IMP-2005: an injury mortality prediction according to the Abbreviated Injury Scale 2005

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Research article

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Abstract

Background: It has been 45 years since the injury severity score (ISS) was first introduced. The method is flawed in traumatic death prediction but still widely used. Based on the abbreviated injury scale 1998 (AIS_98), there is a relatively more accurate trauma scoring method that assesses the injury mortality prediction (IMP) and trauma mortality prediction model (TMPM) with the regression model. Currently, AIS 2005 (AIS_05) is widely used around the world for trauma scores. This article assesses whether the IMP-2005, an AIS_05 based model, is better than the ISS in predicting trauma results.

Methods: Retrospective cohort study is based on the data of 1,239,404 injured patients in the National Trauma Data Bank hospitalized from 2012 to 2014. We established an injury mortality prediction (IMP-2005) model using AIS trauma codes (version 2005) and compared its performance with that of ISS by examining area under the receiver operating characteristic (ROC) curve, the Hosmer-Lemeshow (HL) statistic, and the Akaike information criterion.

Results: IMP-2005 behaves significantly both better discrimination ($ROC_{IMP\text{-}2005}$, 0.904; 95% confidence interval (CI), 0.900 to 0.909 and ROC_{ISS}, 0.844; 95% CI, 0.839 to 0.850) and calibration ($HL_{IMP\text{-}2005}$, 15.2; 95% CI, 8.5 to20.2 and HL_{ISS}, 221; 95% CI, 167 to 268) compared with ISS. Both models showed changes after the extension of gender, age, GCS, mechanism of injury, and mechanical ventilator, but the expansion of IMP-2005 still dominated ISS in every performance.

Conclusions: The IMP-2005 provides far improvement in discrimination and calibration compared with the ISS and accurate predictions of mortality. Therefore, we believe that this is a new and feasible scoring method of trauma research and should replace the ISS.

Background

The abbreviated injury scale (AIS) [1] was founded by the Committee on Medical Aspects of Automotive Safety which has been expanded and improved many times since 1971. The latest AIS version, AIS 2005 (AIS_05), was updated from AIS 1998 (AIS_98) [2]. Many kinds of quick evaluation methods based on AIS code are being gradually well established, such as the injury severity score (ISS), the new ISS (NISS), the changed injury severity score (CISS) and so on [3, 4, 5]. Their ability to predict traumatic mortality has been improved as well. In particular, with the development of the trauma mortality prediction model (TMPM) and the injury mortality prediction (IMP) based on regression model [6, 7] the accuracy of trauma prediction has been greatly improved. Researchers concluded that the TMPM outperforms the NISS and the ISS as a predictor of mortality [8]. The IMP is the most accurate trauma scoring method at present, which is a combination of a regression model including three different variables and mathematics to reach the optimal value. Both scoring methods that involves regression model are based on AIS_98.

Since the introduction of the ISS, many other scoring methods (e.g., NISS and CISS) that give more accurate trauma results prediction cannot completely substitute the ISS, which may come from the wide acceptance and familiarity to the ISS. The ISS's accuracy will be better with other clinical information (such as blood pressure, respiratory rate, Glasgow Coma Score (GCS) and so on) [9]. However, the ISS's performance has been proved disappointing without available clinical predictors.

Currently, version AIS_05 is widely applied in the world for trauma score. This article evaluates whether IMP-2005 based on AIS_05 is better than ISS in predicting trauma results.

Methods

Data source

This text was conducted using data from the National Trauma Data Bank (NTDB) on patients hospitalized with traumatic injuries between 2012 and 2014 [10]. Available information included patient demographics, AIS codes and ISS (version 2005), mechanism of injury (based on ICD-9-CM E-codes), GCS, length of stay, ICU admission, total number of days spent on the mechanical ventilator, in-hospital mortality, and encrypted hospital identifiers. The dataset consisted of 1,754,977 patients with one or more AIS_05 codes.

