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Predicting Work-Related Disability and Medical Cost Outcomes: Estimating Injury Severity Scores from Workers' Compensation Data

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Abstract *Purpose* Acute work-related trauma is a leading cause of death and disability among US workers. The research objectives were to assess: (1) the feasibility of estimating Abbreviated Injury Scale-based injury severity scores (ISS) from ICD-9-CM codes available in workers' compensation (WC) medical billing data, (2) whether ISS predicts work-related disability and medical cost outcomes, (3) whether ISS adds value over other injury severity proxies, and (4) whether the utility of ISS differs for an all-injury sample compared with three specific injury samples (amputations, extremity fractures, traumatic brain injury). *Methods* ISS was estimated from ICD-9-CM codes using Stata's user-written -icdpic- program for 208,522 compensable nonfatal WC claims for workers injured in Washington State from 1998 to 2008. The Akaike Information Criterion and R^2 were used to compare severity measures. Competing risks survival analysis was used to evaluate work disability outcomes. Adjusted total medical costs were modeled using linear regression. *Results* Work disability and medical costs increased monotonically with injury severity. For a subset of 4,301 claims linked to the Washington State Trauma Registry (WTR), there was moderate agreement between WC-based ISS and WTR-based ISS. Including ISS together with an early hospitalization indicator resulted in the most informative models; however, early hospitalization is a more downstream measure. *Conclusions* ISS was significantly associated with work disability and medical cost outcomes for work-related injuries. Injury severity should be considered as a potential confounder for occupational injury intervention, program evaluation, or outcome studies, and can be estimated using existing software when ICD-9-CM codes are available.

Keywords Injury severity · Trauma severity indices · ICDPIC · Occupational injuries · Workers' compensation · Work disability

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Introduction

Acute work-related trauma is a leading cause of death and disability among US workers. Every day, approximately 9,000 workers are treated in emergency departments (EDs), 200 are hospitalized, and 15 die due to traumatic injuries [1]. Severe traumatic injury can lead to long-term pain and disability and is very costly for workers' compensation (WC) systems and society as a whole [2, 3]. The total national direct and indirect cost of occupational injuries was recently estimated to approach $192 billion annually [4].

Most states maintain a trauma registry, and researchers in several states (e.g., Alaska, Illinois, Washington) have begun to explore these registries as a resource for occupational injury surveillance and research [5–9]. Trauma registries typically contain injury severity measures based on the Association for the Advancement of Automotive Medicine's abbreviated injury scale (AIS) [10] that were generated via expert assessment by trauma surgeons, review of medical records by trauma registrars, and/or estimated from ICD-9-CM codes by trauma registry software [11]. Two software packages that estimate injury severity scores directly from ICD-9-CM codes have been used for injury research using hospital discharge data: (1) ICDMAP-90 software developed by and available from the Johns Hopkins Bloomberg School of Public Health [12], and (2) Stata's user-written -icdpic- suite of programs (ICDPIC), developed using National Trauma Data Bank (NTDB) data to assign approximate injury severity scores by classifying injuries into general severity and body region categories [13]. ICDMAP-90 is not current to the most recent ICD-9-CM and AIS changes and does not run on newer computers. ICDPIC is freely available and easily run by Stata users. ICDPIC-based injury severity scores are now included in some ED discharge files released by the Healthcare Cost and Utilization Project (HCUP).

Previous studies of AIS-based injury severity scores for prediction of work-related outcomes have had mixed findings. When self-reported or directly assessed measures of functional status were included, such measures tended to predict work-related outcomes better than did injury severity scores [14–17]. However, most such studies have been small-scale and focused on functional capacity or short-term work status rather than longer-term outcomes such as the total lost work time, total costs, or total permanent disability. The few studies that have used a continuous measure of work disability along with survival analysis or regression methods have found a significant association between injury severity and work disability [15, 18, 19]. One small-scale study in an industrial setting attempted to use AIS-based severity to predict disability without success; however, the severity range was constricted with 91 % of the 197 injuries scoring as the most minor possible and no injury scoring as severe, critical, or nonsurvivable [20]. No large-scale WC-based studies were identified that used AIS-based injury severity to predict outcomes, although one study used ICDMAP-90 to classify injury severity for surveillance purposes [21].

Our primary interest lies in demonstrating the potential value of injury severity scoring to occupational injury researchers seeking additional methods of risk adjustment for intervention or program evaluation studies. Higher severity is associated with increased medical costs, disability, and time lost from work [22–25]. There is a clear need for better severity measures for occupational health services research [26]. AIS-based injury severity scoring is theoretically appealing, since it estimates baseline injury severity as opposed to the more indirect or more downstream severity proxies sometimes used in occupational injury research relying on WC or other administrative data (e.g., industry, occupation, early hospitalization, amount of time loss compensation). However, in a previous Washington State WC-based study, a simple indicator of early hospitalization was found to be the strongest and most consistent correlate of longer term disability [23].

Objectives

The objectives of this study were to: (1) demonstrate the feasibility of estimating AIS-based injury severity scores from the ICD-9-CM codes available in WC medical billing data, (2) describe the degree to which AIS-based injury severity predicts work-related disability and medical cost outcomes, (3) assess whether AIS-based injury severity adds value over an indicator of early hospitalization, and (4) assess whether the utility of AIS-based injury severity differs for an all-injury sample compared with several specific injury samples (i.e., amputations, extremity fractures, traumatic brain injury).

