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A New Method to Classify Injury Severity by Diagnosis: Validation Using Workers' Compensation and Trauma Registry Data

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Abstract *Purpose* Acute work-related trauma is a leading cause of death and disability among U.S. workers. Existing methods to estimate injury severity have important limitations. This study assessed a severe injury indicator constructed from a list of severe traumatic injury diagnosis codes previously developed for surveillance purposes. Study objectives were to: (1) describe the degree to which the severe injury indicator predicts work disability and medical cost outcomes; (2) assess whether this indicator adequately substitutes for estimating Abbreviated Injury Scale (AIS)-based injury severity from workers' compensation (WC) billing data; and (3) assess concordance between indicators constructed from Washington State Trauma Registry (WTR) and WC data. *Methods* WC claims for workers injured in Washington State from 1998 to 2008 were linked to WTR records. Competing risks survival analysis was used to model work disability outcomes. Adjusted total medical costs were modeled using linear regression. Information content of the severe injury indicator and AIS-based injury severity measures were compared using Akaike Information Criterion and R^2. *Results* Of 208,522 eligible WC claims, 5 % were classified as severe. Among WC claims linked to the WTR, there was substantial agreement between WC-based and WTR-based indicators (kappa = 0.75). Information content of the severe injury indicator was similar to some AIS-based measures. The severe injury indicator was a significant predictor of WTR inclusion, early hospitalization, compensated time loss, total permanent disability, and total medical costs. *Conclusions* Severe traumatic injuries can be directly identified when diagnosis codes are available. This method provides a simple and transparent alternative to AIS-based injury severity estimation.

Keywords Injury severity · Trauma severity indices · ICDPIC · Occupational injuries · Workers' compensation · Work disability · ICD-9-CM

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Introduction

Acute work-related trauma is a leading cause of death and disability among U.S. workers [1]. Severe traumatic injury can lead to long-term pain and disability and is very costly for workers, workers' compensation (WC) systems and society as a whole [2–4]. Higher injury severity is associated with increased medical costs, disability, and time lost from work [5–8]. Controlling for differences in injury severity can be important when comparing the impact of different patterns of health care services on outcomes such as return to work. Injury severity measures may also be important when predicting the likelihood of clinical interventions such as hospitalization or surgery, when predicting claim costs or future wage loss, or when evaluating the effectiveness of a clinical or workplace intervention. The identification and validation of severity measures and case mix adjusters is an important occupational health services research priority [9–11].

One approach to injury severity measurement is provided by the Association for the Advancement of Automotive Medicine's Abbreviated Injury Scale (AIS), an anatomically-based consensus-driven scoring system that rates injury severity based on threat to life and does not take comorbidity or complications into account [12]. AIS is a measure of initial injury severity, independent of patient-specific factors that may influence hospitalization. In particular, AIS has more face validity and empirical support as a measure of initial injury severity than do hospital admission or length of stay, both of which can be related to co-existing conditions, health status, and trends in insurance coverage and standards of care [13–16]. AIS-based injury severity scores have been validated for prediction of mortality [17–21], and recent studies have established their association with occupational injury outcomes such as work disability and medical costs [11, 22, 23]. AIS-based injury severity scoring is theoretically appealing, since it estimates initial injury severity as opposed to the more indirect or more downstream severity proxies sometimes used in occupational injury research based on WC or other administrative data (e.g., industry, occupation, early hospitalization, amount of time loss compensation [6, 11, 24]). However, AIS was developed to describe motor vehicle crash-related injuries, and is most useful for discriminating relatively severe levels of trauma. Trauma registries typically contain AIS measures that were generated via expert assessment by trauma surgeons, review of medical records by trauma registrars, and/or estimated from International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) diagnosis codes by trauma registry software [25].

In contrast, for injury research based on WC claims, there are typically large numbers of relatively minor injuries and small numbers of the most severe injuries [11]. WC billing data may contain ICD-9-CM diagnosis codes, but typically do not contain AIS scores. Two software packages that estimate injury severity scores directly from ICD-9-CM codes have been used for WC-based injury research [11, 22, 23]: (1) ICDMAP-90 software developed by and available from the Johns Hopkins Bloomberg School of Public Health [26], and (2) Stata's user-written—ICDPIC—suite of programs (ICDPIC), developed using the National Trauma Data Bank, which assigns approximate injury severity scores by classifying injuries into general severity and body region categories [27]. However, both methods have important limitations. ICDMAP-90 is not current to the most recent ICD-9-CM and AIS changes and cannot be run on newer computers. ICDPIC is freely available and easily run by Stata users; however, the crosswalk doesn't include the most recent ICD-9-CM codes, and is based on an outdated version of AIS.

