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Incidence and Characterization of Major Upper-Extremity Amputations in the National Trauma Data Bank

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Background: There are few recent data examining the epidemiology of severe upper-extremity trauma in non-military patients. We used the National Trauma Data Bank (NTDB) to investigate the epidemiology and descriptive characteristics of upper-extremity amputations in U.S. trauma centers.

Methods: We queried the 2009 to 2012 NTDB research datasets for patients undergoing major upper-extremity amputation and extracted characteristics of the patient population, injury distribution, and treating facilities. In addition, multivariable regression models were fit to identify correlates of reoperation, major in-hospital complications, duration of hospitalization, and in-hospital mortality.

Results: A total of 1,386 patients underwent a major upper-extremity amputation secondary to a trauma-related upper-extremity injury, representing 46 per 100,000 NTDB trauma admissions from 2009 to 2012. The most frequent definitive procedures performed were amputations through the humerus (35%), forearm (30%), and hand (14%). The average duration of hospitalization for all amputees was 17 days. Thirty-one percent of patients underwent at least 1 reoperation. The rate of reoperation was significantly higher at university-associated hospitals compared with nonteaching or community hospitals ($p < 0.0001$). Patients who had at least 1 reoperation stayed in the hospital approximately 7 days longer than patients who did not undergo reoperation. The Injury Severity Score, hospital teaching status, concomitant neurovascular injury, and occurrence of a complication were significantly associated with reoperation.

Conclusions: The present study provides an updated report on the epidemiology and characteristics of trauma-related major upper-extremity amputation in the U.S. civilian population. Additional work is necessary to assess the long-term outcomes following attempted upper-extremity salvage. The population-level data provided by the present study may help to inform the design and implementation of future studies on the optimum treatment for this survivable but life-altering injury.

The expanded presence of U.S. forces in overseas military theaters over the past decade has fueled important research in extremity trauma after severe injury[1]. These data have demonstrated that these injuries have a large impact on the ability of troops to continue to serve; 4 of the 5 most common conditions that rendered a service member unfit for duty involved injury to an extremity[2]. Upper-extremity amputation results in the highest levels of impairment of all war-related extremity injuries[3].

Recent studies investigating severe extremity trauma, including the Lower Extremity Assessment Project (LEAP) and the Military Extremity Trauma Amputation/Limb Salvage Study (METALS), have focused on epidemiology and outcomes following lower-extremity trauma[4-16]. However, the disease burden of trauma-related major upper-extremity amputation has not been characterized in the U.S. within the last decade. The purpose of the present study is to provide updated information on the incidence and characteristics of severe upper-extremity trauma in a civilian population as reflected in the National Trauma Data Bank (NTDB). The NTDB dataset draws from a large and geographically distributed network of U.S. trauma centers, providing a cross-section of the U.S. trauma population. This database facilitates analysis of thousands of trauma-related major upper-extremity amputations without the biasing effects inherent to other large government or private insurer databases that can stratify patients on the basis of

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demographic characteristics. These data will improve our understanding of the disease burden of major upper-extremity amputation on society during the initial period of hospitalization.

Materials and Methods

Subjects

The cohort in the present study consisted of patients who sustained a traumatic limb-threatening injury and underwent a major upper-extremity amputation during their subsequent initial hospitalization. The ICD-9 (International Classification of Diseases, Ninth Revision) procedure codes that were screened within the 2009 to 2012 NTDB Research Data Set (RDS) included 84 (upper-extremity amputation, not otherwise specified), 84.01 (finger amputation and disarticulation), 84.02 (thumb amputation and disarticulation), 84.03 (hand amputation), 84.04 (wrist disarticulation), 84.05 (forearm amputation), 84.06 (elbow disarticulation), 84.07 (humerus amputation), 84.08 (shoulder disarticulation), and 84.09 (interthoracoscapular amputation). Subjects were additionally screened for upper-extremity injuries with use of ICD-9 diagnostic codes 810 to 818.1, 831 to 834.12, 840 to 842.19, 880 to 887.7, 903 to 903.9, 927 to 927.9, 943 to 944.58, 953.4, 955 to 955.9, and 959.2 to 959.5. Finally, patients only undergoing minor amputations, defined as digit-only or thumb-only amputations, were excluded. The patient-selection process is detailed in Figure 1.