Methods

Study Population and Data Sources

Washington State has a single payer WC system (State Fund) that covers approximately 70 % of those workers covered by the Industrial Insurance Act [27]. Self-insured employers account for the remaining 30 %; self-insured claims were excluded from this study because detailed medical billing and outcomes data were not available. All compensable WC claims were obtained from the Washington State Department of Labor and Industries for injuries occurring from 1998 to 2008, excluding injuries among those younger than 16 and those occurring outside Washington State. Proximate fatalities (e.g., before or during an immediate post-injury hospitalization, accepted fatal WC claims filed by survivors) were excluded as our population of interest was injured workers who might return to work; later deaths were treated as a competing risk/censoring mechanism.

Claims were linked to Washington State Trauma Registry (WTR) records, maintained by the Washington State Department of Health. The WTR contains traumatic injuries meeting specific inclusion criteria from all state-designated acute trauma care facilities, including at least one of the following: trauma resuscitation team activation, dead on arrival or death during hospital stay, interfacility transfer by Emergency Medical Services or ambulance, or inpatient admission of at least 48 h. Records were linked and deduplicated using The Link King, a public domain software program developed in Washington State for deterministic and probabilistic linkage of administrative records [28]. There were a total of 347,184 eligible compensable State Fund deduplicated injury events, and 5,477 (1.6 %) of those linked to a WTR record (Table 1). Further detail about the two data sources and the data linkage procedure can be found in previous related publications [8, 9]. This study was approved by the Washington State Institutional Review Board.

We used the Occupational Injury and Illness Classification System (OIICS), developed by the Bureau of Labor Statistics (BLS), to identify the primary occupational injury and to identify denominators for the purpose of describing the feasibility of injury severity scoring. OIICS codes were available for essentially all claims. The AIS system was not designed to score occupational diseases and certain occupational injuries (e.g., systemic injuries, environmental injuries, complications). In addition, AIS-based injury severity scores do not reliably classify burns due to the importance of inhalation injuries (not scored by AIS). Therefore, we used OIICS to identify a set of primary injuries that we would expect ICDPIC to be able to score given adequate ICD-9-CM codes using the following criteria for the OIICS nature of injury code: (1) the first digit was 0 (traumatic injuries and disorders), (2) the first two digits were not 05 (burns), (3) the first two digits were not 07 (effects of environmental conditions), and (4) the first three digits were not 091 (asphyxiation), 092 (drowning), 093 (electrocution), 095 (other poisonings and toxic effects), or 096 (traumatic injury complications). A total of 269,153 claims, or 77.5 % of all State Fund compensable nonfatal claims, met these criteria (Table 1). Only 78 claims were excluded due to a missing OIICS nature of injury code.

Outcome Samples and Measures

Outcomes data were extracted from WC records in December of 2010, allowing for 2–13 years of follow-up, depending on when the injury occurred. The number of compensated lost work days was used as a proxy for length of work disability. The end of time loss compensation without total permanent disability (TPD) determination or death usually, but not always, means that the worker is able to or has returned to work. TPD (also known as permanent total disability, or PTD, in many jurisdictions) is determined when medical and vocational evaluations indicate that the injury prevents the worker from ever becoming gainfully employed, and confers eligibility for a pension. Time loss compensation is not measured comparably for two types of WC claims, Kept on Salary (KOS) and Loss of Earning Power (LEP), which were therefore excluded from the work disability analyses (but included for medical cost analyses). The sample available for work disability analyses consisted of 191,820 injury events.

Total medical costs were based on paid-to-date facility, professional, and pharmacy costs for closed claims. Open claims were excluded from cost analyses. Total medical costs were adjusted to December 2008 using the medical care component of the Consumer Price Index, based on month and year of injury. Data for the month and year that costs were actually incurred were unavailable. Paid-to-date costs accumulated over time, but were highly front-loaded, with more than 90 % of medical costs occurring in the first month after injury for 92 % of the claims (as well as for 80 % of the claims with at least 3 years of time loss compensation). We conducted the analyses with and without this adjustment, and there was little practical difference. The sample available for medical cost analyses consisted of 200,800 injury events.

Injury Samples

We assessed the association of injury severity with cost and work disability outcomes for all traumatic injuries combined and for three specific injury subsets: (1) amputations, (2) extremity fractures, and (3) traumatic brain injury (TBI). These injury samples were constructed separately for the cost sample and for the work disability sample,

Table 1 Percent of claims that were severity scored and/or linked to WTR injuries

Denominator/Injury type	N	Claim had ICD-9-CM codes available		Injury severity was scored by ICDPIC		Claim linked to WTR	
		N	%	N	%	N	%
All compensable State Fund claims	347,184	304,201	87.6	231,661	66.7	5,477	1.6
All traumatic injuries[a]	269,153	242,095	90.0	216,386	80.4	4,772	1.8
Amputations[a]	2,180	2,014	92.4	2,001	91.8	227	10.4
Non-fingertip amputations[a]	237	219	92.4	217	91.6	63	26.6
Extremity fractures[a]	26,168	24,117	92.2	23,683	90.5	1,407	5.4

WTR Washington State Trauma Registry

[a] Defined using OIICS criteria but not ICD-9-CM criteria

resulting in a total of eight samples (Table 2). For the purposes of defining the injury sample and for injury severity scoring purposes, we used all ICD-9-CM codes from facility and professional billing data for the first medical encounter occurring within 30 days after the injury date. We used OIICS codes to define the primary/most severe injury for the injury subsets, and additionally required at least one relevant ICD-9-CM code for purposes of severity scoring (workers with multiple injuries were not excluded).