For WC-based research, it is desirable to have a simple and transparent method to identify severe injuries which doesn't require complex modeling and that can be easily implemented by state-based public health and occupational health programs. Mortality is often not fully captured in WC data, making the use of predictive injury severity models, such as the ICD-based Injury Severity Score (ICISS) [28], more challenging.

This study was designed to assess whether a list of severe traumatic injury diagnosis codes previously developed for injury surveillance purposes could be used to classify injury severity for other purposes, e.g., control of confounding in occupational injury intervention or outcome studies. Study objectives were to: (1) describe the degree to which a binary indicator based on a list of severe traumatic injury diagnoses predicts work disability and medical cost outcomes; (2) assess whether this severe injury indicator can adequately substitute for estimating AIS-based injury severity from WC billing data; and (3) assess concordance between severe injury indicators constructed from trauma registry clinical diagnoses versus from WC billing diagnoses.

Methods

Study population and data sources

Washington State has a single payer WC system (State Fund) that covers approximately 70 % of workers who are covered by the Industrial Insurance Act [29]. 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 through 2008, excluding injuries among those younger than 16 and those occurring outside Washington State. Injuries qualified for inclusion if there was at least one ICD-9-CM diagnostic code for a traumatic injury as specified by the inclusion criteria of the National Trauma Data Bank, with adjustments related to superficial injuries and burns (800–904.9, 910–929.9, 950–957.9, 959–959.9). Superficial injuries were included due to their prevalence and relevance to occupational injury research [30]. Isolated burns were excluded from this study; they were originally excluded from the severe traumatic injury list under investigation because AIS-based injury severity scores do not reliably classify burns due to the importance of inhalation injuries, which are not scored by AIS (or ICDPIC). Proximate fatalities (i.e., deaths before or during the initial injury hospitalization, or accepted fatal WC claims filed by survivors) were excluded because our population of interest was injured workers who might return to work; later deaths were treated as a competing risk/censoring mechanism.

WC claims were linked to Washington State Trauma Registry (WTR) records, maintained by the Washington State Department of Health. The WTR contains traumatic injury reports from all state-designated acute trauma care facilities; specific inclusion criteria include 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 [31]. Further details about the two data sources and the data linkage procedure can be found in previous related publications [11, 32, 33]. This study was approved by the Washington State Institutional Review Board.

Injury severity measures

The list of severe traumatic injury diagnosis codes used for this study was originally developed by our team for state-based injury surveillance purposes. The National Institute for Occupational Safety and Health (NIOSH) and Council of State and Territorial Epidemiologists (CSTE) Occupational Health Surveillance Work Group has developed 22 standard occupational health surveillance indicators that can be implemented using existing state data [34, 35]. The diagnosis list presented in Table 1 was approved by CSTE in December 2014 for national implementation as Occupational Health Indicator (OHI) #22: Work-Related Severe Traumatic Injury Hospitalizations [36]. Development procedures for this severe traumatic injury list have not previously been published, and are described herein.

The candidate list of ICD-9-CM diagnosis codes for severe traumatic injuries included only traumatic injury N-codes as defined by the National Trauma Data Bank (800–904.9, 910–929.9, 950–957.9, 959–959.9) [30]. Isolated burns were excluded for reasons described earlier. As a starting point, we estimated AIS for each diagnosis code using both ICDMAP-90 and ICDPIC. AIS ranges from 1 (minor) to 6 (maximal). The primary intent was to identify traumatic injuries with an AIS of 3 or higher. These injuries are serious and usually result in hospitalization [14]. Our expert coder (M. Rotert) independently assigned AIS based on AIS 2008 (a more recent AIS version than that used by either software package). She initially reviewed all injury diagnosis codes for which ICDMAP-90 and ICDPIC assigned different AIS scores, as well as all those for which either ICDMAP-90 or ICDPIC assigned an AIS of 6. Our team then reviewed the entire list of diagnosis codes, discussed all discrepancies between the three sources of severity assignment, and assigned AIS (where possible) to diagnosis codes that were not scored by either ICDMAP-90 or ICDPIC (e.g., newly developed, rare, or combination codes). In general, we used the following rules for these assignments, leaning toward conservative severity assignments: (1) when the ICD-9-CM code mapped to more than one possible AIS, we assigned the lowest AIS, and (2) when the ICD-9-CM code included more than one definite injury (i.e., combination injuries), we assigned the lowest AIS for the most severe definite injury. Finally, we revised the resulting set of diagnosis codes to improve face validity based on our team's assessment of high probability of hospital admission, including, for example, all skull fractures and all crush injuries in the final severe injury list, even though AIS was estimated as lower than 3 for some individual injuries within those groups. Accurate severity assignment was balanced with simplicity; i.e., a few vague unscored ICD-9-CM codes were assigned the AIS of neighboring codes.