Statistical Analysis

With use of statistical methods similar to those described previously for the assessment of lower-extremity amputations in the NTDB[17], the dataset was queried for patients undergoing major upper-extremity amputation; characteristics of the patient population, injury distribution, and treating facility were then extracted. Multivariable regression models were fit to identify characteristics that correlate with major in-hospital complications, reoperation, duration of hospitalization, and in-hospital mortality, as described previously (see Appendix)[17]. Statistical analysis was performed with use of Statistical Analysis System (version 9.4; SAS Institute) for Windows (Microsoft).

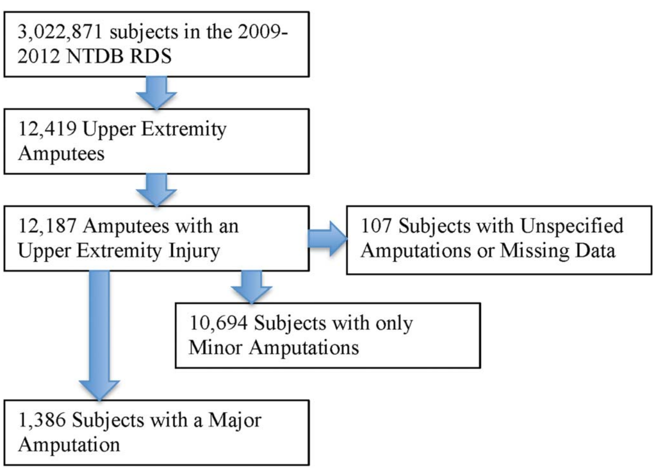

Fig. 1

Chart illustrating the patient-selection process.

TABLE I Demographic Characteristics

Characteristic	No. of Patients (N = 1,386)
Sex	
Male	1,049 (75.7%)
Female	337 (24.3%)
Ethnicity	
Not Hispanic or Latino	840 (60.6%)
Hispanic or Latino	206 (14.9%)
Not known	340 (24.5%)
Race	
White	931 (67.2%)
Other	187 (13.5%)
Black or African-American	162 (11.7%)
Asian	19 (1.4%)
Not known/other	87 (6.3%)
Mechanism of injury*	
MVT (occupant)	459 (33.1%)
Machinery accident	287 (20.7%)
MVT (motorcyclist)	98 (7.1%)
Cutting/piercing accident	84 (6.1%)
Firearm accident	81 (5.8%)
Transportation (other)	62 (4.5%)
MVT (pedestrian)	60 (4.3%)
Other	255 (18.4%)
Associated upper-extremity injury	
Neurovascular	317 (22.9%)
Crush injury	172 (12.4%)
Compartment syndrome	58 (4.2%)

*MVT = motor-vehicle trauma.

Major complications were selected to be consistent with information in previous reports in the literature[17] and included graft/prosthesis/flap failure, deep surgical site infection, decubitus ulcer, osteomyelitis, deep-vein thrombosis (DVT)/thrombophlebitis, pulmonary embolism (PE), pneumonia, acute kidney injury, acute lung injury/acute respiratory distress syndrome (ARDS), and severe sepsis. Reoperations were defined as all repeat procedures that were performed following the initial operative intervention, including irrigation and debridement, delayed closure of a residual limb stump, and more proximal amputation.

Results

Patient Characteristics

One thousand three hundred and eighty-six patients had a major upper-extremity amputation following traumatic injury to the upper extremity (Fig. 1), representing an incidence rate of 46 cases per 100,000 admissions (or 0.05% of all