Injuries qualified for the all-injury sample if there was at least one ICD-9-CM diagnostic code for a traumatic injury as specified by the NTDB (800–904.9, 910–929.9, 950–957.9, 959–959.9); however, superficial injuries were not excluded due to their prevalence and relevance to occupational injury research [29]. Isolated burns were excluded for reasons explained earlier. Injuries qualified for the amputation subset when the first three digits of the OIICS nature of injury code were 031 (amputation with bone loss). Relevant ICD-9-CM codes for amputations were 885–887 and 895–897. Injuries qualified for the extremity fracture subset when the first three digits of the OIICS nature of injury code were 012 (fracture) and either the first two digits of the OIICS part of body code were 21 (shoulder) or the first digit was 3 (upper extremities) or 4 (lower extremities). Relevant ICD-9-CM codes for extremity fractures (including clavicle and scapula fractures) were 810–829. Injuries qualified for the TBI subset when either: (1) the first two digits of the OIICS nature of injury code were 06 (intracranial) or (2) the first three digits of the OIICS nature of injury code were 012 (fracture) in combination with the first two digits of the OIICS part of body code being 01 (cranial region). We followed the CDC case definition with respect to the relevant ICD-9-CM codes for TBI: 800.0–801.9, 803.0–804.9, 850.0–854.1, 950.1–950.3, or 959.01 [30]. TBI was problematic to identify using OIICS; there is no accepted OIICS-based definition [31], and it was also clear from our data that this set of OIICS codes were quite insensitive for identifying nonfatal TBI. However, for purposes of this paper, we needed a specific rather than sensitive definition.

Injury Severity

We used the Injury Severity Score (ISS) to summarize AIS-based injury severity, which has been well-validated for the prediction of mortality [32] and remains the most common measure of injury severity used by trauma systems and in trauma research. AIS ranges from 1 (minor) to 6 (nonsurvivable). ISS is the sum of squares of the highest AIS scores from up to three different body regions and has a range of 1–75, with 75 assigned whenever AIS is 6. ISS is technically non-continuous; a jump from an ISS of 1–2 means something quite different than a jump from 24 to 25 [33–35]. Copes et al. [33] recommended categorizing ISS into 7 categories (1–8, 9–15, 1-–24, 25–40, 41–49, 50–69, and 75) based on the specific AIS combinations that each category might contain. We categorized ISS following similar logic, except that we also took into account the very different distribution of ISS for WC claims compared with trauma registries (the setting in which ISS has been more commonly used). Due to large numbers of minor injuries and very small numbers of the most severe injuries (in part due to this study's focus on nonfatal injuries), we added an additional category of 1–3 and collapsed the highest four categories into a single category. The new 1–3 category was based on a similar theoretical underpinning; it can contain no injury with AIS above 1. This resulted in 5 categories (1–3, 4–8, 9–15, 16–24, and 25–75). These categories were collapsed further for each injury subset based on the particular distribution of ISS and to ensure a minimum of 30 cases per category, which resulted in two categories for amputations (0–8, 9–75), four categories for extremity fractures (1–3, 4–8, 9–15, 16–75), and three categories for TBI (1–8, 9–15, 16–75).

Early hospitalization has been found to be a strong correlate of longer term disability [23]. Early hospitalization was defined as the presence of any inpatient hospital bill for a date of service within 30 days of injury.

Table 2 Number of injured workers and injury severity distribution for each injury/outcome sample

Injury type	Work disability sample	Cost sample	Claims in either sample	Percent of claims in each ISS category				
				1–3	4–8	9–15	16–24	25–75
All injuries[a]	191,820	200,800	208,522	66.95	29.66	2.74	0.44	0.21
Amputations[a]	1,645	1,799	1,839	0	94.78	4.89	0.22	0.11
Extremity fractures[a]	19,706	21,202	21,825	22.64	70.25	6.69	0.28	0.13
TBI[a]	889	923	995	1.91	80.00	11.16	5.93	1.01

ISS injury severity score, *TBI* traumatic brain injuries

[a] Defined by the corresponding OIICS-based primary injury codes as well as at least one relevant ICD-9-CM code

Data Analysis

Analyses were performed using Stata/SE 11.2 for Windows [56]. There were 4,301 eligible cases that were linked to the WTR and for which ICDPIC was able to estimate ISS from WC-based ICD-9-CM codes; we used this subset to assess concordance between WC-based and WTR-based injury severity. Agreement between the WC-based ISS and each of two versions of WTR-based ISS (the existing ISS as well as ISS estimated using ICDPIC) was assessed with Cohen's kappa using the previously described 5-category ISS [36]. Landis and Koch's guidelines were used to assess the results [36].

Claims are closed when an injured worker is deemed able to work, when TPD is determined, or upon the person's death. Information about length of time loss compensation and TPD determination was censored for open claims. We used a competing risks survival analysis approach for the work disability analyses, with days of time loss compensation as the time scale [37]. We evaluated two outcome events of primary interest: (1) the end of time loss compensation without TPD (as a proxy for ability to return to work), and (2) TPD. The alternate outcome and death were assigned as the competing risks. The Stata command -stcrreg- [38] (based on the Fine and Gray semiparametric method [39]) was used to produce subhazard ratios (SHR) for each outcome event of interest. Adjusted total medical costs were modeled using ordinary least squares regression (OLS) with robust variance estimates [40].

All models included gender and a set of age category indicators (16–24 as the referent category, 25–34, 35–44, 45–54, 55–64, 65+). This provided a naïve model to use as a comparator for the models that included ISS and/or early hospitalization. No cases had missing age data. There was one case with missing gender (present in both all-injury samples, but not included in an injury subsamples) and was therefore dropped from the all-injury regression models. Rural injuries (used solely for an illustration of confounding by injury severity) were defined as those occurring in rural counties using 2009 Washington State Office of Financial Management guidelines [41].