Table 1 presents the final list of severe traumatic injury diagnosis codes, as approved for OHI #22. This list was converted into a binary severe injury indicator (set to 1 in the presence of any listed diagnosis; 0 otherwise), which was constructed using: (1) WC billing diagnoses (for all WC claims), and (2) WTR clinical diagnoses (for the linked subset). WC billing diagnoses included all available ICD-9-CM codes from facility and professional billing data for the first health care encounter occurring within 30 days after the injury date. WTR clinical diagnoses included all available ICD-9-CM codes from the first reported hospitalization. We labeled the resulting two groups as severe and minor/indeterminate, in order to emphasize that this indicator doesn't necessarily identify every severe injury. The minor/indeterminate group contains both relatively minor injuries and those that couldn't be accurately classified with respect to severity due to nonspecific ICD-9-CM codes.

We used ICDPIC to estimate several AIS-based injury severity measures from WC billing data, for comparison with the severe injury indicator. We have previously found substantial agreement between injury severity scores estimated by ICDPIC and ICDMAP-90 [23]. We focused on two recognized injury severity scores: (1) Injury Severity Score (ISS), which has been well-validated for the prediction of mortality [17] and remains

Table 1 ICD-9-CM codes for severe traumatic injuries

ICD-9-CM code (range)	Code description
800.x, 801.x, 803.x	Fracture of skull
804.x	Multiple fractures involving skull or face with other bones
805.x, 806.x	Fracture of vertebral column with or without spinal cord injury
807.03–807.08, 807.13–807.18	Fracture of 3 or more ribs
807.2, 807.3	Sternum fracture
807.4	Flail chest
807.5, 807.6	Larynx or trachea fracture
808.x	Fracture of pelvis
812.1x, 812.3x, 812.5x	Fracture of humerus, open
813.1x, 813.3x, 813.5x, 813.9x	Fracture of radius or ulna, open
820.x, 821.x	Fracture of femur
823.1x, 823.3x	Fracture of upper end or shaft of tibia or fibula, open
824.5, 824.7	Bimalleolar or trimalleolar fracture of ankle, open
850.2, 850.3, 850.4	Concussion with moderate or prolonged loss of consciousness
851.x	Cerebral laceration/contusion
852.x, 853.x, 854.x	Subarachnoid, subdural, extradural, or intracranial hemorrhage/injury
860.x	Traumatic pneumothorax or hemothorax
861.x	Injury to heart or lung
862.8, 862.9	Injury to multiple and unspecified intrathoracic organs
863.x, 864.x, 865.x, 866.x	Injury to gastrointestinal tract, liver, spleen, or kidney
874.1x, 874.5	Open wound of larynx or trachea or pharynx, complicated
887.x, 896.x, 897.x	Traumatic amputation of arm, hand, foot, or leg
900.x, 901.x, 902.x	Injury to blood vessels of head, neck, thorax, abdomen, or pelvis
904.0, 904.1	Injury to common or superficial femoral artery
904.2, 904.3	Injury to femoral or saphenous vein
904.4x, 904.5x	Injury to popliteal or tibial blood vessels
925.x, 926.x, 927.x, 928.x, 929.x	Crushing injury
950.3	Injury to visual cortex
952.x	Spinal cord injury without evidence of spinal bone injury

"x" indicates that all subcodes are also included

the most common measure of injury severity used by trauma systems and in trauma research, and (2) the overall maximum AIS (maxAIS), which performs as well as the ISS in some circumstances [20, 21, 23]. The ISS is the sum of squares of the highest AIS scores from up to three different body regions. The ISS has a range of 1–75, with 75 assigned whenever maxAIS is 6. ISS is technically non-continuous; thus we constructed a five-category ISS (1–3, 4–8, 9–15, 16–24, 25–75) following the methods recommended by Copes et al. [37], which we extended to reflect the nuances of WC data (i.e., large numbers of minor injuries and small numbers of the most severe injuries) [11]. Because the severe injury indicator under investigation is binary, and because very few injuries in the WC data have an estimated AIS of 3 or more (<5 %), the ISS and maxAIS were converted to binary severity measures for some analyses (cut at 9+ and 3+, respectively).

