ORIGINAL ARTICLE

Estimating injury severity using the Barell matrix

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Objective: To determine whether the Barell matrix (*Inj Prev* 2002;8:91–6) could effectively categorize injuries by severity.

Methods: Injury diagnoses of cases in the 2002 US Nationwide Inpatient Sample were classified according to the Barell matrix. For each cell of the matrix, the authors used ICDMAP-90 to determine the predominant Abbreviated Injury Score (AIS) and body region, and calculated the weighted proportion surviving (bPScell) among patients with any diagnosis in that cell. These findings were used to estimate maximum AIS (bAISmax), ISS (bISS), and the minimum or product of bPScell (bPSmin, bPSprod) for injured patients in the 1996–2000 US National Hospital Discharge Surveys. Case survival was determined for different scores, and outcome models using age, sex, comorbidity, mechanism, and bISS or bPSmin were compared to models using ISS calculated from ICDMAP-90 (mISS) or using ICISS.

Results: Case survival decreased with increasing bAISmax or bISS; survival was closely approximated by bPSmin, and also increased monotonically with bPSprod. Outcome models using bISS or bPSmin were similar to those using mISS or ICISS. An Abbreviated Barell Categorization, with only four groups, was also effective.

Conclusion: Barell matrix categorization of administrative data allows severity scoring similar to that obtainable with ICDMAP-90 or ICISS.

Large administrative databases provide an inexpensive opportunity to analyze hospital outcomes and have been increasingly used for injury research. Specific injuries are usually described in these databases using the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM), but clinically relevant aggregation of these thousands of diagnoses is required for meaningful analysis. The ability to stratify patients by injury severity is particularly important.

Sacco and colleagues¹ tabulated the observed hospital mortality for patients with each diagnosis code, and assigned each patient an anatomic index (AI) equal to the maximum of the observed mortality probabilities for that patient's injury diagnoses. Levy and colleagues² similarly tabulated the observed hospital survival for patients with each diagnosis code, and assigned each patient an estimated survival probability (ESP) equal to the product of the observed survival probabilities for that patient's injury diagnoses. A variation of the latter approach, the ICD-9-based Injury Severity Score (ICISS), was popularized years later by Osler and colleagues.³

The Abbreviated Injury Score (AIS)⁴ and Injury Severity Score (ISS)⁵ had been previously introduced for clinical studies, and have continued to be widely used. MacKenzie and colleagues⁶ have developed software (ICDMAP-90, Tri-Analytics, Baltimore, MD, USA) that maps ICD-9-CM diagnoses into AIS categories, thus allowing calculation of approximate AIS and/or ISS scores for administrative data.

More recently, Barell and an international group of colleagues⁷ developed a matrix of ICD-9-CM codes to classify injury diagnoses by type and anatomic region. Some of the original authors of the Barell matrix have subsequently demonstrated that "injury profiles" created by grouping cells of the matrix are associated with different mechanisms and outcomes.⁸ The purpose of our study was to use a large inpatient database to assign a probability of survival, AIS region, and AIS score to each cell of the Barell matrix. We wished to demonstrate that hospital outcomes in administrative data could then be predicted with reasonable accuracy

by using this information to approximate the AI/ESP/ICISS or AIS/ISS methods.

METHODS

Development of severity scores based upon the Barell matrix

After concluding the necessary data use agreement, Nationwide Inpatient Sample (NIS) data for 2002 were obtained from the US Agency for Healthcare Research and Quality.⁹ NIS contains inpatient data from about 1000 hospitals sampled to approximate a 20% stratified sample of US hospital discharges (potentially involving the same person more than once). Each record includes up to 15 ICD-9-CM diagnosis codes, age, sex, and hospital outcomes (including death and discharge to long term care). Each case is assigned a weight (W_i) essentially equal to the inverse of the probability that this case would be sampled, with further adjustments to account for missing data and other practical sampling problems. Summing the weights enables estimates that reflect the distribution of patients in US hospitals.