The Akaike Information Criterion (AIC) allows for direct comparison of non-nested models when the outcome variable and sample size are the same [42]. AIC rewards goodness of fit, penalizes increasing degrees of freedom, and estimates relative information content. Within each model set, we calculated Δ AIC for each model by subtracting the AIC for the best model. The larger the Δ AIC, the more information was lost from that model relative to the best model (for which Δ AIC = 0). Δ AIC of ≤ 2 suggests substantial evidence in support of a model being the most informative, values between 4 and 7 indicate less support, and values of >10 indicates essentially no empirical support that a particular model may be the better model [42]. Differences in amount of variance explained (R^2) were also compared for the cost models (R^2 cannot be calculated for the competing risk models).

Results

In Table 1, we present information on the feasibility and coverage of estimating AIS-based injury severity scores from the ICD-9-CM codes available in WC medical billing data. For several denominators based solely on OIICS criteria, we calculated the number and percent of claims for which ICD-9-CM codes were available and/or for which ICDPIC was able to estimate ISS. ISS could be estimated for 67 % of all compensable nonfatal State Fund claims regardless of the nature of injury or illness, for 80 % of all OIICS-defined traumatic injuries, and for over 90 % of amputations and extremity fractures.

Table 1 also presents the number and percent of claims linking to the WTR using the same denominators. Overall, fewer than 2 % of injuries linked to the WTR due to the relatively minor nature of most work-related injuries; however, more than a quarter of non-fingertip amputations were linked. Progressively more severe injury types were linked at higher rates (data not shown); for example, among all amputations, 65 % of those observed to result in TPD were linked to the WTR. However, even the most severe and disabling injuries were not always linked to the WTR, in part due to trauma treated at non-reporting hospitals, out-of-state injuries, and factors other than anatomic injury severity that can result in TPD.

For the 4,301 eligible linked claims for which ICDPIC was able to estimate ISS from WC-based ICD-9-CM codes, there was moderate agreement between the WC-based ISS and the corresponding ISS contained in the WTR dataset (kappa = 0.43). There was also moderate agreement between the WC-based ISS and the corresponding ISS estimated from WTR-based ICD-9-CM codes using ICDPIC (kappa = 0.51).

Table 2 presents ISS distribution by injury type as well as the number of injuries in each of the eight samples constructed for the outcome analyses. These eight samples were defined by injury type (using a combination of OIICS and ICD-9-CM codes) and outcome (cost or work disability).

As shown in Table 3, there was a large monotonic increase in both median and mean adjusted total medical costs as injury severity increased, for all four injury samples. Table 4 presents the results of the OLS models used to assess the effect of injury severity on adjusted total medical costs. All models that included a severity measure were highly significant ($p \leq .0001$). Δ AIC can be

Table 3 Descriptive summary of adjusted total medical costs (dollars)

Sample/severity level	N	Total for life of claim (closed claims only)				
		Mean	SE	25th Percentile	Median	75th Percentile
All injuries						
ISS: 1–3	134,787	12,987	73	1,085	3,330	13,093
ISS: 4–8	59,593	16,007	126	2,240	6,880	17,679
ISS: 9–15	5,307	38,462	888	5,023	18,779	46,336
ISS: 16–24	769	91,021	5,479	18,994	47,101	111,166
ISS: 25–75	344	181,925	28,826	14,099	66,038	163,302
All severity levels	200,800	15,145	88	1,380	4,409	15,627
Amputations						
ISS: 1–8	1,716	16,479	686	4,266	8,105	15,746
ISS: 9–75	83	119,384	14,761	22,817	72,459	165,790
All severity levels	1,799	21,227	1,070	4,494	8,428	17,411
Extremity fractures						
ISS: 1–3	4,917	6,759	159	1,319	2,646	8,352
ISS: 4–8	14,863	16,654	230	2,382	7,214	19,644
ISS: 9–15	1,349	48,240	1,588	14,516	30,343	61,792
ISS: 16–75	73	193,750	87,112	33,451	71,496	153,576
All severity levels	21,202	16,978	368	2,091	6,309	18,673
TBI						
ISS: 1–8	765	14,989	1,044	1,802	4,254	12,591
ISS: 9–15	99	47,436	8,257	11,118	21,085	48,563
ISS: 16–75	59	99,023	28,349	17,357	36,218	82,979
All severity levels	923	23,841	2,299	2,144	5,681	20,122

TBI traumatic brain injuries

Table 4 Comparison of severity indicators using adjusted total medical cost outcome

Model[a]	All injuries (N = 200,799)		Amputations (N = 1,799)		Extremity fractures (N = 21,202)		TBI (N = 923)	
	R^2	Δ AIC[b]	R^2	Δ AIC	R^2	Δ AIC	R^2	Δ AIC
Reference (age/gender only)	0.007	25499	0.004	551	0.002	2203	0.021	107
ISS	0.063	13709	0.228	94	0.069	735	0.108	25
Early hospitalization	0.086	8788	0.090	391	0.055	1057	0.083	49
Early hospitalization and ISS	0.125	**0**	0.268	**0**	0.101	**0**	0.134	**0**

TBI traumatic brain injuries, *ISS* (Injury Severity Score) categories vary by injury sample as shown in Table 3

[a] All models include age and gender

[b] Δ AIC (Akaike Information Criterion) can be compared only within each injury sample (vertically). The best model for each model set has Δ AIC = 0 (bold)

compared only within each injury sample (vertically). The best model for each model set has Δ AIC = 0. The distance from 0 indicates the amount of information lost relative to the best model within each model set, and absolute differences between other models within a model set are also informative. Early hospitalization contributed more information to the all-injury sample than did ISS, based on both Δ AIC and R^2. The reverse was true for all three injury subsamples, with ISS contributing more information than early hospitalization. In all cases, using both measures resulted in the most informative models.