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 based on month and year of injury, using the medical care component of the Consumer Price Index. The sample available for medical cost analyses consisted of 200,800 injury events.

In addition to work disability and cost outcomes, we also assessed the severe injury indicator's association with mortality and with two measures of medical intensity, namely inclusion in the WTR and early hospitalization. Early hospitalization has been found to be a strong correlate of longer term disability [6]. Early hospitalization was defined as the presence of any inpatient hospital bill for a date of service within 30 days after the injury. Deaths are recorded in the WC claims data when known; however, deaths are likely to be underreported and are not necessarily related to the work injury.

Data analysis

Analyses were performed using Stata/MP 13.1 for Windows (StataCorp LP, College Station, TX). There were 4302 eligible WC claims that linked to WTR records; we used this subset to assess concordance between WC-based and WTR-based versions of the severe injury indicator by calculating Cohen's kappa. We also used Cohen's kappa to assess concordance between three binary WC-based severity measures: (1) the severe injury indicator, (2) binary maxAIS (cut at 3+), and (3) binary ISS (cut at 9+). Landis and Koch's guidelines were used to assess the results [38].

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 [39]. 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- [40] (based on the Fine and Gray semiparametric method [41]) 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 [42].

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 also included severity measures. No cases had missing age data. One case with missing gender was dropped from the regression models.

The Akaike Information Criterion (AIC) allows for direct comparison of non-nested models when the outcome variable and sample size are the same [43]. AIC rewards goodness of fit, penalizes increasing degrees of freedom, and estimates relative information content. Within each set of outcome models, we calculated ΔAIC for each model by subtracting the AIC for the best model. The larger the ΔAIC, the more information was lost from that model relative to the best model (for which ΔAIC = 0). 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). Many of the analyses and tables in this study were intentionally designed to be similar to an earlier study that demonstrated the value of estimating AIS-based severity measures from WC data, in order to facilitate direct comparison of findings [11].

Results

The work disability sample contained 191,820 claims, of which 4.8 % were classified as severe. The cost sample contained 200,800 claims, of which 4.7 % were classified as severe. There was moderate to substantial agreement between the WC-based severe injury indicator and each of the two binary AIS-based severity measures that we estimated from WC billing data: the maxAIS indicator (kappa = 0.60; agreement = 97.0 %) and the ISS indicator (kappa = 0.62; agreement = 97.0 %). For the subset of 4302 WC claims linked to WTR records, there was substantial agreement between the severe injury indicator constructed using WTR diagnoses, which classified 60.8 % as severe, and the severe injury indicator constructed using WC medical billing diagnoses, which classified 64.4 % as severe (kappa = 0.75; agreement = 88.2 %).

Table 2 presents observed outcomes for the work disability sample by injury severity group. Compared with minor/indeterminate injuries, severe injuries were significantly more likely to be reported to the WTR, involve an early hospitalization, result in TPD or death, and have an unresolved claim at the end of the observation period. [Note: Deaths captured in WC claims data are not necessarily related to the work injury. Although there are many deaths in the minor/indeterminate injury group, the mortality rate for minor/indeterminate injuries is roughly 82 deaths per 100,000 claims per year of observation, compared with 148 for severe injuries. Mortality rates for both groups are much lower than the roughly 277 all-cause annual deaths per 100,000 Washington State civilian residents ages 15–64, in part due to incomplete mortality

Table 2 Clinical and claim outcomes by injury severity group (work disability sample, N = 191,820)

Outcome	All injuries		Severe injuries		Minor/indeterminate		*P* value
	n	%	n	%	n	%	
Reported to WTR	3959	2.1	2549	27.9	1410	0.8	<0.0005
Early hospitalization	45,460	23.7	5118	56.0	40,342	22.1	<0.0005
TPD/pension	3602	1.9	447	4.9	3155	1.7	<0.0005
Died	1006	0.5	81	0.9	925	0.5	<0.0005
Claim still open/censored	7710	4.0	677	7.4	7033	3.9	<0.0005

TPD total permanent disability, *WTR* Washington State Trauma Registry

capture by WC data, and likely in part due to the healthy worker effect].