TABLE II Amputation Characteristics by Amputation Level

Amputation Level (see Fig. 2)	Initial Procedure*	Reoperation†	Definitive Procedure*	Injury Severity Score‡	Timing to Procedure‡ *(d)*	Length of Stay‡ *(d)*	Historical Comparison *(no. of patients)* Civilian (1998-1996) (N = 8,922)[29]	Military (2001-2011) (N = 228)[30]
(A) Forequarter amputation	11 (0.8%)	1 (9.1%)	14 (1.0%)	24.8	2.4	22.1	15 (0.2%)	
(B) Shoulder disarticulation	43 (3.1%)	9 (20.9%)	53 (3.8%)	23.6	4.7	21.7	154 (1.7%)	8 (3.5%)
(C) Through humerus	461 (33.3%)	180 (39.0%)	481 (34.7%)	19.0	3.2	19.3	3,008 (33.7%)	81 (35.5%)
(D) Elbow disarticulation	110 (7.9%)	42 (38.2%)	99 (7.1%)	18.5	4.2	20.3	346 (3.9%)	2 (0.9%)
(E) Through forearm	424 (30.6%)	152 (35.8%)	414 (29.9%)	12.8	4.2	17.1	4,001 (44.8%)	110 (48.2%)
(F) Wrist disarticulation	128 (9.2%)	15 (11.7%)	125 (9.0%)	8.9	2.2	8.5	415 (4.7%)	27 (11.8%)
(G) Through hand	209 (15.1%)	32 (15.3%)	200 (14.4%)	10.1	3.7	12.8	983 (11.0%)	

*The percentages are calculated as the proportion of the total study population (n = 1,386). †The percentages are calculated as the proportion of the total number of individuals undergoing a primary procedure at each anatomical level. ‡The values are given as the mean and are calculated on the basis of the number of patients undergoing a definitive amputation at each anatomical level.

NTDB trauma admissions from 2009 to 2012). Seventy-six percent of the patients were male (average age, 42 years), and 24% were female (average age, 41 years). Concurrent injuries of interest included neurovascular injury prior to amputation (23%), compartment syndrome (4%), and crush injuries (12%) (Table I).

Amputation and Reoperation Characteristics

The 3 most frequent definitive amputations performed included amputations through the humerus (35%), forearm (30%), and hand (14%) (Table II and Fig. 2). The Injury Severity Score (ISS) increased with more proximal levels of amputation. For example, subjects with a definitive forequarter amputation had an average ISS of 25, whereas those with a transhumeral or transradial amputation had average ISSs of 19 and 13, respectively.

Thirty-one percent of upper-extremity amputees underwent at least 1 reoperation. Patients in whom the initial amputation was performed between the levels of the forearm and humerus underwent the greatest percentage of reoperations, with the rates of reoperations through the humerus, elbow, and forearm being 39%, 38%, and 36%, respectively (Table II). ISS, hospital teaching status, the presence of a neurovascular injury, and the occurrence of a major complication were significantly associated with reoperation (Table III). While the average duration of hospitalization for all amputees was 17 days, patients who underwent a reoperation stayed for an average of 7 additional days.

Thirty-four percent of amputees at university hospitals underwent 1 or more reoperations following the initial procedure during the initial hospitalization, compared with 22% and 17% at community and nonteaching hospitals, respectively. This finding represents a significant difference in the proportion of patients undergoing reoperation at the 3 types of hospitals ($p < 0.0001$). However, there were no facility-related differences in terms of injury severity, associated injuries, the time to the initial procedure, or the complication rate that may easily explain this observed difference in the reoperation rate (Table IV).

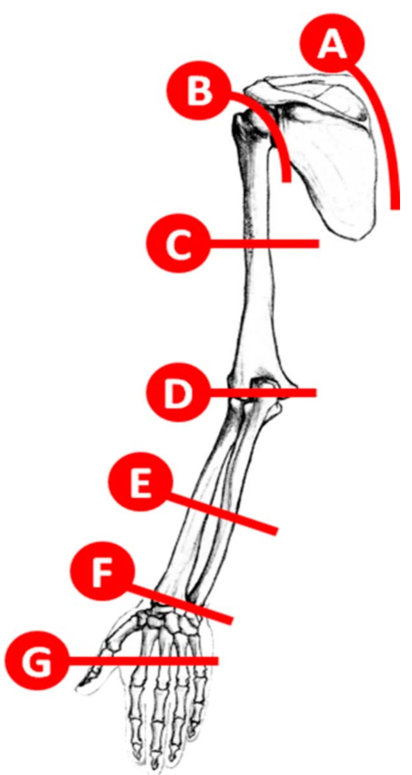

Fig. 2
Diagram illustrating the amputation levels described in Table II.

