Title

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Journal

Journal of Neurotrauma, 39(15-16)

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Publication Date

2022-08-01

DOI

10.1089/neu.2021.0375

Peer reviewed

Journal of Neurotrauma
39:1030–1038 (August 2022)

DOI: 10.1089/neu.2021.0375

Journal of Neurotrauma

ORIGINAL ARTICLE

Appendicular Fracture and Polytrauma Correlate with Outcome of Spinal Cord Injury: A Transforming Research and Clinical Knowledge in Spinal Cord Injury Study

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Abstract

Spinal cord injuries (SCIs) frequently occur in combination with other major organ injuries, such as traumatic brain injury (TBI) and injuries to the chest, abdomen, and musculoskeletal system (e.g., extremity, pelvic, and spine fractures). However, the effects of appendicular fractures on SCI recovery are poorly understood. We investigated whether the presence of SCI-concurrent appendicular fractures is predictive of a less robust SCI recovery. Patients enrolled in the Transforming Research and Clinical Knowledge in SCI (TRACK-SCI) prospective cohort study were identified and included in this secondary analysis study. Inclusion criteria resulted in 147 patients, consisting of 120 with isolated SCIs and 27 with concomitant appendicular fracture. The primary outcome was American Spinal Injury Association (ASIA) Impairment Scale (AIS) neurological grades at hospital discharge. Secondary outcomes included hospital length of stay, intensive care unit (ICU) length of stay, and AIS grade improvement during hospitalization. Multivariable binomial logistical regression analyses assessed whether SCI-concomitant appendicular fractures associate with SCI function and secondary outcomes. These analyses were adjusted for age, gender, injury severity, and non-fracture polytrauma. Appendicular fractures were associated with more severe AIS grades at hospital discharge, though covariate adjustments diminished statistical significance of this effect. Notably, non-fracture injuries to the chest and abdomen were influential covariates. Secondary analyses suggested that appendicular fractures also increased hospital length of stay. Our study indicated that SCI-associated polytrauma is important for predicting SCI functional outcomes. Further statistical evaluation is required to disentangle the effects of appendicular fractures, non-fracture solid organ injury, and SCI physiology to improve health outcomes among SCI patients.

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Keywords: AIS; appendicular fractures; length of stay; polytraumatic SCI; recovery; TRACK-SCI

Introduction

Spinal cord injuries (SCIs) are increasingly recognized as a global health priority, as they represent highly debilitating injuries that require complex and expensive medical care.[1] SCIs frequently co-occur with multiple traumatic injuries, such as traumatic brain injury (TBI) and injuries to the chest, abdomen, and musculoskeletal system (e.g., fractures).[2–4]

Musculoskeletal injury is a common component of polytrauma that can exacerbate other organ injuries sustained, such as acute respiratory distress syndrome, renal failure, and multiple organ failure, which together account for 45% of trauma deaths.[5] In rodent studies, tibia fractures worsen central nervous system (CNS) outcomes by increasing filtration of peripheral immune cells into the CNS, which disrupts the neural circuitry involved in motor behavior, learning, and memory.[6] Our recent study on murine polytrauma models with TBI and concurrent fractures reported a distinct pathological state of polytrauma and co-variations between fractures, TBI, and systemic markers of neuroinflammation.[7] Specifically, our results suggested that contralateral bone fracture and TBI alter the local neuroinflammatory state to accelerate early fracture healing. Conversely, another study demonstrated that mice with skull fractures had severity-dependent worse functional outcomes and greater upregulation of neuroinflammatory genes than mice without skull fractures.[8] Therefore, it is plausible to suspect that fracture presence may influence neurological and functional recovery after SCI.

Existing literature reviews surgical and non-surgical management of lower limb[5,9,10] and osteoporotic fractures as well as the morbidity, mortality, and complications of fractures in patients with long-standing SCIs.[2,9,11–13] Previous reports also describe the characteristics and appendicular fracture types in patients concurrently presenting with SCI.[2,14] However, the effects of appendicular fractures on SCI recovery are poorly understood.[15]

We sought to address these gaps through a chart review of the Transforming Research and Clinical Knowledge in SCI (TRACK-SCI) study database at Zuckerberg San Francisco General Hospital and Trauma Center (ZSFG). The goal of this study was to investigate if the presence of concomitant appendicular fractures is associated with greater neurological impairment in polytraumatic SCI.