We intended to compare different scoring methods based on the version 2005 of the injured AIS predot code. All patients in this research were supposed to have an injury description of the version 2005 for AIS coding. Patients' age over 89 years (69,478), or younger than 1 year (35,657) were excluded from our analysis. Patients with nontraumatic diagnoses (e.g., drowning/submersion, poisoning, and suffocation), overexertion, or burns were excluded (121,257), missing cause of injury (13,083), missing or invalid data (data missing on age, gender, length of hospital stay, or outcome) (41,269), Patients who were treated only in the Emergency department and not hospitalization were excluded (166,990). Patients who were dead on arrival to the hospital (18,581) or transferred to another facility (71,855) were also excluded. We excluded patients who sustained a single or multiple injuries and AIS_05 severity code component was 9 (5,282). At least 500 trauma patients per hospital annually were available (119,393 patients were excluded). E-codes were mapped to 1 of the 6 mechanisms of injury: stab wound, violence, blunt injury, fall, motor vehicle crash, and firearm wound. The final dataset included 1,198,885 patients admitted to 487 hospitals. Recruitment details were shown in Fig. 1.

Development overview of IMP-2005

In this article, 66.6% of the total data was applied to assess trauma mortality rate (TMR) and weighted median death probability (WMDP) values of different AIS predot codes. When the true mortality rate of a specific AIS predot code was 0, the TMR value was set according to the trend of population crude mortality of each age group in the United States between 2012 and 2014 [11]. The TMR and WMDP values were calculated similar to IMP and IMP-ICDX [7, 12], and were displayed in the Additional files 1 and 2, respectively.

16.7% of the data (IMP-2005 development dataset) was used to evaluate IMP-2005. We applied probit regression model to calculate coefficient of IMP-2005 (Table 4) and deduced specific formula for the IMP-

2005. The remaining 16.7% of the data (internal validation dataset) was not applied for the development of WMDP and IMP-2005 to estimate the statistical performance of IMP-2005 and ISS models.

Customized trauma models

This validation dataset provided us with the ability to test the performance of the ISS and IMP-2005. The method to calculate ISS was based on Baker and colleagues [3]. We also computed the total mortality rate for each of the 44 possible ISS values (Fig. 2). The IMP-2005 was defined by four parts. The first part of this model was to incorporate the five most severe (highest) WMDP values as predictors. In order to improve the fitness, we applied a two-term fractional polynomial analysis [13] (WMDP and $WMDP^3$) to each of the first three of these five predictors respectively. The second was to determine whether the worst and second worst traumas were in the same body region. The third was to synthesize the two highest WMDP values into one variable. The last part was NBR (as NBR and $NBR^{0.382}$, suggested by fractional polynomial transformation [13]). Meanwhile, both models were then reestimated after adding gender, age, GCS, injury mechanism, and mechanical ventilator to simple trauma models, which only include anatomical trauma information.

Statistical analysis

The statistical performance of the trauma models was assessed with the area under the receiver operating characteristic (ROC) curve, the Hosmer-Lemeshow (HL) statistics, and the Akaike information criterion (AIC). The AIC was a measure of the Kullback-Leibler information number, which quantifies how close a statistical model approaches the true distribution. The reason of comparison was that the best model in a particular dataset was the model with the lowest AIC. A bootstrapping algorithm (1,000 replications) was used to calculate the bias-corrected 95% confidence intervals for the ROC and the HL. A $P<0.05$ was set as statistically significant. All statistical analyses were performed using STATA/MP version 14.0 for Windows. The article was exempted from the examination of the Institutional Review Board of Hangzhou Normal University, People's Republic of China.

Results

In the research, a total of 1,984 AIS predot injury codes (including 1,198,885 patients) with about 4.2 million injured body regions. There were 335,470 (28.0%) patients with only a single injury. And up to 40 injured body regions were also existing. The average of injured body regions per patient was 3.47. We analysed that the number of injured per AIS predot code was highly skewed in this dataset. 138 (7.0%) AIS predot trauma codes appeared less than or equal to 10 times. 50% of the injuries occurred less than 228 times. There were 96 (4.8%) AIS predot codes occurred greater than 10,000 times. The most common AIS predot injury code (AIS 450203.3: "Rib fracture closed, at least three ribs") ran up to 99,590 (8.3%) times.