NIS cases were selected for this study if their principal ICD-9-CM diagnosis codes were in the range of injuries (800–959), excluding late effects of injury (905–909), foreign bodies (930–939), and complications (958). Cases received in

Abbreviations: ABC, Abbreviated Barell Categorization; AI, anatomic index; AIS, Abbreviated Injury Score; bAIS_{cell}, predominant AIS for a cell of the Barell matrix; bAISmax, maximum AIS for a patient estimated using Barell matrix; bISS, ISS for a patient estimated using Barell matrix; bPScell, proportion of patients surviving with a diagnosis in a cell; bPSmin, minimum bPScell for a patient; bPSprod, product of bPScell for a patient; CDC, Centers for Disease Control and Prevention; ESP, estimated survival probability; ICD-9-CM, International Classification of Diseases, Ninth Revision, Clinical Modification; ICE, International Collaborative Effort on Injury Statistics; ICISS, ICD-9-based Injury Severity Score; ISS, Injury Severity Score; LOS, length of stay; LTC, long term care; mAISmax, maximum AIS for a patient estimated using ICDMAP-90; mISS, ISS for a patient estimated using ICDMAP-90; NHDS, National Hospital Discharge Survey; NIS, Nationwide Inpatient Sample.

transfer from other hospitals were included. Injury diagnoses from these cases were used to assign a predominant AIS score ($bAIS_{cell}$) and body region to each cell of the Barell matrix, as described in the online appendix (see <http://www.injuryprevention.com/supplemental>). The weighted proportion of patients who survived (bPS_{cell}) was calculated as

$$bPS_{cell} = \frac{\sum W_i \text{ (for survivors with a diagnosis in this cell)}}{\sum W_i \text{ (for all valid cases with a diagnosis in this cell)}}$$

Any bPS_{cell} of 1 was replaced with a bPS_{cell} of .999.

For each patient in the NIS sample, the largest $bAIS_{cell}$ ($bAIS_{max}$) was determined overall and for each body region. We calculated $bISS$ for each patient as the sum of squares of $bAIS_{max}$ for the three body regions with the greatest $bAIS_{max}$,⁵ and categorized $bISS$ as recommended by Copes *et al.*¹⁰ The minimum of the bPS_{cell} for a given case will be referred to as that patient's Barell PS minimum (bPS_{min}); the product of all bPS_{cell} for each case was calculated, and will be referred to as that patient's Barell PS product (bPS_{prod}).

ICD-9-CM mapped each patient's ICD-9-CM diagnoses to an ISS body region and AIS score, and calculated the maximum AIS in each body region, maximum AIS overall ($mAIS_{max}$), and ISS ($mISS$).^{5,6} Categorizations of AIS_{max} and ISS derived from ICD-9-CM ($mAIS_{max}$ and $mISS$) were compared to those derived from the Barell matrix ($bAIS_{max}$ and $bISS$). Weighted hospital mortality for cases in the sample was calculated by $bAIS_{max}$, $bISS$, bPS_{min} , and bPS_{prod} .

Validation of severity scores using a separate database

National Hospital Discharge Survey (NHDS) data for 1996–2000 had been obtained from the US Centers for Disease Control and Prevention (CDC) on a compact disc and/or from the internet for a previous study.¹¹ NHDS is a national probability sample of discharge data from acute care general hospitals in the United States conducted annually by the CDC.¹² Like NIS, NHDS includes age, sex, up to seven ICD-9-CM diagnosis codes, hospital outcomes, and weights to allow estimates of national totals.

NHDS cases were selected using the inclusion criteria specified above. For each patient, $bAIS_{max}$, $bISS$, bPS_{min} , and bPS_{prod} were calculated using the Barell matrix along with the $bAIS_{cell}$ and bPS_{cell} values that had been derived from the NIS data. As with the NIS cases, $bAIS_{max}$ and $bISS$ were compared to the scores derived from ICD-9-CM ($mAIS_{max}$ and $mISS$). Weighted hospital mortality for NHDS cases was likewise calculated by $bAIS_{max}$, $bISS$, bPS_{min} , and bPS_{prod} .