Hospitalization Characteristics

The majority of patients (69%) were treated at a level-I trauma center, with only 17% being treated at a level-II center, and <2% being treated at level-III and IV centers (Table V). Sixty-six percent of amputations were performed at university centers, with the remaining one-third being performed at community or nonteaching hospitals (Table V).

Seventy-one patients died prior to discharge, for an overall in-hospital mortality rate of 5%. Significant predictors

TABLE III Logistic Regression Predictors*

Predictor Variable	Major Complications		Reoperation		Length of Hospitalization		Death During Hospitalization	
	OR (95% CI)	P Value	OR (95% CI)	P Value	Difference (95% CI)	P Value	OR (95% CI)	P Value
Injury Severity Score	1.08 (1.06, 1.09)	<0.0001	1.01 (1.00, 1.02)	0.038	0.52 (0.46, 0.58)	<0.0001	1.06 (1.04, 1.08)	<0.0001
Time to initial procedure	1.07 (1.04, 1.09)	<0.0001			0.44 (0.31, 0.56)	<0.0001		
Age	1.01 (1.00, 1.02)	0.005			0.04 (0.001, 0.07)	0.04	1.02 (1.01, 1.04)	0.003
Major complication (yes versus no)			1.40 (1.03, 1.92)	0.034				
Neurovascular injury (yes versus no)	1.62 (1.16, 2.26)	0.005	1.34 (1.01, 1.76)	0.04				
Compartment syndrome (yes versus no)	2.28 (1.18, 4.40)	0.018			4.41 (1.14, 7.68)	0.008	3.39 (1.50, 7.69)	0.004
Hospital teaching status (community versus university)			0.56 (0.42, 0.74)	<0.0001	−2.44 (−3.84, −1.05)	0.001		
Hospital teaching status (nonteaching versus university)			0.38 (0.22, 0.66)	0.001	−2.74 (−5.10, −0.39)	0.004		

*The predictor variables in the left column were tested independently for each dependent variable. The demographic, treating facility, and injury characteristics along with outcome variable covariates were selected if they were associated with an outcome variable in a bivariable logistic model with a p value of <0.2. They were retained if the p value did not exceed 0.25 with the addition of other variables. Major complications were considered individually and as a composite outcome variable for regression analyses. Model fit was assessed with use of the Hosmer-Lemeshow test[17]. OR = odds ratio, CI = confidence interval.

of in-hospital mortality included ISS, age, and the presence of compartment syndrome. Subjects with compartment syndrome had 3.4-times greater odds of mortality during hospitalization than subjects without compartment syndrome (Table III).

The average duration of hospitalization for all amputees was 17 days. Increased length of hospitalization was correlated with ISS, the time to the initial procedure, age, hospital teaching status, and the presence of compartment syndrome (Table III).

Despite the severity of their injuries and the morbidity of their associated hospital courses, the majority of patients (68%) ultimately were discharged to home, with only 26% requiring an interfacility transfer or discharge to a subacute care facility (Table V).

Discussion

The present study demonstrated an incidence of 347 trauma-related major upper-extremity amputations per year within the NTDB, or 46 cases per 100,000 trauma admissions, with the most common levels of amputations being through the humerus (35%), forearm (30%), and hand (14%). Of the 1,386 cases of trauma-related upper-extremity amputations in the present

TABLE IV Amputation Characteristics by Hospital Teaching Status

	Nonteaching Hospital	Community Hospital	University Hospital	P Value
No. of patients treated	103	366	917	
Injury Severity Score*	14.1	15.5	15.3	0.164
No. of days to procedure*	2.8	3.1	3.9	0.055
Reoperation *(no. of patients)*	17 (16.5%)	81 (22.1%)	313 (34.1%)	<0.0001
Major complications *(no. of patients)*	10 (9.7%)	72 (19.7%)	175 (19.1%)	0.055
Compartment syndrome *(no. of patients)*	2 (1.9%)	12 (3.3%)	44 (4.8%)	0.235
Neurovascular injury *(no. of patients)*	25 (24.3%)	78 (21.3%)	214 (23.3%)	0.694

*The values are given as the mean.