66.6% of the data was used to develop WMDP, so 4 AIS predot codes were lost (including 4 patients). We finally got 1,980 WMDP values of different AIS predot codes (Additional file 4). These WMDP values range from 0.0009 for a minor trauma that pose little threat to life (AIS 730204.1: “Digital nerve injury”) to a value of 2.7469 for a very critical trauma (AIS 140216.6: “Brainstem penetrating injury prolonged loss of consciousness with no return”). WMDP values provided more accurate precision than the AIS severity for only six consecutive integer values usable. Interestingly, we noticed what appeared to be “minor” traumas (e.g., AIS 240207.2: “Injury of bilateral inner ear or middle ear”) were assigned to higher WMDP values, while others were “severe” traumas (e.g., AIS 640462.5: “Complete thoracic spinal cord injury syndrome (paraplegia, no sensory function), no fracture or dislocation”) assigned WMDP values were relatively low. We think they are appropriate because, by design, WMDP values reflect a trauma’s propensity lead to death rather than their subjective severity.

Patient demographics were summarized in Table 1. In this article, the overall mortality rate was 3.02%, of which White and Black were 70.5% and 13.7%, respectively. The 2 most common causes of trauma were falls (44.6%) and motor vehicle accidents (32.6%). Males accounted for 62.1%. The statistical performance of both models was presented in Tables 2 and 3. The IMP-2005 exhibited significantly better discrimination, calibration, and AIC statistic, compared with the ISS model. With the addition of gender, age, mechanism of injury, GCS, and mechanical ventilator, IMP-2005 continued to show superior model performance, compared with ISS model. The IMP-2005 coefficients were presented in Table 4.

This text showed that the relationship between mortality and the original ISS score was significantly non-monotonic (Fig. 2). Figure 3 emphasized the superiority of IMP-2005 over ISS calibration. The IMP-2005 mortality rates were evenly distributed very close to the dotted reference line. While the ISS mortality distribution was on the right of dotted reference line.

Discussion

We have the ability to deal with large database thanks to the development of the specific hardware and software equipments. Emerging studies have shown that medical data can be analyzed by means of various complicated calculations. Based on the improvement of trauma scoring method, certain software systems can help to compute and judge the severity of disease, developing from qualitative diagnosis to quantitative diagnosis. As medical costs continue to rise, the accuracy of trauma results reflecting the actual probability of death is urgently needed both for patients and trauma surgeons, and is of increasing interest to stakeholders outside the medical industry. Therefore, we aim to improve the accuracy of trauma results by conducting a digital assessment, so as to determine a quantitative diagnosis. Existing articles include: TMPM, IMP, IMP-ICDX, etc [6, 7, 12].

Since the ISS was founded by Baker and colleagues in 1974 [3], the evaluation of the severity of multiple injuries per patient has become a reality and has been recognized by medical practitioners all over the world. The ISS is defined as the sum of squares of the three highest AIS values in the six injury body regions. Although ISS has many deficiencies, it can serve as the basis for other more accurate scoring, such as TRISS [9].

The results of this research showed that the apparent non-monotonic relationship between the observe mortality rates and individual ISSs for these values may explain some of the ISS's shortcomings (Fig. 2). We found that IMP-2005 was far superior to ISS in various detection indicators (Table 2). The precision of 1,980 WMDP values (differ from one another) was more accurate than that of AIS with only six integer values, which contributes to the superior performance of IMP-2005. WMDP values were derived from empirically calculated big data, while the severity of AIS was set by the trauma specialists. For small data analysis, AIS may have certain advantages. When it comes to big data such as NTDB, using empirical evaluation for prediction accuracy is more recommended [14].

Adding some other available indicators can often improve the accuracy of prediction results, such as TMPM, IMP, and TRISS [6, 7, 9]. A comprehensive model based on IMP-2005 is applied as a measurement of anatomical trauma, since IMP-2005 is better than ISS, it will be superior to TRISS when we add some auxiliary information (such as age, systolic blood pressure, respiratory rate, and GCS). The prediction results of IMP-2005 are satisfied when only anatomical trauma information is available. If we add more auxiliary indicators to IMP-2005, the accuracy of prediction results can be further improved. When we added gender, age, GCS, mechanism of injury, and mechanical ventilator, the IMP-2005 had better discrimination, calibration, and AIC than the ISS with the additional information (Table 3).