Codes for the mechanism of injury (E-codes) were classified as recommended by CDC.¹³ Diagnosis codes potentially relating to pre-existing medical conditions were used to construct a comorbidity score as described by Charlson *et al.*¹⁴ and Romano *et al.*¹⁵

For cases with complete data (including an E-code), logistic regression was used to develop predictive models for hospital mortality based upon $bISS$ or bPS_{min} , mechanism, comorbidity, age, and sex. Modeling techniques (using Stata Version 7.0 SE, College Station TX) included allowance for the weighted survey data.¹⁶ "Model based" evaluation^{11,17} included minimizing the Hosmer-Lemeshow (H-L) goodness-of-fit statistic and maximizing the area under a receiver operating characteristic curve.

For patients surviving to hospital discharge, similar logistic regression models were constructed and compared to predict the discharge destination of "long term care" (LTC). In addition, following the example of Mackenzie *et al.*,¹⁸ multiple

linear regression was used to predict the logarithm of hospital length of stay (LOS) for survivors.

RESULTS

Derivation of scores for Barell matrix cells

The 2002 NIS sample contained 306 303 cases meeting inclusion criteria, with weights ranging from 1.8 to 10.4 (mean 4.8). These cases thus represented about 1 470 000 ($306\,303 \times 4.8$) patients. Of these cases, 39.9% had more than one injury diagnosis, resulting in an average of 1.87 per case and a total diagnosis weight of about 2 749 000 ($1\,470\,000 \times 1.87$). This weight was distributed as described in the online appendix (see <http://www.injuryprevention.com/supplemental>) to obtain the AIS scores given in table 1; 99.0% of the weight was distributed to cells of the Barell matrix for which AIS regions and scores could be assigned objectively using ICD-9-CM, and only 1.0% of the weight was distributed to cells requiring assignment using the authors' judgment. Each cell of the Barell matrix was thus associated with a predominant body region and $bAIS_{cell}$, none of which was greater than 4. Weighted estimates of the proportions of patients who survived for each cell (bPS_{cell}) ranged from .643 to .999 and are also shown in table 1.

Severity scores were easily calculated for individual patients using table 1. For example, consider a hypothetical patient with diagnosis codes 800.00, 801.00, 852.20, and 821.01 (fractures of skull vault and skull base, subdural hematoma, unspecified loss of consciousness, and fracture of the femoral shaft). The Barell matrix⁷ assigns the first two diagnoses to cell 2A, the third to cell 1D, and the last to cell 29A. From table 1, cell 2A is associated with the head/neck region, $bAIS = 3$, $bPS_{cell} = .992$; cell 1D is associated with the head/neck region, $bAIS = 4$, $bPS_{cell} = .877$; cell 29A is associated with the extremity region, $bAIS = 3$, $bPS_{cell} = .974$. Thus, $bAIS_{max}$ in the head/neck region is 4, $bAIS_{max}$ in the extremity region is 3, and $bISS = 4 \times 4 + 3 \times 3 = 25$. We see that bPS_{min} is .877, and calculate bPS_{prod} as $.992 \times .877 \times .974 = .847$.

Evaluation of results in the development (NIS) sample

Calculated $bISS$ ranged from 1 to 33. For lesser degrees of injury, categorization of individual NIS cases by $bISS$ agreed closely with the $mISS$ categorizations obtained using ICD-9-CM (table 2); for ISS above 15, the agreement was not as close but the great majority of cases were in the same or an adjacent category.

Hospital mortality increased monotonically with increasing $bAIS_{max}$ or categorized $bISS$ (fig 1) and decreased monotonically with increasing bPS_{min} or bPS_{prod} (fig 2). There were few cases with $bPS_{min} < .80$ or $bPS_{prod} < .80$; for the others, the expected line of (1 - observed mortality) was more closely approximated by bPS_{min} than by bPS_{prod} .

To evaluate the effect on mortality of $bAIS$ in different body regions, we determined the weighted proportion of patients who died for each $bAIS_{max}$ in each body region, where the patients had no $bAIS_{cell}$ in any other region equal or greater (table 3). Mortality was not linearly or even monotonically related to $bAIS$ and varied by body region: a $bAIS$ of 4 in the head/neck region was associated with the highest mortality (12.5%), followed by a $bAIS$ of 3 in the general or abdominal regions (11.0% and 8.8%, respectively); a $bAIS$ of 3 or 4 in the chest or extremity regions was associated with significantly lower mortality, and a $bAIS$ of 3 in the head/neck region still lower. Of NIS cases with overall $bAIS_{max} = 4$, 97% had a $bAIS$ of 4 in the head/neck region.