TABLE V Hospital Characteristics*

	No. of Patients
State trauma level	
I	950 (68.5%)
II	237 (17.1%)
III	18 (1.3%)
IV	1 (0.1%)
Not known	180 (13.0%)
Teaching status	
University	917 (66.2%)
Community	366 (26.4%)
Nonteaching	103 (7.4%)
Region	
South	593 (42.8%)
Midwest	341 (24.6%)
West	259 (18.7%)
Northeast	161 (11.6%)
Not known	32 (2.3%)
Discharge location	
Acute care transfer	92 (6.6%)
Subacute care	273 (19.7%)
Home	935 (67.5%)
Death	71 (5.1%)
Other/not known	15 (1.1%)
Total in-hospital complications	1,716 (100%)
Pneumonia	108 (6.3%)
ARDS	68 (4.0%)
DVT/thrombophlebitis	54 (3.2%)
Acute kidney injury	36 (2.9%)
Severe sepsis	47 (2.7%)
Decubitus ulcer	26 (1.5%)
Graft/flap/prosthesis failure	20 (1.2%)
Deep surgical site infection	18 (1.1%)
Pulmonary embolism	13 (0.8%)
Osteomyelitis	2 (0.1%)
Total Subjects with at least one complication	257

*ARDS = acute respiratory distress syndrome, and DVT = deep-vein thrombosis.

study, the largest percentage occurred in white males and were treated at southern, level-I, university-associated trauma centers. For these individuals, the loss of an upper extremity is a life-altering event and causes a great degree of disability. A recent study involving a military population indicated that patients with an isolated upper-extremity amputation had a significantly greater combined disability rating than those with an isolated lower-extremity amputation (83% versus 62%; $p < 0.0001$) and that none of the upper-extremity amputees were found fit for duty[18].

There is ongoing debate about whether lower-extremity trauma-scoring scales are applicable to severe upper-extremity trauma[19]. For example, conflicting data exist as to whether the Mangled Extremity Severity Score (MESS) can be applied accurately to the severely injured upper extremity[20]. A 2005 study examined outcomes following upper-extremity crush injuries that would have fallen into the amputation category under MESS but instead were treated with limb salvage and were found to have good outcomes at the time of the latest follow-up[21]. Outcomes following neural and vascular injury historically have been better in patients with upper-extremity injuries than in those with lower-extremity injuries as a result of anatomical differences affecting the capacity for functional recovery[19,22,23].

Our study demonstrated concomitant neurovascular injury in 23% of patients with a major upper-extremity amputation, concomitant crush injury in 12%, and concomitant compartment syndrome in 4%. It is important to note that these data should be interpreted with extreme caution. Questions about the specific roles that these concomitant injuries play in cases of upper-extremity trauma are unanswerable with use of the NTDB, which provides limited granularity of patient data. It is possible that these represent injuries to neurovascular structures that are distinct from other osseous and soft-tissue injuries and may represent segmental or complex mixed injury patterns. Similarly, the exact definition of crush injury is difficult to pin down when many high-velocity injuries are mixed-modality injuries with at least some element of crush. The inability to rigorously differentiate these injury patterns represents one of the largest limitations of the present study. Additional discussion of these concomitant injuries has been included because the large size of this cohort allows us to identify population-level correlates that help to describe the recovery potential following these injuries.

Logistic regression analysis showed that the presence of a neurovascular injury, which is a negative long-term prognostic indicator in cases of lower-extremity injury, was associated with both reoperation and complications but not with short-term outcomes such as the duration of hospital stay or in-hospital mortality. However, a concurrent compartment syndrome was associated with both increased length of stay and mortality. Surprisingly, the presence of crush injury, which many regard as an indicator of a poor prognosis, was not associated with reoperation, major complications, the duration of hospitalization, or mortality. As previously stated, these data are difficult to interpret because of the limited granularity in the dataset. The mixed outcomes of neurovascular injury and crush injury found in the present study are undoubtedly multifactorial but may stem from differences in vascularity affecting post-injury tissue perfusion that make this pattern more survivable in the upper extremity relative to the lower extremity. To answer this question more completely, a study describing patient injury, care, and outcome to the level of detail of the individual patient is required.