The TMPM and the IMP based on AIS_98 have become historical trauma score methods because of the popularity of AIS_05 version. The classification of AIS_05 predot codes is about a third more than AIS_98 predot codes. In theory, IMP-2005 based on AIS_05 is more precise and accurate in predicting traumatic death. But the ROC absolute value of IMP-2005 is not much better than that of IMP based on the AIS_98. This may be caused by too many homogeneous AIS_05 trauma classification codes leading to non_obvious advantage. In this study, we evaluated the IMP-2005 model based on AIS_05 using statistical and mathematical approaches similar to IMP and IMP-ICDX [7, 12]. The unique calculation method showed in this research can improve the ability to predict trauma death. Simultaneously, it can be used to indicate the possibility of death by more intuitive quantitative diagnosis. It is easier for clinicians to accept and understand. We calculate the WMDP for AIS_05 predot code to predict the death probability of trauma. These values may change with the upgrade of AIS predot code version, but these WMDP values can be recalculated according to the upgraded AIS predot code dataset.

Theoretically, as long as the death (survival) probability of each trauma can be obtained, it is possible for clinicians to judge the severity of trauma accurately. In other words, the clinicians are supposed to enter correct diagnoses of an individual patient in electronic medical records, and then the corresponding probability of death (survival) of the patient can calculated by a specific program automatically. It will become a preliminary artificial intelligence for the benefit of mankind. This calculation method can be extended to all clinical diagnoses (such as different ICD-10-CM codes), and the probability of death (survival) of each individual patient can be evaluated at any time.

Conclusions

The IMP-2005 provides far improvement in discrimination, calibration, and AIC compared with the ISS and accurate predictions of mortality than it. Therefore, we believe that this is a new and feasible scoring method of trauma research and should replace the ISS.

Abbreviations

AIC: Akaike information criterion; **AIS:** Abbreviated injury scale; **BR:** Body region;

CI: Confidence interval; **CISS:** changed injury severity score; **GCS:** Glasgow coma score; **HL:** Hosmer-Lemeshow; **ICD-9-CM E-codes:** International Classification of Diseases Ninth Revision Clinical Modification External cause of injury codes; **ICD-10-CM:** International Classification of Diseases Tenth Revision Clinical Modification; **ICU:** Intensive Care Unit; **IMP:** Injury mortality prediction; **IMP-2005:** Injury mortality prediction for AIS 2005;

IQR: Interquartile range; **ISS:** Injury severity score; **ln:** Natural logarithm; **MMR:** Multiple injuries mortality rate; **NBR:** Number of body region; **NISS:** New injury severity score; **NTDB:** National Trauma Data Bank; **PMR:** Possible mortality rate; **ROC:** Area under the receiver operating characteristic; **SMR:** Single injury mortality rate; **TDP:** Trauma death probability; **TMPM:** Trauma mortality prediction model; **TMR:** Trauma mortality rate; **WMDP:** Weighted median death probability

Declarations

Acknowledgments

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Authors’ contributions

MDW contributed to the study concept and design. MDW, YS, and WSQ contributed to the analysis and interpretation of data. MDW contributed to the acquisition of data. All authors contributed to the critical revision of the manuscript for important intellectual content. MDW and WSQ contributed to the drafting of the manuscript. YJZ, WHF, and XMW contributed to the literature search. All authors read and approved the final manuscript.

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Availability of data and material

The data that support the findings of this study are available from NTDB databases of American College of Surgeons.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

References

1. Keller WK, Dillihunt RC, Fenner HA, Jolley FL, Keeney AH, Weygandt PL, Hames LN. Rating the severity of tissue damage: I. The abbreviated injury scale, JAMA. 1971;215(2): 277-80.
2. The Abbreviated Injury Scale 2005-Update 2008. Des Plaines, IL 60018: Association for the Advancement of Automotive Medicine; 2008.
3. Baker SP, O'Neill B, Haddon W, Long WB. The injury severity score: a method for describing patients with multiple injuries and evaluating emergency care. J Trauma. 1974; 14:187-96.
4. Osler T, Baker SP, Long W. A modification of the injury severity score that both improves accuracy and simplifies scoring. J Trauma. 1997;43(6):922-6.
5. Wang MD, Cai WW, Qiu WS, Qiu F, Lv WS. A changing of the abbreviated injury scale that improves accuracy and simplifies scoring. Hong Kong J Emerg Med. 2013; 20(3): 138-45.
6. Osler T, Glance L, Buzas JS, Mukamel D, Wagner J, Dick A. A trauma mortality prediction model based on the anatomic injury scale. Ann Surg. 2008;247:1041-8.
7. Wang MD, Wu D, Qiu WS, Fan WH, Zeng YJ, Shen Y. An injury mortality prediction based on the anatomic injury scale. Medicine. 2017; 96(35):e7945.
8. Cook A, Weddle J, Baker S, Hosmer D, Glance L, Friedman L, Osler T. A comparison of the injury severity score and the trauma mortality prediction model. J Trauma. 2013; 76(1): 47-53.
9. Boyd CR, Tolson MA, Copes WS. Evaluating trauma care: the TRISS method. J Trauma. 1987; 27(4):370-8.
10. National Trauma Data Bank, Committee on Trauma, American College of Surgeons. NTDB. Chicago, IL; 2012-2014.
11. Kochanek KD, Murphy SL, Xu JQ, Tejada-Vera B. Deaths: Final data for 2014. National Vital Statistics Reports. Available at: https://www.cdc.gov/nchs/data/nvsr/nvsr65/nvsr65_ 04.pdf. Accessed June 30, 2016.
12. Wang MD, Qiu WS, Zeng YJ, Fan WH, Lian X, Shen Y. IMP-ICDX: an injury mortality prediction based on ICD-10-CM codes. World J Emerg Surg. 2019;14:46.