Evaluation of results in the validation (NHDS) sample

The 1996–2000 NHDS sample contained 62 248 cases meeting inclusion criteria, with weights ranging from 6 to 3507

Table 1 Barell matrix,⁷ with each cell (of those containing one or more diagnosis codes) assigned an AIS body region (A, abdomen; C, chest; E, extremity/pelvis; F, face; G, general; H, head/neck) bAIS_{cell}, and bPS_{cell}.)

	A. Fracture	B. Dislocation	C. Sprain/ strain	D. Internal	E. Wound	F. Amputation	G. Vascular	H. Superficial	I. Crush	J. Burn	K. Nerves	L. Unsp
1. TBI Type I	H4 .838			H4 .877							H1 .999	
2. TBI Type II	H3 .992			H2 .994								
3. TBI Type III	H3 .992											
4. Other head												
5. Face	F1 .976	F2 .970	F1 .999		G1 .962					G1 .963	H2 .999	H1 .987
6. Eye					G1 .980			F1 .986		G1 .985	H1 .969	
7. Neck	H4 .982		H1 .999		G1 .983					G1 .966	H2 .999	
8. Unsp head/neck					G1 .977				G2 .999	G1 .948	G2 .999	G1 .978
9. Cervical SCI	H4 .856			H4 .938			H2 .891	G1 .985	G2 .941	G1 .934		
10. Thoracic SCI	C4 .951			C4 .968								
11. Lumbar SCI	A3 .982			A3 .990								
12. Sacral SCI	E3 .885			A3 .999								
13. Unsp SCI	A2 .999			A3 .951								
14. Cervical VCI	H2 .946	H2 .948	H1 .997									
15. Thoracic VCI	C2 .979	C2 .981	C1 .999									
16. Lumbar VCI	A2 .981	A2 .999	A1 .999									
17. Sacral VCI	E2 .964	E2 .981	E1 .999									
18. Unsp VCI	A2 .966	A3 .658										
19. Chest	C2 .961	C2 .999	C1 .999	C3 .929	G1 .973							
20. Abdomen				A2 .923	G1 .986							
21. Pelvis/urogenital	E3 .963	E3 .972	A1 .999	A2 .941	G1 .978							
22. Trunk	C2 .999				G1 .973							
23. Back/buttock			A1 .999		G1 .983							
24. Shoulder/arm	E2 .980	E2 .993	E1 .999		G1 .983							
25. Forearm/elbow	E2 .990	E1 .988	E1 .996		G1 .983							
26. Wrist/hand	E2 .991	E1 .996	E1 .999		G1 .991							
27. Unsp upper extr	E2 .643				G1 .956							
28. Hip	E3 .967	E2 .992	E1 .996									
29. Thigh	E3 .974											
30. Knee	E2 .991	E2 .998	E2 .999									
31. Leg/ankle	E2 .992	E2 .998	E1 .998									
32. Foot	E2 .995	E1 .998	E1 .999									
33. Unsp lower extr	E2 .887		E2 .999									
34. Other/multiple	G2 .928											
35. Unsp	G2 .952	G2 .999	G1 .999	G3 .941	G1 .954							

TBI, traumatic brain injury; SCI, spinal cord injury; VCI, vertebral column injury; Unsp, unspecified.

Table 2 Percentages of NIS (development) cases and NHDS (validation) cases (shown in *italics*) with the given ISS scores derived using the Barell matrix (bISS) compared to their ISS scores derived using ICDMAP-90 (mISS)