In the amputation arm of the LEAP study, 30% of patients were rehospitalized because of complications within the first 2 years and 14.5% required stump revision[24]. Similarly, a retrospective analysis of upper-extremity amputations in a military population showed a 42% rate of revision surgery after a median duration of follow-up of 20 months[25]. In many publications, such delayed reoperations are listed as complications. In the context of the index hospitalization immediately following a limb-threatening trauma, however, reoperation should be the expectation. Current military protocols for severe extremity trauma encourage early aggressive debridement with repeat trips to the operating room every 48 to 72 hours until wounds are clean and definitive orthopaedic treatment and wound closure can be provided[19,26,27]. In the absence of definitive evidence that early amputation yields superior results to attempted limb salvage, damage-control procedures focused on tissue preservation followed by later "second-look" finalization procedures are becoming the norm in an attempt to improve outcomes[27].

The present study demonstrated a 31% rate of acute inpatient reoperation as well as significant variance between the likelihood of reoperation at a university-associated center compared with that at a community or nonacademic center. While there was no significant difference between these types of facilities with regard to injury severity or other patient or injury-related characteristics, there is no way to exclude the possibility that unknown or unmeasured differences in case mix may have biased this association. Also, the low and variable reoperation rate may be a reflection of surgeon preference to proceed with definitive amputation at the time of injury and therefore may be a function of practice environment and potentially modifiable surgeon behaviors. The significant difference in reoperation rates between academic and nonacademic settings may further indicate that there is a meaningful difference in behaviors between these 2 practice environments. Current behaviors in academic settings may more closely follow current military treatment recommendations of planned debridement and observation of wounds as a part of a deliberately staged limb-salvage attempt[26]. It is possible that patients managed in nonacademic settings may benefit from similar management, although no studies have been performed to date directed at answering this question. However, it is important to note that our methodology does not provide a way to determine whether these reoperations were planned or unplanned and that the relative pros and cons of early versus late amputation remain unclear.

The observation that the most frequent levels of definitive amputation are transhumeral, transradial, and through the hand is consistent with data from European countries[28] as well as historical data from the United States[29] and from recent military conflict[30]. A combination of factors, including the frequency of distal versus proximal injuries, the procedural efficacy of treating amputations at these levels, and surgeon knowledge of prosthetic fitting options all may play a role in surgical decision-making. Our observation that initial amputations performed between the levels of the forearm and humerus are associated with the highest rates of reoperation may indicate that surgeons working in these regions of the upper-extremity area are willing to participate in multiple surgical procedures in an effort to preserve limb length, consistent with general recommendations that longer residual limbs contribute to improved patient outcomes[19].

The present study has limitations inherent in the study design, including missing data and unmeasured confounding factors. The NTDB provides data about a large population from a representative cross-section of trauma patients in the U.S. However, the data are limited to the index hospitalization; there are no data on complications or reoperations in upper-extremity amputees that occur after the initial hospital visit. While it is likely that the NTDB accurately reflects the incidence and injury characteristics for this injury pattern in the overall U.S. population, these data cannot be used to improve our insight into the long-term-care burden or functional outcomes for these patients. Similarly, because the data are taken in aggregate, it is difficult to use this dataset to make specific recommendations for patient care.

The present study is an important first step in understanding the magnitude of the care burden of major upper-extremity amputations in the U.S. civilian population. Efforts to provide decision support regarding early amputation versus staged salvage of mangled upper extremities will be based on research into both current surgeon behaviors and long-term outcomes of early definitive amputation, planned staged amputation, and attempted limb salvage.

Appendix

eA Descriptions of the regression models are available with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJSOA/A39). ■

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References

1. Owens BD, Kragh JF Jr, Macaitis J, Svoboda SJ, Wenke JC. Characterization of extremity wounds in Operation Iraqi Freedom and Operation Enduring Freedom. J Orthop Trauma. 2007 Apr;21(4):254-7.