13. Sauerbrei W, Royston P. Building multivariable prognostic and diagnostic models: Transformation of the predictors by using fractional polynomials. J R Stat Soc Ser A. 1999; 162:71-94.
14. Osler TM, Glance LG, Cook A, Buzas JS, Hosmer DW. A trauma mortality prediction model based on the ICD-10-CM lexicon: TMPM-ICD10. J Trauma Acute Care Surg. 2019; 86(5): 891-5.

Tables

Table 1 Patient demographics

Patient characteristics	No mechanical ventilator n = 1,054,519 (88.0%)	Mechanical ventilator n = 144,366 (12.0%)
Age, years, median (IQR)	48 (26-68)	45 (26-62)
Male, n (%)	638,989 (60.6)	106,020 (73.4)
Race, n (%)		
White, not Hispanic	748,765 (71.0)	96,226 (66.6)
Black or African American	141,221 (13.4)	22,968 (15.9)
Hispanic or Latino	91,951 (8.7)	13,650 (9.5)
Asian	17,181 (1.6)	2,215 (1.5)
Native American or Alaskan Native	11,703 (1.1)	2,248 (1.6)
Other races	43,698 (4.2)	7,059 (4.9)
Mechanism of injury, n (%)		
Falls	493,509 (46.8)	41,652 (28.9)
Motor vehicle accident	324,298 (30.8)	66,681 (46.2)
Violence *	81,654 (7.7)	7,717 (5.3)
Blunt	72,116 (6.8)	7,472 (5.2)
Stab	45,895 (4.4)	5,692 (3.9)
Firearm	37,047 (3.5)	15,152 (10.5)
ICU admission, n (%)	241,183 (22.9)	138,712 (96.1)
ICU, length of stay, median (IQR)	0 (0)	5 (2-12)
Length of stay, days, median (IQR)	3 (2-6)	10 (4-19)
NBR, median (IQR)	2 (1-4)	6 (3-9)
Injury severity score, median (IQR)	8 (4-10)	17 (10-26)
Dead, n (%)	7,552 (0.72)	28,803 (19.95)

IQR Interquartile range; *NBR* Number of body regions

* Violence indicates to strike or against

Table 2 Performance comparison of ISS and IMP-2005 models

Model description	ROC (95% CI)	HL stat (95% CI)	AIC
Injury severity score	0.844 (0.839-0.850)	221 (167-268)	41,001
IMP-2005	0.904 (0.900-0.909)	15.2 (8.5-20.2)	34,083

IMP-2005 showed better discrimination, calibration, and AIC compared with ISS model.

Table 3 Performance comparison of ISS and IMP-2005 models augmented with age, gender, mechanism of injury, GCS, and mechanical ventilator

Model description	ROC (95% CI)	HL stat (95% CI)	AIC
Injury severity score	0.947 (0.945-0.949)	201 (148-250)	31,178
IMP-2005	0.960 (0.958-0.962)	22.7 (7.2-31.7)	27,189

Although each model will be changed as more predictors were added, IMP-2005 still exhibited better than ISS model.