Methods

Overview

TRACK-SCI is a multi-center, prospective observational study conducted by the University of California San Francisco (UCSF) Brain and Spinal Injury Center (BASIC) that recruits patients from Zuckerberg San Francisco General Hospital (ZSFGH) and Fresno's Community Regional Medical Center, two level I trauma centers. Created in 2013, TRACK-SCI is funded by the Department of Defense (DOD) and is described in depth in a previous publication.[16] Institutional review board (IRB) approval was obtained at this site for all study procedures.

Patient selection and demographics

Patients enrolled in the TRACK-SCI study from 2015 to 2020 were identified and included in this secondary analysis of a prospective observational study[16] (Fig. 1). Inclusion criteria for the TRACK-SCI study is composed of (1) all traumatic SCI patients presenting to the emergency room of a level I trauma center, (2) presence of neurological deficit with an associated spinal fracture or ligamentous injury based on computed tomography (CT) scans or magnetic resonance imaging (MRI), and (3) ability to consent to the study. Exclusion criteria consisted of patients being (1) < 18 years old, (2) prisoners or patients in custody, (3) pregnant, or (4) on a medically indicated psychiatric hold or otherwise unable to consent to study participation. Our current study further excluded patients missing data regarding the (1) presence/absence of an appendicular fracture, (2) measure of SCI severity at hospital discharge, and (3) Injury Severity Score (ISS), an internationally recognized scoring system assessing the combined effects of multiply injured patients.[17]

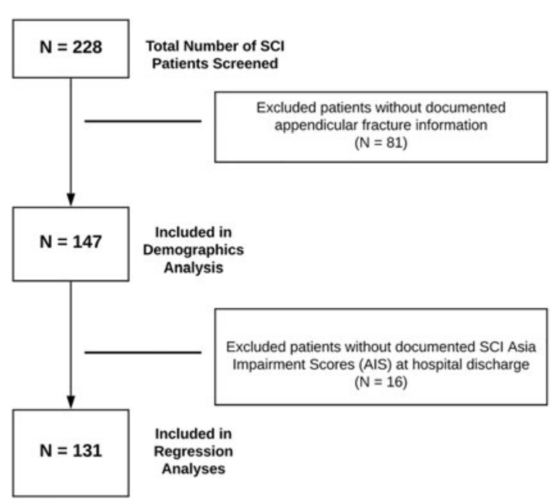

FIG. 1. Flow diagram for study inclusion/exclusion.

Data variables and outcomes

The International Standard for Neurological Classification of Spinal Cord Injury (ISNCSCI) is published by the American Spinal Injury Association (ASIA) and assesses patients' motor function and sensory impairment. The ISNSCI examination uses the ASIA Impairment Scale (AIS) to test bilateral body motions and degree of sensation after light touch.[18] The scale has five classification levels ranging from total loss of neural function in the affected area (Grade A) to completely normal motor and sensory functions (Grade E).[18]

ISNCSCI examinations were performed by healthcare providers who completed in-person training and the ASIA International Standards Training E Program (InSTEP). If a reliable ISNCSCI examination was possible, providers conducted examinations at regular intervals – including admission (day 0 = 0–23 h from injury), every 48 h until post-injury day 7, discharge, 6-month follow-up (± 2 weeks), and 12-month follow-up (± 2 weeks) – either for clinical care or research. However, the ISNCSCI was not always performed, because of staff limitations and patients' altered mental state, sedation, language barriers, polytrauma, refusal to complete examination, withdrawal from study, and death. When the ISNCSCI examination was unobtainable or not performed, an estimated AIS grade was periodically determined by providers. Our primary outcome was AIS grade at hospital discharge, specifically A versus non-A grades, which is a clinically useful distinction for SCI treatment and prognosis.[19] Based on significant 0.93 ($p < 0.001$) and 0.84 ($p < 0.001$) Spearman's correlations between estimated and ISNCSCI-determined AIS scores at hospital discharge and admission, respectively, the AIS-estimated and AIS-determined variables were pooled to increase sample size. If conflict occurred during pooling, ISNCSCI-determined AIS scores were selected over estimated AIS scores. Secondary outcomes were the probability of improvement of ≥1 AIS grade and the hospital and ICU lengths of stay (LOS) between SCI-isolated and SCI-concomitant appendicular fracture groups.