Table 5 presents the observed outcome distribution for all four injury samples, by injury severity. As shown in Table 6, there was a large monotonic increase in median time loss days to claim closure as injury severity increased for all four injury samples.

Figure 1 presents a series of stacked cumulative incidence plots that display the estimated relative probability

Table 5 Outcome status and censoring by injury severity (work disability samples)

Severity level	Total N	Outcome status			
		Time loss ended without TPD	TPD	Died	Censored/claim still open
All injuries					
ISS: 1–3	129,025	121,563 (94.2 %)	2,022 (1.6 %)	622 (0.5 %)	4,818 (3.7 %)
ISS: 4–8	56,433	52,926 (93.8 %)	927 (1.6 %)	324 (0.6 %)	2,256 (4.0 %)
ISS: 9–15	5,139	4,475 (87.1 %)	210 (4.1 %)	50 (1.0 %)	404 (7.9 %)
ISS: 16–24	816	587 (71.9 %)	77 (9.4 %)	6 (0.7 %)	146 (17.9 %)
ISS: 25–75	407	264 (64.9 %)	53 (13.0 %)	4 (1.0 %)	86 (21.1 %)
All severity levels	191,820	179,815 (93.7 %)	3,289 (1.7 %)	1,006 (0.5 %)	7,710 (4.0 %)
Amputations					
ISS: 1–8	1,556	1,515 (97.4 %)	8 (0.5 %)	S	S
ISS: 9–75	89	63 (70.8 %)	11 (12.4 %)	S	S
All severity levels	1,645	1,578 (95.9 %)	19 (1.2 %)	8 (0.5 %)	40 (2.4 %)
Extremity fractures					
ISS: 1–3	4,436	4,392 (99.0 %)	10 (0.2 %)	S	S
ISS: 4–8	13,857	13,127 (94.7 %)	187 (1.4 %)	S	S
ISS: 9–15	1,329	1,163 (87.5 %)	46 (3.5 %)	S	S
ISS: 16–75	84	55 (65.5 %)	11 (13.1 %)	S	S
All severity levels	19,706	18,737 (95.1 %)	254 (1.3 %)	93 (0.5 %)	622 (3.2 %)
TBI					
ISS: 1–8	731	652 (89.2 %)	25 (3.4 %)	S	S
ISS: 9–15	98	78 (79.6 %)	8 (8.2 %)	S	S
ISS: 16–75	60	43 (71.7 %)	7 (11.7 %)	S	S
All severity levels	889	773 (87.0 %)	40 (4.5 %)	4 (0.5 %)	72 (8.1 %)

TPD total permanent disability, *S* suppressed due to several very small cell sizes, *TBI* traumatic brain injuries

of each outcome over time for the all-injury work disability sample by injury severity [38]. The probability of each outcome grows as open claims shrink over time. The cumulative incidence of TPD was notably larger for major compared with minor injuries. Minor injuries had a more convex curve for time loss ending without TPD, indicating more rapid resolution of the claim. The cumulative incidence of death was very small with little increase over time.

Table 7 presents the results of the competing risk survival analysis models used to assess the effect of injury severity on work disability. All models that included ISS and/or early hospitalization were more informative than those including just age and gender. For the end of time loss outcome, early hospitalization contributed more information to all of the injury samples except amputations than did ISS. The reverse was true for amputations, with ISS contributing more information than early hospitalization. In all cases, using both measures resulted in the most informative models. There is a less consistent pattern for the TPD outcome. For amputations, ISS alone had a lower AIC than both ISS and early hospitalization together (but with a Δ AIC of only 2, there is substantial evidence that the combined model may be the most informative). For TBI, early hospitalization alone had the lowest AIC (but again, the Δ AIC was only 3 for the combined model). For both the all-injury sample and extremity fractures, including both ISS and early hospitalization together were most informative.

Table 8 presents trends in effect sizes by injury severity for each of the three outcomes for all four injury samples. For example, workers with the most severe extremity fractures had $186,372 higher adjusted total medical costs on average than those with the most minor extremity fractures. Workers with major TBI were half as likely to end time loss compensation (without TPD determination or death) at any given time compared with those with minor TBI. Severe amputations (e.g., above the knee) were roughly 34 times as likely to result in a TPD determination as were minor amputations, such as a finger or thumb (though significant, the confidence interval was quite wide). These were overly parsimonious models and these estimates are provided just as examples; observed effect sizes will vary depending on details of the sample, setting, covariates, outcome definitions, etc. There was no significant difference between ISS 1–3 and ISS 4–8 for the TPD

Table 6 Compensated time loss duration by injury severity (work disability samples)

Sample/severity level	N	Median	95 % CI
All injuries			
ISS: 1–3	129,025	21	21–22
ISS: 4–8	56,433	40	39–41
ISS: 9–15	5,139	91	85–96
ISS: 16–24	816	250	210–341
ISS: 25–75	407	406	276–607
All severity levels	191,820	27	27–28
Amputations			
ISS: 1–8	1,556	32	29–35
ISS: 9–75	89	433	234–728
All severity levels	1,645	34	31–38
Extremity fractures			
ISS: 1–3	4,436	18	17–20
ISS: 4–8	13,857	61	59–62
ISS: 9–15	1,329	162	145–179
ISS: 16–75	84	394	322–839
All severity levels	19,706	51	50–53
TBI			
ISS: 1–8	731	18	14–23
ISS: 9–15	98	83	48–154
ISS: 16–75	60	128	67–366
All severity levels	889	26	22–32