2. Cross JD, Ficke JR, Hsu JR, Masini BD, Wenke JC. Battlefield orthopaedic injuries cause the majority of long-term disabilities. J Am Acad Orthop Surg. 2011;19(Suppl 1):S1-7.

3. Ficke JR, Bosse M. Extremity war injuries V: barriers to return of function and duty. J Am Acad Orthop Surg. 2011;19(Suppl 1)(Suppl 1):v-viii.

4. MacKenzie EJ, Bosse MJ. Factors influencing outcome following limb-threatening lower limb trauma: lessons learned from the Lower Extremity Assessment Project (LEAP). J Am Acad Orthop Surg. 2006;14(10 Spec No.):S205-10.

5. Bosse MJ, MacKenzie EJ, Kellam JF, Burgess AR, Webb LX, Swiontkowski MF, Sanders RW, Jones AL, McAndrew MP, Patterson BM, McCarthy ML, Travison TG, Castillo RC. An analysis of outcomes of reconstruction or amputation after leg-threatening injuries. N Engl J Med. 2002 Dec 12;347(24):1924-31.

6. MacKenzie EJ, Bosse MJ, Castillo RC, Smith DG, Webb LX, Kellam JF, Burgess AR, Swiontkowski MF, Sanders RW, Jones AL, McAndrew MP, Patterson BM, Travison TG, McCarthy ML. Functional outcomes following trauma-related lower-extremity amputation. J Bone Joint Surg Am. 2004 Aug;86(8):1636-45.

7. MacKenzie EJ, Bosse MJ, Pollak AN, Webb LX, Swiontkowski MF, Kellam JF, Smith DG, Sanders RW, Jones AL, Starr AJ, McAndrew MP, Patterson BM, Burgess AR, Castillo RC. Long-term persistence of disability following severe lower-limb trauma. Results of a seven-year follow-up. J Bone Joint Surg Am. 2005 Aug;87(8):1801-9.

8. MacKenzie EJ, Bosse MJ, Kellam JF, Pollak AN, Webb LX, Swiontkowski MF, Smith DG, Sanders RW, Jones AL, Starr AJ, McAndrew MP, Patterson BM, Burgess AR, Travison T, Castillo RC. Early predictors of long-term work disability after major limb trauma. J Trauma. 2006 Sep;61(3):688-94.

9. McCarthy ML, MacKenzie EJ, Edwin D, Bosse MJ, Castillo RC, Starr A; LEAP Study Group. Psychological distress associated with severe lower-limb injury. J Bone Joint Surg Am. 2003 Sep;85(9):1689-97.

10. Doukas WC, Hayda RA, Frisch HM, Andersen RC, Mazurek MT, Ficke JR, Keeling JJ, Pasquina PF, Wain HJ, Carlini AR, MacKenzie EJ. The Military Extremity Trauma Amputation/Limb Salvage (METALS) study: outcomes of amputation versus limb salvage following major lower-extremity trauma. J Bone Joint Surg Am. 2013 Jan 16;95(2):138-45.

11. Pollak AN, McCarthy ML, Burgess AR; The Lower Extremity Assessment Project (LEAP) Study Group. Short-term wound complications after application of flaps for coverage of traumatic soft-tissue defects about the tibia. J Bone Joint Surg Am. 2000 Dec;82(12):1681-91.

12. MacKenzie EJ, Bosse MJ, Kellam JF, Burgess AR, Webb LX, Swiontkowski MF, Sanders R, Jones AL, McAndrew MP, Patterson B, McCarthy ML, Rohde CA; LEAP Study Group. Factors influencing the decision to amputate or reconstruct after high-energy lower extremity trauma. J Trauma. 2002 Apr;52(4):641-9.

13. Smith JJ, Agel J, Swiontkowski MF, Castillo R, Mackenzie E, Kellam JF; LEAP Study Group. Functional outcome of bilateral limb threatening: lower extremity injuries at two years postinjury. J Orthop Trauma. 2005 Apr;19(4):249-53.