Table 4 IMP-2005 regression coefficients

Predictor		Coefficients	Robust std. error	Z	$P > \|z\|$	95% CI
$WMDP_1$	C_1	0.95905	0.04485	21.38	0.000	0.87114–1.04695
$WMDP_2$	C_2	1.12676	0.07367	15.29	0.000	0.98236–1.27115
$WMDP_3$	C_3	0.42112	0.05272	7.99	0.000	0.31779–0.52445
$WMDP_4$	C_4	0.17661	0.05384	3.28	0.001	0.07109–0.28214
$WMDP_5$	C_5	0.41282	0.05353	7.71	0.000	0.30790–0.51775
$WMDP_1{}^3$	C_6	0.07825	0.00724	10.81	0.000	0.06406–0.09244
$WMDP_2{}^3$	C_7	0.03273	0.01220	2.68	0.007	0.00882–0.05665
$WMDP_3{}^3$	C_8	-0.05189	0.01254	-4.14	0.000	-0.07647 to -0.02731
$WMDP_1 \times WMDP_2$	C_9	-0.41597	0.04368	-9.52	0.000	-0.50158 to -0.33035
Same region	C_{10}	-0.12204	0.01742	-7.01	0.000	-0.15618 to -0.08790
NBR	C_{11}	0.12206	0.00903	13.51	0.000	0.10435–0.13976
$NBR^{0.382}$	C_{12}	-1.60605	0.09643	-16.65	0.000	-1.79505 to -1.41704
Constant	C_0	-1.69713	0.10713	-15.84	0.000	-1.90709 to -1.48716

Coefficients for IMP-2005 model were recalculated based on 199,840 patients. $WMDP_1$ is the worst injury (max WMDP value), $WMDP_2$ the second worst injury, and so on. Same region indicates a binary variable, which is equal to 1 if the 2 worst traumas are in the same region, 0 otherwise. $WMDP_1 \times WMDP_2$ represents the product of the WMDP values for the 2 worst injuries. NBR is the number of body regions for each injured patient. WMDP represents weighted median death probability.