Our analyses included ISS on arrival and injury etiology. The ISS is based on the Abbreviated Injury Scale, in which injuries are assigned to six body regions (head and neck, face, chest, abdominal or pelvic contents, extremities or pelvic girdle, and external[20]) and assigned a value from 1 (least severe) to 6 (most severe). The scores from the three most severely injured ISS body regions are squared then added together to produce an overall ISS.[20] The injury etiology describes SCI etiology according to the following six categories: assault, crush, fall, sports or leisure, transport, or other traumatic cause.

To control for the impact of non-fracture injuries on AIS discharge scores, a recalculated ISS score was produced that excluded extremity and pelvic girdle injuries, such as sprains, fractures, dislocations, and amputations. A Pearson's product-moment correlation test revealed a significant 0.99 ($p < 0.001$) correlation between the original ISS and the recalculated ISS that excluded extremity and pelvic girdle injuries.

All data were stored in the Research Electronic Data Capture (REDCap) database, which is in full compliance with Health Insurance Portability and Accountability Act (HIPAA) security standards for protection of personal health information (PHI).

Statistical analysis

All statistical analyses were conducted with R Version 4.1.0 GUI 1.76 High Sierra Build.[21] Differences in subject characteristics (Table 1) between patients with isolated SCI and patients with SCI-concomitant appendicular fractures were assessed for statistical imbalance using Mann–Whitney *U* tests and two-sided *t* tests (ordinal and continuous variables, respectively), and Fisher exact tests (categorical variables).

Binomial logistical regression analyses assessed whether SCI-concomitant appendicular fractures are predictors of

Table 1. Demographic and Injury Characteristics of Included Patients ($n = 147$)

Variable	*Isolated SCI group (n = 120)*	*SCI + appendicular fracture group (n = 27)*	p *value*
Age (mean)	53.0 (20.5)	45.7 (18.7)	0.078[a]
Gender			0.643[b]
Male	86 (71.7)	18 (66.7)	
Female	34 (28.3)	9 (33.3)	
AIS Grade on admission			**0.007**[b]
A	23 (23.2)	13 (59.1)	
B	7 (7.1)	3 (13.6)	
C	20 (20.2)	2 (9.1)	
D	46 (46.5)	4 (18.2)	
E	3 (3.0)	0 (0)	
Unspecified	16 (Excluded from analysis)		
AIS Grade on discharge			0.187[b]
A	23 (21.5)	11 (45.8)	
B	5 (4.7)	1 (4.2)	
C	19 (17.8)	3 (12.5)	
D	56 (52.3)	9 (21)	
E	4 (3.7)	0 (0)	
Unspecified	16 (Excluded from analysis)		
Original Injury Severity Score (ISS) on arrival	23.0 (15.9)	30.9 (11.9)	**<0.001**[c]
Injury etiology			0.865[b]
Assault	18 (15.0)	3 (11.1)	
Crush	1 (8.0)	0 (0)	
Fall	58 (48.3)	16 (59.2)	
Other traumatic cause	4 (3.3)	1 (3.7)	
Sports/Leisure	6 (5.0)	0 (0)	
Transport	33 (27.5)	7 (25.9)	

Bold indicates statistical significance.

Continuous variables are presented as mean (SD) and analyzed using either the Mann–Whitney *U* Test or two-sided *t* test; categorical variables are presented as *n* (%) and analyzed using a Fisher's exact test.

[a]Welch two sample *t* test

[b]Fisher's exact test

[c]Mann–Whitney *U* test

SCI, spinal cord injury; AIS, American Spinal Injury Association (ASIA) Impairment Scale; SD, standard deviation.

SCI neuromotor outcome. Linear regression (lm R function) and binomial logistical regressions (glm R function with binomial family) analyzed secondary outcomes of probability of SCI improvement and ICU and hospital LOS. All analyses were adjusted for putative confounding or covariate factors including age, gender, and other associated polytrauma through the recalculated ISS variable that excludes extremity and pelvic girdle injuries. Significance was assessed at $p < 0.05$.