	bISS 1-3	bISS 4-8	bISS 9-15	bISS 16-24	bISS 25-75
NIS (development) sample					
(n=50072)	(n=114948)	(n=109124)	(n=28366)	(n=5006)	
mISS 1-3	75.5%	4.3%	0.1%	1.4%	0.0%
mISS 4-8	15.5%	82.4%	4.4%	4.0%	0.2%
mISS 9-15	2.4%	10.8%	91.2%	36.6%	8.7%
mISS 16-24	0.3%	1.4%	3.1%	44.2%	37.3%
mISS 25-75	0.2%	0.8%	1.1%	13.2%	53.8%
Not mapped	6.1%	0.4%	0.2%	0.5%	0.0%
NHDS (validation) sample					
(n=11613)	(n=23083)	(n=21177)	(n=5634)	(n=741)	
mISS 1-3	76.3%	4.4%	0.1%	5.8%	0.4%
mISS 4-8	15.0%	84.7%	5.2%	12.3%	0.9%
mISS 9-15	1.2%	8.6%	90.4%	32.6%	20.9%
mISS 16-24	0.1%	0.9%	3.0%	35.7%	34.1%
mISS 25-75	0.3%	0.7%	1.0%	12.1%	43.6%
Not mapped	7.1%	0.8%	0.2%	1.5%	0.0%

(mean 126). Of these cases, 36.7% had more than one injury diagnosis, resulting in an average of 1.73 per case.

Hospital mortality in the NHDS sample increased monotonically with increasing categories of bAISmax or bISS (fig 1) and decreased monotonically with increasing categories of bPSmin or bPSprod (fig 2). There were few cases with bPSmin<.80 or bPSprod<.80; for the others, the expected line of (1 - observed mortality) was again more closely approximated by bPSmin than by bPSprod.

Calculated bISS ranged from 1 to 36. Categorization of individual NHDS cases by bISS also corresponded well to the mISS categorizations obtained using ICDMAP-90 (table 2), although not quite as closely as the development cases from NIS. For cases with bISS 25 or greater, 98.0% had a bAISmax of 4 in the head/neck region; for those with bISS 16–24, 91.5% had a bAISmax of 4 in the head/neck region. The effects of bAISmax in different body regions were similar to those seen with the NIS development sample (table 3).

Multivariate models using either bISS or bPSmin along with other factors (see online appendix at <http://www.injuryprevention.com/supplemental>) gave similar results to those reported previously using the same database and same data categorizations but grading anatomic severity using mISS or ICSS.¹¹ Increased bISS or decreased bPSmin increased mortality, LTC, and LOS, as did age and comorbidity. Sex affected LTC and LOS but not mortality. Age was

much more important than injury severity in determining LTC, and all these covariates had less effect on LOS than on other outcomes. Penetrating, burn, or vehicle mechanisms tended to increase mortality and decrease LTC, but these effects were not always significant.

Abbreviated Barell Categorization

Inspection of the variable effects of regional bAIS on mortality, using either NIS or NHDS data (table 3), showed that the calculated bISS depends mostly on the presence or absence of a diagnosis resulting in bAIS = 4 in the head/neck region, and to a lesser degree on the presence or absence of a diagnosis resulting in bAIS≥3 in any other region. We therefore defined an Abbreviated Barell Categorization (ABC), as:

- 0 for head/neck bAIS<4 with all other bAIS<3;
- 1 for head/neck bAIS<4 with another regional bAIS≥3;
- 2 for head/neck bAIS = 4 with all other bAIS<3; and
- 3 for head/neck bAIS = 4 with another regional bAIS≥3.

Figure 1 Hospital mortality for NIS (development) and NHDS (validation) samples, categorized by Barell Injury Severity Score (bISS) and Barell maximum AIS (bAISmax).

Figure 2 Hospital mortality for NIS (development) and NHDS (validation) samples, categorized by the minimum or product (bPSmin or bPSprod) of the estimated hospital survival for all cells of the Barell matrix containing one or more of the patient's diagnoses. The line of identity would be expected if the observed mortality were exactly equal to 1 minus the predicted survival.