TBI traumatic brain injuries

outcome using the all-injury sample; TPD was equally rare in both categories (see Table 5). There was also no significant difference between major TBI and either moderate or minor TBI with respect to the TPD outcome, but both moderate and major TPD involved very few instances of observed TPD; perhaps too few to allow for discrimination. Aside from those two anomalies, there was a monotonic trend by injury severity in the expected direction for every injury sample and every outcome. Although each individual ISS category was not always significantly different from the adjacent category, ISS categories were always jointly significant ($p < .00005$ for all models, except $p = .03$ for the TBI sample/TPD outcome model).

Discussion

This study demonstrated the feasibility of estimating ISS for most traumatic injury claims using medical billing data and also demonstrated that ISS was significantly associated with work disability and medical cost outcomes. Work disability and medical costs consistently increased monotonically with injury severity for almost all injury samples and outcomes. There were two exceptions, both involving the TPD outcome. ISS appeared less strongly predictive of TPD (but not time loss ending without TPD) specifically for the TBI sample. It is not clear why this would be the case; perhaps due to particularities of the case definition we used or perhaps the relationship between TBI and TPD is differentially more dependent on factors other than injury severity compared with other injury types. It is perhaps more surprising that ISS did have a measurable effect on TPD for all four injury samples, given the complexity of factors leading to TPD as well as the length of time usually

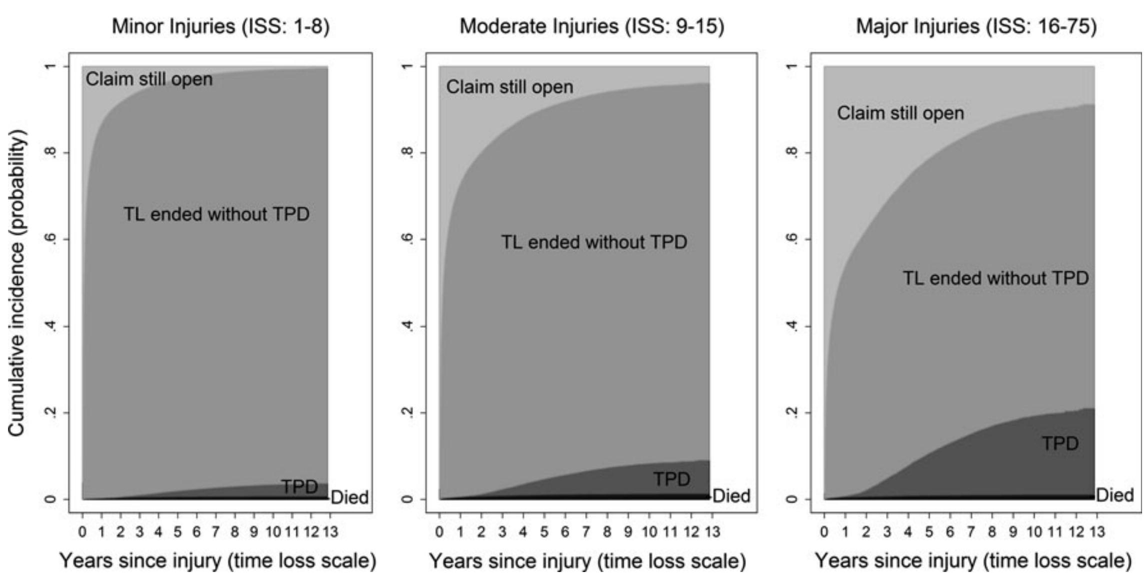

Fig. 1 This series of stacked cumulative incidence plots shows the estimated relative probability of each competing outcome over time for the all-injury work disability sample (N = 191,820), by injury severity. The cumulative incidence probability of each of the competing outcomes (including censored status) sums to 1 at every point in time

Table 7 Comparison of severity indicators using work disability outcomes, competing risk models

Model[a]	All injuries (N = 191,819) Δ AIC	Amputations (N = 1,645) Δ AIC	Extremity fractures (N = 19,706) Δ AIC	TBI (N = 889) Δ AIC
Time loss ended without TPD				
Reference (age/gender only)	20,993	190	3,767	127
ISS	18,190	56	1,513	96
Early hospitalization	706	88	1,387	1
Early hospitalization and ISS	**0**	**0**	**0**	**0**
TPD				
Reference (age/gender only)	2,196	42	206	22
ISS	1,841	**0**	103	20
Early hospitalization	133	36	51	**0**
Early hospitalization & ISS	**0**	2	**0**	3

TBI traumatic brain injuries, *Δ AIC* (Akaike Information Criterion) can be compared only within each injury sample (vertically). The best model for each model set has Δ AIC = 0 (bold), *TPD* total permanent disability, *ISS* (Injury Severity Score) categories vary by injury sample as shown in Table 6

[a] All models include age and gender

Table 8 Trends in effect sizes by injury severity for medical cost and work disability outcomes