To detect potential inflated effects of predictors on SCI outcomes caused by collinearity between predictor variables, a logistical least absolute shrinkage and selection operator (LASSO) regression analysis was conducted, which shrinks regression coefficients from a large and potentially multi-collinear set of variables in the regression and ultimately removes less predictive or redundant predictors from the model.[22,23] LASSO was fitted using the glmnet R package.[24] The amount of shrinkage parametrized by the penalty factor (λ) was decided by cross-validation over the binomial deviance metric.

Results

Demographic and injury characteristics

The TRACK-SCI database comprised 228 patients, but we excluded 81 patients without documented information on the presence or absence of appendicular fracture. Overall, 147 patients with SCI were included and evaluated in the demographics analysis, 120 with isolated SCI and 27 with SCI-concomitant appendicular fractures (Fig. 1). Of the 27 patients with SCI-concomitant appendicular fractures, 8 had sustained upper extremity fractures, 8 had sustained lower extremity fractures, and 11 had sustained both upper and lower extremity fractures. Before conducting regression analyses, we excluded another 16 patients with missing AIS scores at hospital discharge from the remaining 147 patients, because these scores were the primary outcome of our regression. Thus, 131 patients were included and evaluated in the regression analyses, 107 with isolated SCI and 24 with SCI-concomitant appendicular fractures (Fig. 1).

Patient demographics, AIS scores, and etiology and severity of injury are presented in Table 1. SCI patients with appendicular fracture had higher ISS on arrival ($p < 0.001$) and differing proportions of AIS grade on admission ($p = 0.007$). Notably, SCI patients with appendicular fracture had a higher frequency of AIS Grade A (13 [59.1%]) than SCI isolated patients (23 [23.2%]). The isolated SCI and SCI-concomitant appendicular fracture groups did not significantly differ in age, gender, AIS score on discharge, or injury etiology.

ISS breakdown

ISS breakdown by body region between isolated SCI patients and SCI-concomitant appendicular fracture patients is provided in Table 2. SCI patients with appendicular

Table 2. Injury Severity Score (ISS) Breakdown by Body Region between Appendicular Fracture Groups ($n = 147$)

Injury Severity Score (ISS) by body region	*Isolated SCI Group (n = 120)*	*SCI + Appendicular Fracture Group (n = 27)*	*p value*
ISS	23.0	30.9	**<0.001[a]**
Abdomen			**<0.001[b]**
No injury	81 (81)	8 (29.6)	
Minor	1 (1)	0 (0)	
Moderate	8 (8)	7 (25.9)	
Serious	2 (2)	7 (25.9)	
Severe	4 (4)	3 (11.1)	
Critical	4 (4)	2 (7.4)	
Chest			**<0.001[b]**
No injury	65 (65)	5 (18.5)	
Minor	0 (0)	1 (3.7)	
Moderate	12 (12)	3 (11.1)	
Serious	9 (9)	9 (33.3)	
Severe	2 (2)	6 (22.2)	
Critical	12 (12)	3 (11.1)	
External			0.172[b]
No injury	39 (39)	6 (22.2)	
Minor	58 (58)	19 (70.4)	
Moderate	2 (2)	2 (7.4)	
Serious	0 (0)	0 (0)	
Severe	0 (0)	0 (0)	
Critical	1 (1)	0 (0)	
Face			0.084[b]
No injury	77 (77)	22 (81.5)	
Minor	17 (17)	1 (3.7)	
Moderate	6 (6)	4 (14.8)	
Serious	0 (0)	0 (0)	
Severe	0 (0)	0 (0)	
Critical	0 (0)	0 (0)	
Extremity			**<0.001[b]**
No injury	93 (93)	1 (3.7)	
Minor	4 (4)	0 (0)	
Moderate	3 (3)	18 (66.7)	
Serious	0 (0)	8 (29.6)	
Severe	0 (0)	0 (0)	
Critical	0 (0)	0 (0)	
Head and neck			0.356[b]
No injury	13 (13)	7 (25.9)	
Minor	5 (5)	0 (0)	
Moderate	23 (23)	7 (25.9)	
Serious	42 (42)	8 (29.6)	
Severe	12 (12)	4 (14.8)	
Critical	4 (4)	0 (0)	
Unspecified ISS	20	0	

Bold indicates statistical significance.