Table 3 Proportions of NIS (development) cases and NHDS (validation) cases (shown in italics) who died with the given regional bAIS_{max}, and no bAIS_{cell} in any other body region that was equal or greater

	bAIS = 1	bAIS = 2	bAIS = 3	bAIS = 4
Head and neck				
NIS	0.7% (0.4–1.1%)	1.1% (0.9–1.3%)	0.5% (0.3–0.8%)	12.5% (12.1–12.8%)
NHDS	0.9% (0–2.4%)	0.5% (0.1–0.9%)	0.4% (0–0.8%)	10.5% (9.1–11.9%)
Face				
NIS	0.3% (0.2–0.5%)	0		
NHDS	0.4% (0–0.9%)	0		
Chest				
NIS	0	1.2% (1.0–1.4%)	3.9% (3.5–4.3%)	2.9% (1.5–4.3%)
NHDS	0	1.1% (0–2.2%)	4.5% (3.0–6.0%)	1.7% (0–4.3%)
Abdomen				
NIS	0.2% (0–0.4%)	2.0% (1.8–2.2%)	8.8% (6.7–10.9%)	
NHDS	0	1.3% (0.6–2.0%)	10.2% (4.1–16.3%)	
Extremities				
NIS	0.1% (0–0.2%)	0.3% (0.3–0.3%)	2.7% (2.6–2.8%)	2.7% (0–6.4%)
NHDS	0.0% (0–0.1%)	0.2% (0.1–0.3%)	2.5% (2.0–2.9%)	0.3% (0–0.9%)
General				
NIS	0.9% (0.8–1.0%)	0.7% (0.3–1.1%)	11.0% (5.9–16.1%)	
NHDS	1.0% (0.7–1.3%)	1.3% (0–2.9%)	2.6% (0–5.2%)	

95% confidence limits are given in parentheses.

To a large extent, ABC = 0 corresponds to patients with bISS less than 9, ABC = 1 corresponds to patients with bISS 9–15, ABC = 2 corresponds to patients with bISS 16–24, and ABC = 3 corresponds to patients with bISS 25 or more. ISS scores for these patients obtained using ICDMAP-90 (mISS) are similar, and inpatient mortality is similar to that seen with categorized bISS or mISS (table 4). When ABC categories were substituted for the corresponding bISS categories in regression models using NHDS data, similar results were obtained (see online appendix).

DISCUSSION

Much has been written about injury severity scoring, and many scores have been proposed.^{19–20} However, there has been no agreement on a standard methodology, especially for administrative data.²¹ The AIS is now owned by the American Association for Automotive Medicine, which has updated the methods and changed the body regions from those traditionally used to calculate the ISS. ICDMAP-90 also remains proprietary, and has not been updated to include ICD-9-CM diagnoses added since 1990. The developers of ICISS originally provided a table of survival statistics grouped by ICD-9-CM codes through an internet site,³ which is no longer available.

The development of the Barell matrix under the direction of an International Collaborative Effort (ICE) on Injury Statistics,⁷ and its placement in the public domain, therefore offer a new opportunity to make a severity scoring system available at no cost for administrative studies anywhere that data are coded using ICD-9-CM (or its successors). The original authors of the Barell matrix clearly did not intend it

to be used for severity scoring, and the adaptations we describe may at first appear to be oversimplified. However, we believe our results show that these methods are adequate for most purposes, such as selecting the most serious of several injuries, stratifying patients for outcome studies, or comparing statistics among different countries or regions.

Administrative data are usually derived from records intended to justify hospital claims for reimbursement. Accordingly, any use of their diagnosis codes for other purposes must be undertaken with caution. Among other concerns, discharge data reflect an episode of care rather than an incident case. Patients transferred from another hospital may be counted twice if they were originally inpatients in another sampled hospital, but excluding such patients (assuming they can be identified) would falsely eliminate patients transferred from another hospital's outpatient (emergency) department as well as those transferred from hospitals outside the sample. Patients readmitted for complications or other follow up care may also be falsely included as incident cases.

In addition, outcome analysis using hospital records by definition ignores the large proportion of injury deaths that occur before hospital admission as well as the large proportion of deaths in older patients that occur after hospital discharge.²² A survival probability calculated from an individual diagnosis code may also give a false sense of accuracy if it is based on a small number of cases or identifies an injury (for example, hip fracture) for which the apparent mortality reflects host factors or the timing of discharge to LTC facilities more than anatomic damage.