Figure 1 presents a series of stacked cumulative incidence plots that display the estimated relative probability of each outcome over time for the work disability sample by injury severity group [40]. The probability of each outcome grows as the proportion of open claims shrinks over time. The cumulative incidence of TPD was notably larger for severe injuries compared with minor/indeterminate injuries. Minor/indeterminate injuries had a more convex curve for time loss ending without TPD, indicating more rapid resolution of the claim. In both groups, the cumulative incidence of death was very small with little increase over time.

As shown in Table 3, median time loss duration for severe injuries was more than twice that for minor/indeterminate injuries. As shown in Table 4, mean and median adjusted total medical costs for severe injuries were roughly three times higher than for minor/indeterminate injuries.

Table 5 presents the results of the competing risk survival analysis models used to assess the effect of injury severity on work disability. Table 5 also presents the results of the OLS model used to assess the effect of injury severity on adjusted total medical costs. Workers with severe injuries were about two-thirds as likely to have their time loss compensation end (without TPD determination or death) at any given time compared with those with minor/

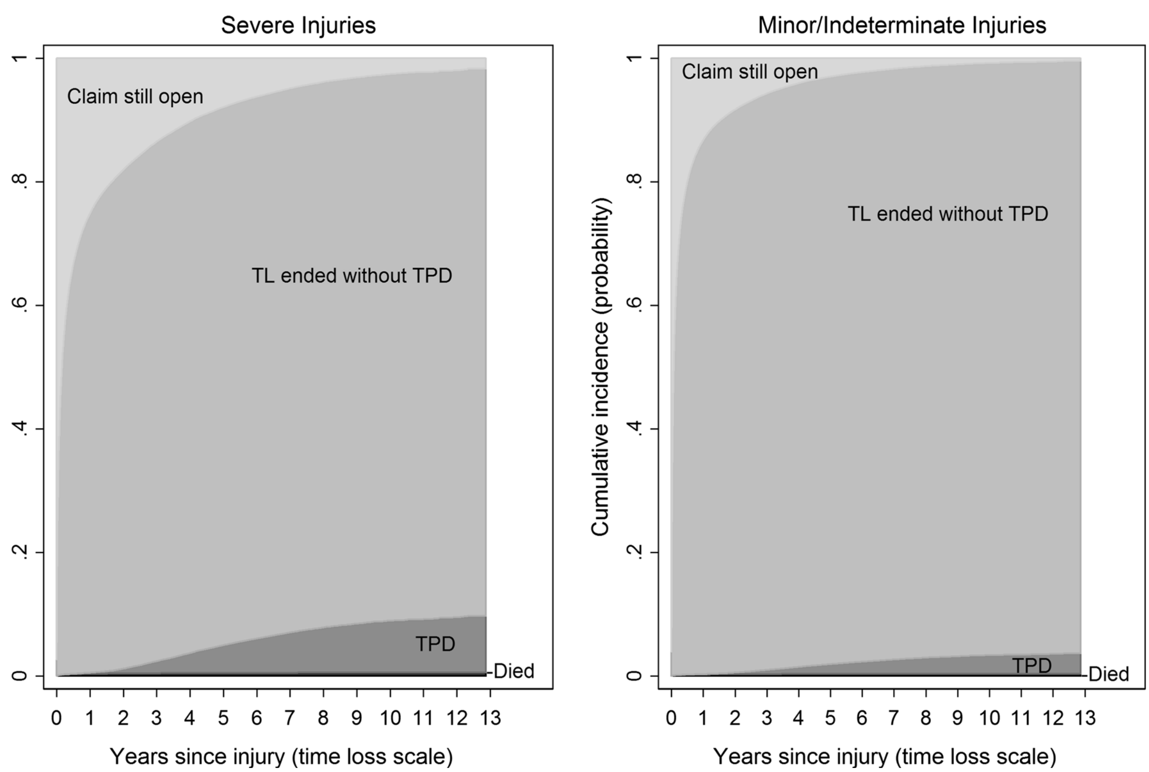

Fig. 1 These stacked cumulative incidence plots show the estimated relative probability of each competing outcome over time for the work disability sample (N = 191,820), by injury severity group. The cumulative incidence (probability) of each of the competing outcomes (including censored status) sums to 1 at every point in time. *TL* time loss compensation, *TPD* total permanent disability (pension)

Table 3 Compensated time loss duration by injury severity group (work disability sample)

Severity group	n	%	Median days	95 % CI
Severe injuries	9133	4.8	68	65–72
Minor/indeterminate	182,687	95.2	26	26–27
All injuries	191,820	100.0	27	27–28

indeterminate injuries. Severe injuries were more than two and one-half times as likely to result in a TPD determination compared with minor/indeterminate injuries. Workers with severe injuries had $17,991 higher adjusted total medical costs on average than those with minor/indeterminate injuries. 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. However, these results demonstrate that the severe injury indicator is a significant predictor of time loss duration, TPD, and total medical costs.