Model[a]	Total medical costs (dollars)		TL ended without TPD		TPD	
	β	95 % CI	SHR	95 % CI	SHR	95 % CI
All injuries						
ISS: 1–3	0	Reference	1	Reference	1	Reference
ISS: 4–8	2,913	2,628–3,199	0.880	0.871–0.888	0.93	0.86–1.001
ISS: 9–15	25,520	23,775–27,264	0.607	0.591–0.624	2.18	1.89–2.52
ISS: 16–24	78,083	67,362–88,803	0.373	0.346–0.401	5.39	4.27–6.81
ISS: 25–75	169,245	112,819–225,670	0.315	0.282–0.352	8.38	6.35–11.05
Amputations						
ISS: 1–8	0	Reference	1	Reference	1	Reference
ISS: 9–75	102,695	73,814–131,577	0.282	0.223–0.356	34.42	11.56–102.54
Extremity fractures						
ISS: 1–3	0	Reference	1	Reference	1	Reference
ISS: 4–8	9,890	9,302–10,478	0.472	0.453–0.491	5.29	2.80–9.99
ISS: 9–15	41,331	38,206–44,456	0.273	0.257–0.291	12.83	6.47–25.45
ISS: 16–75	186,372	16,701–356,042	0.154	0.121–0.197	50.15	21.38–117.64
TBI						
ISS: 1–8	0	Reference	1	Reference	1	Reference
ISS: 9–15	30,121	13,115–47,127	0.611	0.493–0.756	2.44	1.12–5.32
ISS: 16–75	81,181	24,592–137,770	0.510	0.386–0.673	2.34	0.87–6.27

TL time loss, *TPD* total permanent disability, *SHR* subhazard ratio, *TBI* traumatic brain injuries

[a] All models include only age, gender, and the ISS categories listed

involved in arriving at a TPD determination [43]. The median observed time to TPD determination was 3.9 years (measured in compensated time loss days), without significant variation by ISS. Previous studies have suggested that ISS is less strongly associated with longer-term compared with shorter-term work disability outcomes [16, 44].

Although each individual ISS category was not always significantly different from the adjacent category, each set of ISS categories was always jointly significant overall. These categories could be further collapsed depending on research goals, however more complete adjustment for confounding may be obtained by retaining as many of these categories as feasible, assuming a large enough sample to support the necessary degrees of freedom. For purposes of illustrating the potential for confounding by injury severity, let's imagine that we are interested in the effect of an injury occurring in a rural (compared with urban) area on outcomes. Rural injuries were positively associated with higher injury severity as well as higher medical costs and more lost work days in this data set. Using the all-injury sample and including age, gender, and the rural indicator in a linear regression model, the rural coefficient for adjusted total medical costs was $1,104 (95 % CI: $762, $1,447). Adding the set of ISS categories to the model resulted in a rural coefficient of $638 (95 % CI: $293, $984), a 42 % reduction in magnitude. A similar but smaller reduction occurred for the comparable time loss model; rural injuries were estimated to be 8.0 % less likely to have time loss end at any given time assuming TPD or death does not occur, compared with non-rural injuries (95 % CI: 7.1, 8.9 %). After the set of ISS categories was added to the model, the estimate shrunk 12.5 % to become 7.0 % less likely (95 % CI: 6.0, 7.9 %).

An indicator of early hospitalization was often at least as good a predictor of work disability and cost outcomes as was ISS and may be simpler to construct. Although using ISS together with an early hospitalization indicator usually resulted in the most informative models, there may be reasons to avoid the use of one or the other in particular circumstances. In addition to being a proxy for higher severity, early hospitalization is also a measure of clinical intervention, and could be considered an outcome for some studies (for example, whether surgery is performed 2 weeks after a back injury). It has been pointed out that length of stay, and by extension, inpatient hospitalization, is subject to a number of influences other than severity or medical need, due to changes in standards of care and service delivery over time [45]. In contrast, AIS-based injury severity scoring is theoretically appealing, since it estimates baseline anatomic injury severity. ISS provides the benefit of further severity discrimination for injuries that don't involve hospitalization, or between injuries that do. The fact that ISS cannot always be calculated or may not be appropriate for every type of injury may present a significant barrier for some studies. There are alternative validated severity measures for certain specific injuries which focus on the unique issues and functional challenges associated with the particular body part or mechanism (e.g., Hand Injury Severity Score for hand trauma [46], Abbreviated Burn Severity Index for burns [47]). Injury severity adjustment may be useful as an adjunct (rather than alternative) to other forms of risk adjustment based on related but separate constructs (such as the Charlson comorbidity index [48], which can also be estimated from ICD-9-CM codes using ICDPIC or Stata's-Charlson-program).

There was moderate agreement between WC-based and WTR-based estimates of injury severity (kappa = 0.43, or 0.51 when ISS for both was estimated using ICDPIC). This may in part be due to the differing purposes of these data across data sets. The WTR-based ICD-9-CM codes and injury severity estimates were generated for clinical descriptive purposes, while the ICD-9-CM codes in the L&I billing data were generated solely for billing purposes. Although it is true that WTR scores may be based on informed and careful decisions made by trauma surgeons and trauma registrars, it is also true that the trauma registrars have quite variable levels of training and experience. Therefore, this comparison provides us with an idea of the amount of concordance with the existing and accepted WTR-based ISS, rather than with a gold standard. It is possible that the quality and completeness of the ICD-9-CM codes available in WC billing data are inferior to those available in the WTR and that those characteristics vary greatly by facility/provider. It is not possible to distinguish codes present for diagnostic ("rule-out") purposes from those that indicate definitive diagnoses. Fee schedules may affect how ICD-9-CM codes are entered by billing specialists, which could also vary by facility/provider type.