Continuous variables are presented as mean (SD) and analyzed using either the Mann–Whitney *U* test or two-sided *t* test; categorical variables are presented as *n* (%) and analyzed using a Fisher's exact test.

Examples of injuries by body region[17]:

1. Head or neck: injury to brain or cervical spine, skull or cervical spine fractures, and asphyxia/suffocation
2. Face: involving mouth, ears, nose, eyes, and facial bones
3. Chest: all lesions to internal organs, diaphragm, rib cage, and thoracic spine, drowning and inhalation injury
4. Abdomen or pelvic contents: lumbar spine lesions and all lesions to internal organs
5. Extremities or pelvic girdle: sprains, fractures, dislocations and amputations.
6. External: lacerations, contusions, abrasions, and burns, independent of their location on the body surface, except amputation burns that are assigned to the appropriate body region. Other traumatic events assigned to this body region are electrical injury, frostbite, hypothermia, and whole body (explosion-type) injury.

[a]Mann–Whitney *U* test.
[b]Fisher's exact test.
SCI, spinal cord injury; SD, standard deviation.

fracture differ significantly from isolated SCI patients in ISS for the abdomen ($p < 0.001$), chest ($p < 0.001$), and extremity ($p < 0.001$). The isolated SCI and SCI-concomitant appendicular fracture groups do not significantly differ in the ISS for the external ($p = 0.172$), face ($p = 0.084$), or head and neck ($p = 0.356$) regions.

Appendicular fractures and AIS grade at discharge

We tested whether appendicular fracture presence predicted complete (A Grade) versus incomplete (non-A Grade) SCI at hospital discharge. Specifically, we used a binomial logistical regression with AIS discharge grade as the output and SCI-concomitant appendicular fracture presence as the predictor, adjusting for age and gender. The odds ratio (OR) for appendicular fracture presence was 9.47 (95% confidence interval [CI]: 0.989–89.1), demonstrating that appendicular fracture presence was a significant predictor for complete SCI (A Grade) at hospital discharge ($p = 0.049$).

To control for severity of initial injury without controlling for the effect of appendicular fractures, we also adjusted our regression model for the recalculated ISS that excludes extremity and pelvic girdle injuries (Table 3). After adjustment, a logistical regression of AIS A versus non-A at discharge as the outcome and appendicular fractures as the predictor yielded an OR of 7.08 (95% CI: 97.7–0.48), which did not reach statistical significance ($p = 0.149$). The recalculated ISS variable yielded an OR of 1.35 (95% CI: 1.20–1.55), which was significant ($p < 0.001$). Because the recalculated ISS was a significant predictor, we conducted another regression separating the ISS into its six-constituent body region severity scores (Table 4). The association between appendicular fractures and AIS still did not reach significance, and the only significant associations between body-region-specific ISS and AIS were the Abdomen and Chest scores.

To better understand whether the recalculated ISS merely associates with worse SCI functional outcomes via greater initial SCI severity, we also conducted a Pearson's correlation test between the recalculated ISS and AIS at hospital admission, showing a significant correlation of 0.55 ($p < 0.001$).

To detect potential inflated effects of chest and abdomen polytrauma on SCI outcomes caused by collinearity between predictors, we applied a LASSO regression to the model in Table 4. As the penalty factor (λ) increased in our LASSO, only trauma to the chest (OR = 2.75) and abdomen (OR = 2.14) remained in the model as influential predictors for SCI functional outcome.

Table 3. Binomial Logistical Regression Model with A versus non-A AIS Grades at Discharge as Outcome (*n* = 131)

Characteristic	*Log(OR)*	*95% CI*	*p value*
Appendicular fractures			
No fracture	–	–	
Fracture	0.83	-0.34, 2.0	0.2
Recalculated ISS (excluding extremity and pelvic girdle injuries)	0.13	0.08, 0.19	<0.001
Age	-0.03	-0.07, 0.00	0.028
Gender			
Female	–	–	
Male	-0.62	-1.9, 0.60	0.3

Bold indicates statistical significance.
AIS, American Spinal Injury Association (ASIA) Impairment Scale; OR, odds ratio, CI, confidence interval; ISS, Injury Severity Score.