14. Castillo RC, MacKenzie EJ, Webb LX, Bosse MJ, Avery J; LEAP Study Group. Use and perceived need of physical therapy following severe lower-extremity trauma. Arch Phys Med Rehabil. 2005 Sep;86(9):1722-8.

15. Castillo RC, Bosse MJ, MacKenzie EJ, Patterson BM; LEAP Study Group. Impact of smoking on fracture healing and risk of complications in limb-threatening open tibia fractures. J Orthop Trauma. 2005 Mar;19(3):151-7.

16. Bosse MJ, McCarthy ML, Jones AL, Webb LX, Sims SH, Sanders RW, MacKenzie EJ; Lower Extremity Assessment Project (LEAP) Study Group. The insensate foot following severe lower extremity trauma: an indication for amputation? J Bone Joint Surg Am. 2005 Dec;87(12):2601-8.

17. Low EE, Inkellis E, Morshed S. Complications and revision amputation following trauma-related lower limb loss. Injury. 2017 Feb;48(2):364-70. Epub 2016 Nov 18.

18. Tennent DJ, Wenke JC, Rivera JC, Krueger CA. Characterisation and outcomes of upper extremity amputations. Injury. 2014 Jun;45(6):965-9. Epub 2014 Feb 15.

19. Tintle SM, Baechler MF, Nanos GP 3rd, Forsberg JA, Potter BK. Traumatic and trauma-related amputations: part II: upper extremity and future directions. J Bone Joint Surg Am. 2010 Dec 15;92(18):2934-45.

20. Slauterbeck JR, Britton C, Moneim MS, Clevenger FW. Mangled Extremity Severity Score: an accurate guide to treatment of the severely injured upper extremity. J Orthop Trauma. 1994 Aug;8(4):282-5.

21. Togawa S, Yamami N, Nakayama H, Mano Y, Ikegami K, Ozeki S. The validity of the Mangled Extremity Severity Score in the assessment of upper limb injuries. J Bone Joint Surg Br. 2005 Nov;87(11):1516-9.

22. Jupiter JB, Kellam JF. Diaphyseal fractures of the forearm. In: Browner BD, Levine AM, Jupiter JB, Trafton PG, Krettek C, editors. Skeletal trauma, 4th ed. Philadelphia: W.B. Saunders; 2009.

23. Jupiter JB, Kleinert HE. Vascular injuries in the upper extremity. In: Tubiana R., editor. The hand. 3rd ed. Philadelphia: W.B. Saunders; 1988.

24. Harris AM, Althausen PL, Kellam J, Bosse MJ, Castillo R; Lower Extremity Assessment Project (LEAP) Study Group. Complications following limb-threatening lower extremity trauma. J Orthop Trauma. 2009 Jan;23(1):1-6.

25. Tintle SM, Baechler MF, Nanos GP, Forsberg JA, Potter BK. Reoperations following combat-related upper-extremity amputations. J Bone Joint Surg Am. 2012 Aug 15;94(16):e1191-6.

26. Valerio IL, Masters Z, Seavey JG, Balazs GC, Ipsen D, Tintle SM. Use of a dermal regeneration template wound dressing in the treatment of combat-related upper extremity soft tissue injuries. J Hand Surg Am. 2016 Dec;41(12):e453-60. Epub 2016 Oct 13.

27. Bernstein ML, Chung KC. Early management of the mangled upper extremity. Injury. 2007 Dec;38(Suppl 5):S3-7. Epub 2007 Dec 3.

28. Ostlie K, Franklin RJ, Skjeldal OH, Skrondal A, Magnus P. Musculoskeletal pain and overuse syndromes in adult acquired major upper-limb amputees. Arch Phys Med Rehabil. 2011 Dec;92(12):1967-1973.e1.

29. Dillingham TR, Pezzin LE, MacKenzie EJ. Limb amputation and limb deficiency: epidemiology and recent trends in the United States. South Med J. 2002 Aug;95(8):875-83.

30. Krueger CA, Wenke JC, Ficke JR. Ten years at war: comprehensive analysis of amputation trends. J Trauma Acute Care Surg. 2012 Dec;73(6)(Suppl 5):S438-44.