Table 6 presents information content of the outcome regression models for all severity measures assessed. All models that included a severity measure were highly significant ($p \leq 0.0001$). Δ AIC can be compared only within each outcome (vertically). The best model for each model set has $\Delta AIC = 0$. The distance from 0 indicates the amount of information lost relative to the best model within each outcome model set, and absolute differences between other models within an outcome model set are also informative. All models that included any severity measure were more informative than those including just age and gender. For all outcomes, inclusion of the five-category ISS resulted in the most informative model. Among the three binary severity measures, results differed by outcome. The binary ISS indicator contributed the most information for all three outcomes, but was least dominant and comparable to the severe injury indicator for the TPD outcome.

Discussion

Compared with minor/indeterminate injuries, injuries classified as severe were significantly more likely to be reported to the WTR, involve an early hospitalization, result in TPD or death, have higher total medical costs, and have an unresolved claim at the end of the observation period. Although the five-category ISS clearly resulted in the most informative models, the binary severe injury indicator was roughly comparable to the binary AIS-based measures. Fewer than 5 % of injuries in this WC-based sample were classified as severe by any of the methods used, and there may be little advantage to having the additional severity categories offered by AIS at the upper end of the scale, particularly in smaller samples where injuries with an AIS of 3 or above would likely be collapsed into a single category for analysis. In addition, there was substantial agreement between the severe injury indicator constructed using WTR clinical diagnoses and the severe injury indicator constructed using WC billing diagnoses (kappa = 0.75), suggesting that the diagnostic information contained in billing data is adequate for this purpose.

When AIS is available or AIS estimation is feasible, the severe injury indicator described herein offers no particular advantage. In fact, when the sample is large and contains substantial variability in injury severity, it will be unquestionably more informative to use a multiple-category AIS-based score such as ISS. However, existing methods to estimate AIS-based injury severity from ICD-9-CM diagnosis codes have important limitations, e.g., requiring use

Table 4 Adjusted total medical costs (dollars) by injury severity group (cost sample)

Severity group	n	%	Total for life of claim (closed claims only)				
			Mean	SE	25th percentile	Median	75th percentile
Severe injuries	9501	4.7	27,114	925	2110	8759	26,874
Minor/indeterminate	191,299	95.3	9293	42	894	2790	9855
All injuries	200,800	100.0	10,136	60	925	2929	10,389

Table 5 Work disability and medical cost outcomes regressed on injury severity group

Severity group[a]	TL ended without TPD (N = 191,819)		TPD (N = 191,819)		Total medical costs (dollars) (N = 200,799)	
	SHR	95 % CI	SHR	95 % CI	β	95 % CI
Severe injuries	0.668	0.654–0.682	2.62	2.37–2.89	17,991	16,181–19,801
Minor/indeterminate	1	Reference	1	Reference	0	Reference

SHR subhazard ratio, *TL* time loss, *TPD* total permanent disability

[a] Models included age, gender, and the severe injury indicator; 1 case was excluded from each sample due to missing gender

Table 6 Comparison of amount of information contributed to regression models by severity measures

Model[a]	TL ended without TPD (N = 191,819)	TPD (N = 191,819)	Total medical costs (N = 200,799)	
	ΔAIC[b]	ΔAIC[b]	R^2	ΔAIC[b]
Reference (age/gender only)	2803	369	0.006	11,440
Severe injury indicator (severe, minor/indeterminate)	1418	89	0.026	7343
Binary maxAIS indicator (1–2, 3–6)	1288	108	0.033	6008
Binary ISS indicator (1–8, 9–75)	845	82	0.035	5570
Five-category ISS (1–3, 4–8, 9–15, 16–24, 25–75)	0	0	0.061	0