In the only previous evaluation of ICDPIC that we were able to identify, Di Bartolomeo et al. concluded that ICDPIC agreed poorly with scores estimated by expert trauma registrars [49]. However, the study was conducted using a small sample (N = 272) from the Italian Trauma Registry, which, as the authors noted, differs in several important respects from US-based trauma registries. ICDPIC's underlying tables that crosswalk from ICD-9-CM codes to AIS severity and body region are modifiable by the user. Due to the empirical methodology used to construct these tables, they may benefit from a thorough review by an AIS-trained clinical trauma specialist to determine whether any particular mapping might merit adjustment. ICDMAP-90 is another existing software package that can be used to estimate AIS-based injury severity. Although ICDMAP-90 has some advantages, it is not current to the most recent ICD-9-CM and AIS changes and does not run on newer computers. However, it does estimate ISS for burns (though those scores may be overly conservative). We found that ISS estimated by ICDMAP-90 from WC ICD9 codes had slightly higher concordance with WTR-based scores than those estimated by ICDPIC, but remained within the "moderate agreement" range (kappa = 0.51). In preliminary head-to-head comparisons of ICDMAP-90 with ICDPIC, we have found that ICDMAP-90 has only a slight advantage over ICDPIC for prediction of work-related outcomes. We used ICDPIC for this study because ICDPIC may be more accessible to most researchers; it is freely available to Stata users, runs on modern computers, is updated periodically, and has an intuitive interface. ICD-9-CM codes are still in use in the US, where this study was based. Jurisdictions that have transitioned to ICD-10 will not be able to use ICDMAP or ICDPIC in their present forms to estimate AIS-based injury severity.

Other injury severity scoring systems have been proposed. For example, the New Injury Severity Score (NISS) has sometimes been found more predictive of injury mortality than ISS, particularly for penetrating injuries [50, 51]. NISS is calculated similarly to ISS, but is based on the three highest AIS scores, regardless of body region. However, in preliminary work, we found little difference between ISS and NISS with regard to predicting work-related outcomes. Another injury severity measure which has been shown to out-perform ISS, the International Classification of Disease Injury Severity Score (ICISS), is based on empirically derived survival risk ratios [52]. This type of score is not likely to be as useful for the purposes we are contemplating because it is derived from injury mortality as an observable and measurable outcome; whereas we are most interested in outcomes for injury survivors. Estimation of ICISS for every ICD-9-CM code requires a sufficiently large generalizable sample. Previously promulgated ICISS estimates are generally based on predicting hospital survival conditional on hospital admission and lack the independent descriptive value of AIS-based severity [53, 54].

ISS can be estimated using ICDPIC and potentially used in a variety of ways for occupational injury surveillance and research. For example, ISS could be used as a method of risk adjustment or control of confounding for intervention, program evaluation or outcome studies. It could also be used as a vehicle for imposing a severity restriction for purposes of constructing comparison groups or constructing case definitions for surveillance. Even when ICD-9-CM codes are unavailable in WC data, ISS could be estimated after obtaining such codes by linking with other sources such as hospital discharge records, medical billing data from providers, insurance records, or trauma registry records.

Strengths and Limitations

Our study brought a number of unique strengths to bear on our aims. In contrast to many previous studies that reported no association between injury severity and work disability, we had a large sample available that included a variety of injury types and an unrestricted injury severity range. We had long-term outcomes data (2–13 years) with negligible loss to follow-up and used survival analysis methods to account for competing outcomes and censoring. In contrast, the longest follow-up of work outcomes we identified in the literature was 5 years [16]. However, it should be noted that although it is a commonly-used proxy, the end of time loss compensation has been found to underestimate the actual amount of time lost from work. [55].

AIS-based injury severity scoring is not possible or even appropriate for every work-related injury. In particular, we had to exclude burns from this study (which accounted for fewer than 1.5 % of otherwise eligible injuries). Non-specific back pain is an important condition for occupational research but unless linked to a specific traumatic injury, cannot be assigned an ISS. This may the most important limitation to the use of ISS, since non-specific back pain is a large contributor to work-related time loss and costs. This doesn't detract from the potential value of ISS for studies that focus on specific back injuries (e.g., sprains, strains) or on other traumatic occupational injuries such as amputations. We were able to estimate ISS for 67 % of all State Fund compensable claims, regardless of the nature of the injury or illness. As we focused in more specifically on traumatic injuries, we were able to estimate ISS for the vast majority of claims (upwards of 80 and 90 %).

We did not have medical aid-only claims available for this study (claims that did not involve any missed work days after the initial 3-day post-injury waiting period). Their inclusion would push average injury severity lower, but ISS may remain useful as long as a reasonably wide range of injury severity is present in a particular sample. Self-insured claims were also excluded due to unavailable/inadequate ICD-9-CM codes and outcome data. This excluded a large portion of claims that may have a different injury severity mix and different outcomes than the State Fund population.

Finally, the effect estimates presented here are not meant for any purpose other than for model comparison and to demonstrate relative trends in outcomes by injury severity within the context of this study. We did not include in our models any of a number of other important factors that are known to affect work disability and medical cost outcomes (e.g., occupation, industry, health status, comorbidity, availability of job modifications, etc.). Due to censoring, we excluded open claims from the cost models and this differentially excluded more severe injuries and claims with higher costs, so our findings are conservative estimates of association.

Conclusions

We conducted this study as an effort toward addressing the clear need for better severity measures for occupational health services research [26]. This study demonstrated that AIS-based injury severity measures were significantly associated with work disability and medical cost outcomes for work-related injuries. Injury severity should be considered as a potential confounder for occupational injury intervention, program evaluation, or outcome studies, and can be estimated using existing software when ICD-9-CM codes are available.

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