Table 4. Binomial Logistical Regression Model with A versus non-A AIS Grades at Discharge as Outcome (*n* = 131)

Characteristic	*Log(OR)*	*95% CI*	*p value*
Appendicular fractures			
No fracture	–	–	
Fracture	-0.74	-2.2, 0.60	0.3
Age	0.00	-0.03, 0.03	>0.9
Gender			
Female	–	–	
Male	-1.0	-2.3, 0.26	0.13
Original ISS by body region			
ISS Abdomen	0.67	0.30, 1.1	<0.001
ISS Chest	0.77	0.43, 1.2	<0.001
ISS External	-0.37	-1.2, 0.46	0.3
ISS Face	-0.28	-1.4, 0.65	0.6
ISS Head and Neck	0.12	-0.22, 0.49	0.5

Bold indicates statistical significance.
AIS, American Spinal Injury Association (ASIA) Impairment Scale; OR, odds ratio, CI, confidence interval; ISS, Injury Severity Score.

Appendicular fractures and probability of improvement

We also tested whether appendicular fracture presence predicts probability of improvement in SCI of ≥1 AIS grade at hospital discharge. We used a binomial logistical regression with improvement as the outcome (''Yes''/''No'') and appendicular fractures as the predictor. The OR for appendicular fracture presence was 9.77 (95% CI: 0.66–125.9), which did not reach statistical significance ($p = 0.082$).

Table 5. Binomial Logistical Regression Model with AIS Improvement as Binary Outcome (*n* = 131)

Characteristic	*Log(OR)*	*95% CI*	*p value*
Appendicular fractures			
No fracture	–	–	
Fracture	1.0	-0.26, 2.2	0.11
Recalculated ISS (excluding extremity and pelvic girdle injuries)	0.03	-0.02, 0.07	0.2
Age	-0.02	-0.05, 0.01	0.2
Gender			
Female	–	–	
Male	1.1	-0.17, 2.7	0.12

Bold indicates statistical significance.
AIS, American Spinal Injury Association (ASIA) Impairment Scale; OR, odds ratio, CI, confidence interval; ISS, Injury Severity Score.

Using the same regression model, we added other predictors into our analysis, including age, gender, and the recalculated ISS (Table 5). No variable reached statistical significance. The estimates for appendicular fractures resembled those of the unadjusted model, suggesting that the addition of adjusting predictors did not modify the relationship between appendicular fractures and probability of SCI improvement.

Appendicular fractures and hospital and ICU LOS

We examined whether appendicular fracture presence predicted both hospital and ICU LOS. Before covariate adjustment, the presence of appendicular fractures was significantly associated with an increased hospital stay of 22.4 days (95% CI: 6.82–37.9 days) and increased ICU stay of 5.52 days (95% CI: 1.08–9.96 days). After adjustment for age, gender, and injury severity via our recalculated ISS, the association between appendicular fractures and hospital LOS remained significant ($\beta = 17.4$ days, 95% CI: 0.52–34.4 days, $p = 0.044$), and the association between appendicular fractures and ICU LOS did not ($\beta = 3.78$ days, 95% CI: -0.98–8.54 days, $p = 0.12$) (Table 6).

Discussion

Our study sought to determine whether the presence of SCI-concomitant appendicular fractures predicted greater SCI severity at hospital discharge. We secondarily investigated whether appendicular fractures were predictive of extended hospital and ICU LOS, and decreased probability of neurological improvement after SCI. Appendicular fractures were significantly associated with more severe AIS grades at hospital discharge, but this statistical effect was attenuated after adjusting for other covariates, notably injury severity. A LASSO regression revealed that only trauma to the chest (OR = 2.75) and abdomen (OR = 2.14) remained in the model as influential predictors for SCI functional outcome. For our secondary outcomes, appendicular fractures were significantly associated with increased hospital LOS, but did not reach significance with ICU LOS or decreased probability of SCI improvement.

