is traumatically amputated is:
   a. toe.
   b. leg.
   c. arm.
   d. finger.
3. The management of traumatic amputations in the prehospital setting includes:
   a. scene transfer to a trauma center.
   b. damage-control principles.
   c. recovery of the amputated limb.
   d. All of the above
4. What traumatic amputation mechanism has the highest rate of successful replantation?
   a. Avulsion injury
   b. Guillotine injury
   c. Crush injury
   d. None of the above
5. What are possible complications of traumatic amputations?
   a. Infection
   b. Bone nonunion
   c. Chronic pain
   d. Flap failure
   e. All of the above
6. Which of the following is true regarding the outcomes of traumatic amputations?
   a. Persistent postoperative pain is uncommon.
   b. Treatment of phantom limb pain is effective with analgesics alone.
   c. Functional outcomes are dependent on the level of injury and number of amputated limbs.
   d. Depression after traumatic amputations is infrequent.
7. Risk factors for poor psychosocial outcomes after traumatic amputations include which of the following?
   a. Poverty
   b. Less than high school education
   c. Poor social support system
   d. Chronic pain
   e. All of the above

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