If hospital survival given hospital admission is the only outcome of interest, a PSmin/PSprod/AI/ESP/ICISS type of

Table 4 Abbreviated Barell Categorization (ABC), showing distributions of bISS and mISS, along with hospital mortality estimated from the development sample (NIS) and the validation sample (NHDS, shown in italics)

ABC	Description using bAIS	Number of cases	bISS Median (IQR)	mISS Median (IQR)	% Mortality mean, 95% CI
0	Head/neck bAIS < 4, Other bAIS < 3	175743 NIS 35877 NHDS	4 (1–4) 4 (1–4)	4 (2–5) 4 (1–4)	0.7 (0.6–0.7) 0.5 (0.4–0.7)
1	Head/neck bAIS < 4, Other bAIS ≥ 3	103379 NIS 20488 NHDS	9 (9–9) 9 (9–10)	9 (9–9) 9 (9–9)	2.9 (2.8–3.0) 2.9 (2.5–3.3)
2	Head/neck bAIS = 4, Other bAIS < 3	24163 NIS 5157 NHDS	16 (16–17) 17 (16–17)	16 (9–17) 13 (9–16)	11.6 (11.2–12.0) 9.7 (8.3–11.1)
3	Head/neck bAIS = 4, Other bAIS ≥ 3	3018 NIS 726 NHDS	25 (25–25) 25 (25–26)	25 (19–34) 22 (17–32)	18.8 (17.3–20.2) 17.1 (12.1–22.1)

IQR, interquartile range; CI, confidence interval.

Key points

- Although the Barell matrix was not originally intended as a method of injury severity scoring, the authors adapt it for this purpose, using the US Nationwide Inpatient Sample as a reference database.
- Table 1 in this article associates each cell of the Barell matrix with an Abbreviated Injury Score and the proportion of patients surviving with a diagnosis in this cell.
- The Barell matrix, along with table 1, can be used to calculate approximate regional or overall maximum AIS, ISS, or ICISS-type severity scores for case records in administrative datasets.
- The authors also propose an Abbreviated Barell Categorization as a simple way to approximate ISS in administrative data.
- The usefulness of these methods is demonstrated by accurately predicting patient outcomes in another database (the US National Hospital Discharge Survey).

statistic may logically be used, although there is no longer any standard reference database. Any rational subgrouping of the thousands of possible injury diagnoses would probably have some value, but it is appealing to build upon the longstanding efforts of the ICE to distinguish clinically meaningful anatomic categories. In their evaluation of the ICISS method, Kilgo and colleagues²³ found that the survival probability for the single worst injury (like the PSmin or AI) predicted survival for a given patient better than a multiplicative model (like the PSprod, ESP, or ICISS). The present study confirms that a multiplicative model tends to overpredict mortality.

Further grouping of diagnoses using AIS incorporates prior expert opinion ranking severity ordinally by the amount of energy transferred, which may account for the continued popularity of ICDMAP-90. Our findings suggest that the ICD-9-CM diagnoses it is unable to map are mostly minor injuries (table 2). However, previous evaluation of the relation of mortality to AIS (as assigned by ICDMAP-90) has shown that this effect is non-linear and varies by region;¹¹ this variability is confirmed in the present study (tables 2 and 3). Gennarelli and colleagues²⁴ have emphasized that neurological injuries are the most important contributors to hospital trauma mortality, and our analysis of bAIS also shows the dominant effect of severe injuries in the head/neck region.

For most applications, a theoretically continuous scale of injury severity is no more useful than classification into a few ranked strata.¹⁰ When dealing with large numbers of patients and data of marginal descriptive power, a simpler scale may be sufficient and preferable. Our table 1 uses the NIS as a large reference database, and may be applied to any large set of administrative data for which the diagnoses have been categorized using the Barell matrix. This approach is easier than using ICDMAP-90 or an ICISS-type score that assigns a score to every ICD-9-CM diagnosis code. The Abbreviated Barell Categorization we describe (table 4) is still easier and may be sufficient for many studies using administrative data.

Methods for predicting hospital mortality directly from ICD codes, as well as those incorporating AIS, can be adapted for use with the Barell matrix, with the advantages of simplicity, free access, and an internationally accepted nomenclature. Considering that any scoring system based on billing codes will have limited accuracy, these methods appear to stratify

anatomic diagnoses adequately for most outcome studies, especially when used along with measures of comorbidity (including age) and other factors available in administrative data.

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