Prognostic factors associated with functional and neurological recovery from SCI in prior analyses include initial severity of SCI,[25–28] distribution and injury etiology,[25,27–29] early neurological improvement,[29] timing of surgical decompression,[29] and various dynamic variables (which change with time) such as first aid and transportation, duration of spinal shock, rate of reflex recovery, flexor spasms and bed sores, and sacral sparing.[29,30] However, analyses generally found that static variables (which do not change with time) such as age at time of injury, sex, type of treatment,[25,27] and injury etiology had no significant correlation with neurological recovery and rehabilitation.[30,31] Our study is consistent with prior work in that SCI severity at hospital discharge had (1) a significant but marginal association with age, (2) no significant association with the static variable of gender, and (3) significant association with the severity and pattern of injury.

The association between severity of injury and SCI functional outcomes at discharge appears to be largely influenced by non-fracture injury to the chest and abdomen, which were the only significant predictors of more severe SCI discharge outcomes after LASSO regression. This is consistent with studies pointing to abdominal injuries as important risk factors for mortality and morbidity in patients with multi-system trauma.[32,33] It is possible that (1) chest and abdomen polytrauma impacts SCI functional outcomes at hospital discharge because of impaired recovery through neuroinflammation,[5,6] but it is also possible that (2) chest and abdomen polytrauma merely associates with worse SCI functional outcomes via greater initial SCI severity. With only a 0.55 ($p < 0.001$) moderate correlation between the recalculated ISS and AIS at hospital admission, it remains unclear why the recalculated ISS diluted the predictive effect of appendicular fractures on worse SCI functional outcomes. Regardless, our work reaffirms that SCI-associated polytrauma is important in predicting SCI functional outcomes.

The association between appendicular fracture presence and increased hospital LOS has important implications in healthcare costs and resource utilization. In

Table 6. Linear Regression Model with Effect of Predictors on Hospital LOS and ICU LOS (N = 131)

Hospital LOS			
Characteristic	*Beta*	*95% CI*	*p-value*
Appendicular fractures			
No fracture	–	–	
Fracture	17	0.52, 34	0.043
Recalculated ISS (excluding extremity and pelvic girdle injuries)	0.60	0.13, 1.1	0.013
Age	-0.24	-0.61, 0.12	0.2
Gender			
Female	–	–	
Male	6.9	-8.3, 22	0.4
ICU LOS			
Characteristic	*Beta*	*95% CI*	p *value*
Appendicular fractures			
No fracture	–	–	
Fracture	3.8	-1.0, 8.5	0.12
Recalculated ISS (excluding extremity and pelvic girdle injuries)	0.15	0.02, 0.28	0.023
Age	-0.07	-0.18, 0.03	0.2
Gender			
Female	–	–	
Male	1.0	-3.3, 5.3	0.7

Bold indicates statistical significance.

LOS, length of stay; ICU, intensive care unit; CI, confidence interval; ISS, Injury Severity Score.

2016, the average hospital stay in the Pacific United States for all diagnoses was 4.4 days and cost $15,600.[34] Applying these values to our data, a 17-day increase in length of hospital stay for SCI-concomitant appendicular fracture patients relative to non-appendicular fracture patients would cost $60,273 more per patient. Longer hospital stays may also delay rehabilitation and development of essential daily living skills after SCI, which is detrimental to efficient rehabilitation.