AIC Akaike Information Criterion, *AIS* Abbreviated Injury Scale, *ISS* Injury Severity Score, *maxAIS* maximum AIS, *SHR* subhazard ratio, *TL* time loss, *TPD* total permanent disability

[a] All models included age and gender; 1 case was excluded from each sample due to missing gender

[b] ΔAIC can be compared only within each outcome (vertically). The best model for each model set has ΔAIC = 0; higher numbers for ΔAIC indicate more loss of information relative to the best model

of out-of-date platforms or proprietary software, not being current to the most recent coding revisions, or not allowing for transparent updating. It is also important to note that there is no single straightforward and direct crosswalk between AIS and ICD-9-CM. These coding systems were developed by different organizations for different purposes. Some ICD-9-CM codes can be mapped to more than one AIS, or are so vague that they cannot be mapped with confidence to any AIS.

In settings where use of a simple diagnosis list is more feasible than use of ICDMAP-90 and/or ICDPIC, this severe injury indicator may facilitate control for injury severity that might not otherwise occur. Where the intent is not to predict individual outcomes but rather to employ a basic level of control for confounding by severity or identify a group of more severe cases, this list of severe traumatic injuries may be adequate and useful. Another potential strength is that the same list of severe traumatic injury diagnoses is already being used for state-based surveillance of occupational injuries, which may facilitate translation for additional uses. The list of severe traumatic injury diagnoses is transparent and easily modified by the user to suit their purposes. The list was developed in part using AIS 2008, which is a more current version than that used by either ICDMAP-90 or ICDPIC. The severe injury indicator can also be used if only a single diagnosis field is available for each injury, unlike ISS, which requires a bare minimum of three available diagnosis fields and preferably more.

Alternatively, an indicator of early hospitalization is also relatively easy to construct, captures substantially more cases than the severe injury indicator, and has been found to predict work disability and cost outcomes [6, 11]. However, 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). Inpatient hospitalization and length of stay are subject to a number of influences other than severity or medical need, such as changes in standards of care and service delivery over time [13]. In contrast, this severe injury indicator classifies initial injury severity. 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 [44], which can also be estimated from ICD-9-CM codes using ICDPIC or Stata's -charlson-program).

Limitations

Medical aid-only claims were not available for this study (claims that did not involve any missed work days after the initial three-day post-injury waiting period). Self-insured claims were also excluded due to unavailable/inadequate ICD-9-CM codes and outcomes data, and they may have a different injury severity mix and different outcomes than the State Fund population. 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 [45].

The severe injury indicator is applicable only for the subset of traumatic injuries. For example, nonspecific back pain is an important condition for WC research but unless linked to a specific traumatic injury, cannot be classified by this indicator. This may the most important limitation, since nonspecific back pain is a large contributor to work-related time loss and costs. However, this doesn't detract from the potential value of this indicator for studies that focus on specific traumatic back injuries (e.g., sprains, strains) or on other traumatic occupational injuries such as amputations. Burns were excluded from this study (which accounted for fewer than 1.5 % of otherwise eligible injuries) because burn diagnoses were not included in the severe injury diagnosis list for the reasons already described. Although beyond the scope of this study, further research to assess whether particular burn diagnoses could be added to the severe injury diagnosis list would be useful, which might obviate the need to exclude isolated burns during construction of the severe injury indicator.

ICD-9-CM codes are still in use in the U.S., where this study was based. Jurisdictions that have transitioned to more recent ICD classification systems will not be able to use the diagnosis list in its present form. Even in the U.S., the list of severe traumatic injury diagnosis codes will need to be revised once ICD-10-CM is implemented.

Finally, the effect estimates presented herein are not meant for any purpose other than for model comparison 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.). We excluded open claims from the cost models due to censoring, which differentially excluded more severe injuries and claims with higher costs. As such, our findings are conservative estimates of association.

Conclusions

We conducted this study in an effort to address the pressing need for better injury severity measures for occupational health services research [9–11]. We have described a new method of identifying severe traumatic injuries that does not require special software, predictive models, or data on mortality or long-term outcomes. This study demonstrated that a severe injury indicator, based on an existing list of ICD-9-CM diagnosis codes for severe traumatic injuries, was a significant predictor of work disability, medical intensity, and medical costs. This severe injury indicator can potentially be used in a variety of ways for occupational injury surveillance and research. For example, it could be used as a method of risk adjustment or to control for confounding in 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. This method provides a simple and transparent alternative to AIS-based injury severity estimation.

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