The authors acknowledge that there are limitations to this study. This is a secondary analysis of the prospective TRACK-SCI project data with variables curated from chart review and is therefore vulnerable to the biases inherent with such studies. As AIS grades are determined by healthcare providers completing thorough, time-consuming ISNSCI examinations on willing and conscious patients, the ISNCSCI examination was occasionally administered outside of the hospital admission or discharge time frames, or not administered at all. This may have underestimated SCI severity at admission or overestimated SCI severity at discharge, lessening our ability to detect neurological improvement. Limitations notwithstanding, AIS at discharge is a specific target of the TRACK-SCI project[16] and provides a viable target outcome for testing whether appendicular fractures adversely influence SCI recovery. Selection bias may also have led to less available data for patients at certain clinical sites or presenting with certain injuries, and SCI patients with appendicular fractures may have worse neuromotor outcomes because they sustained more extreme injuries overall. We therefore attempted to control for the impact of non-fracture polytrauma on AIS discharge scores through a recalculated ISS score that excluded extremity and pelvic girdle injuries. We justified the inclusion of this variable because extremity injuries were rarely included in the original and recalculated ISS, which displayed 0.99 correlation (Pearson's method). Use of the ISS incurs limitations because it (1) is based on subjective expert opinion, (2) does not incorporate the impact of multiple injuries within one body region, and (3) categorizes severity scores in the head region as comparable to those of other body regions.[35,36] Nonetheless, ISS correlates well with mortality and duration of hospitalization, and remains a widely used scoring system in the trauma literature.[36] Because of concerns over potential power limitations, our study did not account for spinal level of injury and whether appendicular fractures were sustained above or below the neurological level of injury, which both may affect changes in AIS. Lastly, although adjustment for covariates attenuated the significant effect of appendicular fractures on AIS at discharge, appendicular fractures remained the predictor with the greatest effect. Therefore, the effect of appendicular fractures on AIS at discharge may exist, but we lack statistical power in the sample size to identify it. Novel aspects of our study include a relatively larger sample size for an SCI study population, and an examination of how SCI-concurrent appendicular fractures influence neurological outcomes.

Conclusion

To our knowledge, this is the first study to provide a detailed analysis of the relationship between SCI-concomitant appendicular fractures and SCI recovery. SCI-concomitant appendicular fractures were significantly associated with greater hospital LOS and more severe AIS grades at hospital discharge. Covariate models attenuated AIS significance after adjusting for potential confounders, notably non-fracture polytrauma, highlighting the complex ways that polytrauma influences spinal cord outcome prediction. Our study reaffirms that SCI-associated polytrauma is important in determining SCI outcomes, especially for trauma to the chest and abdomen. Further studies are required to disentangle the effects of appendicular fractures, non-fracture polytrauma, and SCI physiology to improve health outcomes among SCI patients.

Acknowledgments

We thank Theodore Miclau III, MD (chief of Orthopaedic Surgery at ZSFG and vice chairman in the UCSF Department of Orthopaedic Surgery), Anastasia Keller (UCSF post-doctoral scholar), Hannah Radabaugh (UCSF post-doctoral scholar, neurological surgery), and Nikolaos Kyritsis (ZSFG assistant professional researcher, neurological surgery) for their intellectual contributions. We also thank Xuan Duong Fernandez (clinical research coordinator) for her help in acquiring and interpreting data. None of these individuals received funding or compensation for their contributions.

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Authors' Contributions

T.A.M., S.M., A.T.E., K.M., A.D., A.N.E.N., and J.R.H. were responsible for the study conception and design; T.A.M., A.T.E., J.R.H., and A.D. were responsible for data collection; T.A.M., A.T.E., R.H., A.D., and A.C. were responsible for analysis and interpretation of results; and T.A.M., S.M., A.T.E., K.M., A.D., A.N.E.N., J.R.H., A.C., L.P., P.W., S.S.D., J.C.B., and M.S.B. were responsible for draft manuscript preparation: T.A.M. (UCSF School of Medicine) had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. All authors critically reviewed the content, approved the final version to be published, and agreed to be accountable for all aspects of the work.

Funding Information

This work was supported by National Institutes of Health (NIH)/National Institute for Neurological Disorders and Stroke (NINDS) grants R01NS088475, R01NS122888, and UG3/UH3NS106899, and U24NS122732 (A.R.F.); Department of Veterans Affairs grants 1I01RX002245 and I01RX002787 (A.R.F.); Craig H. Neilsen Foundation and Wings for Life Foundation (A.R.F.); Wings for Life Foundation (A.T.E.); Department of Defense grant W81XWH2010245 (M.S.B.); CH Neilsen Foundation (M.S.B.); and UCSF Department of Orthopaedic Surgery Heiman Research Fellowship Award (T.A.M.). The contents are solely the responsibility of the authors and do not necessarily represent the official views of the funding agencies.

Author Disclosure Statement

No competing financial interests exist.

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