Figures

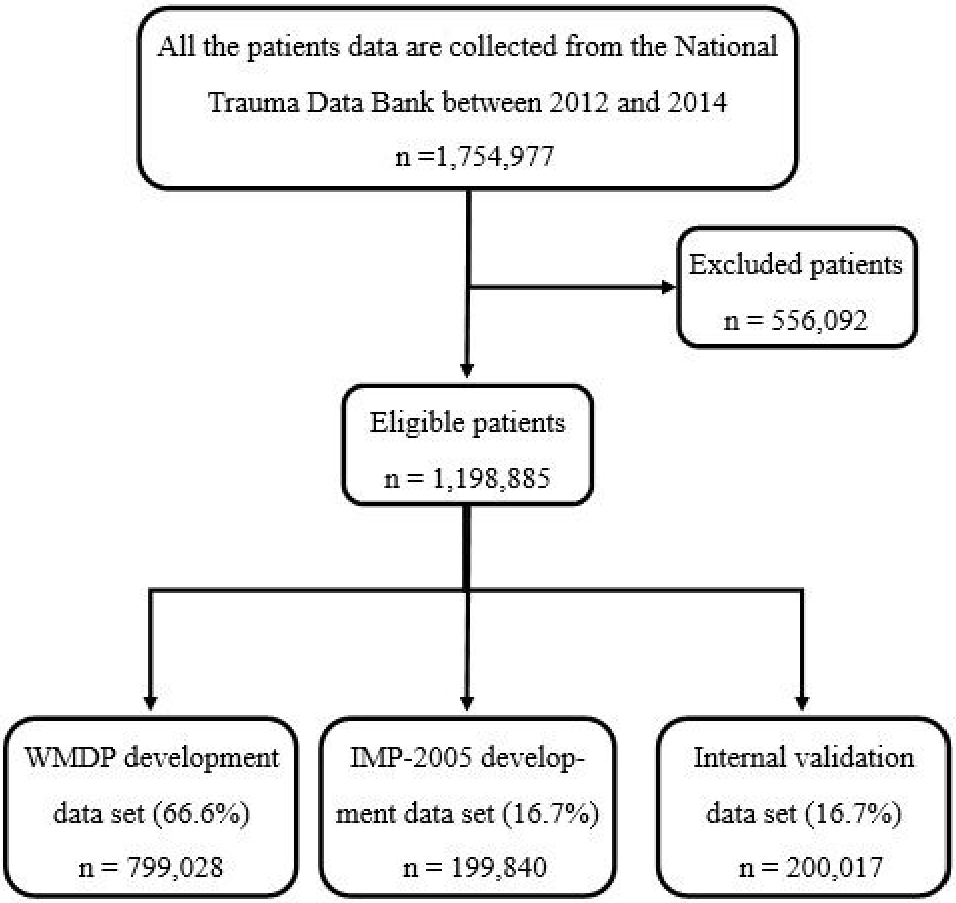

Fig. 1 Flowchart for data analyzed. *IMP-2005* Injury mortality prediction for AIS_05, *WMDP* Weighted median death probability.

Figure 1

Flowchart for data analyzed.

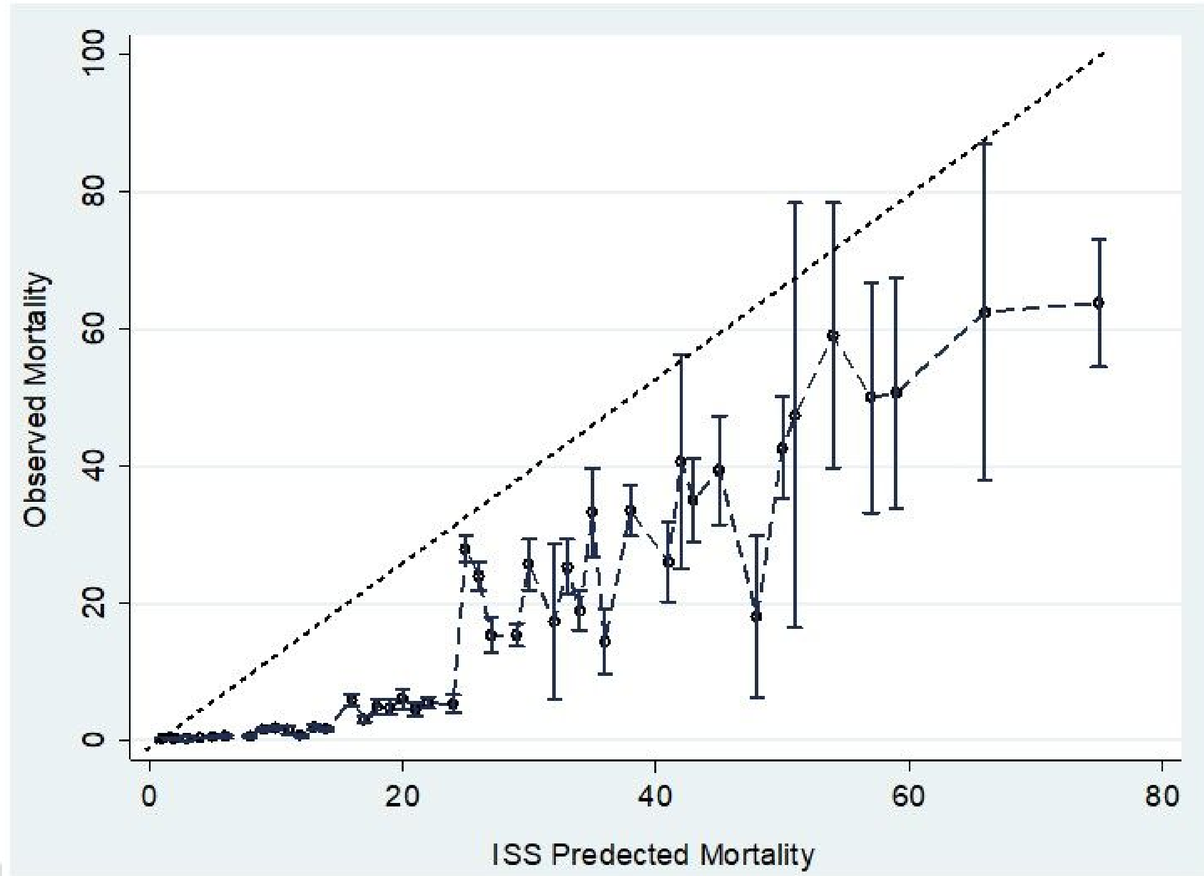

Figure 2

Observed mortality for each of the 44 possible ISS values.

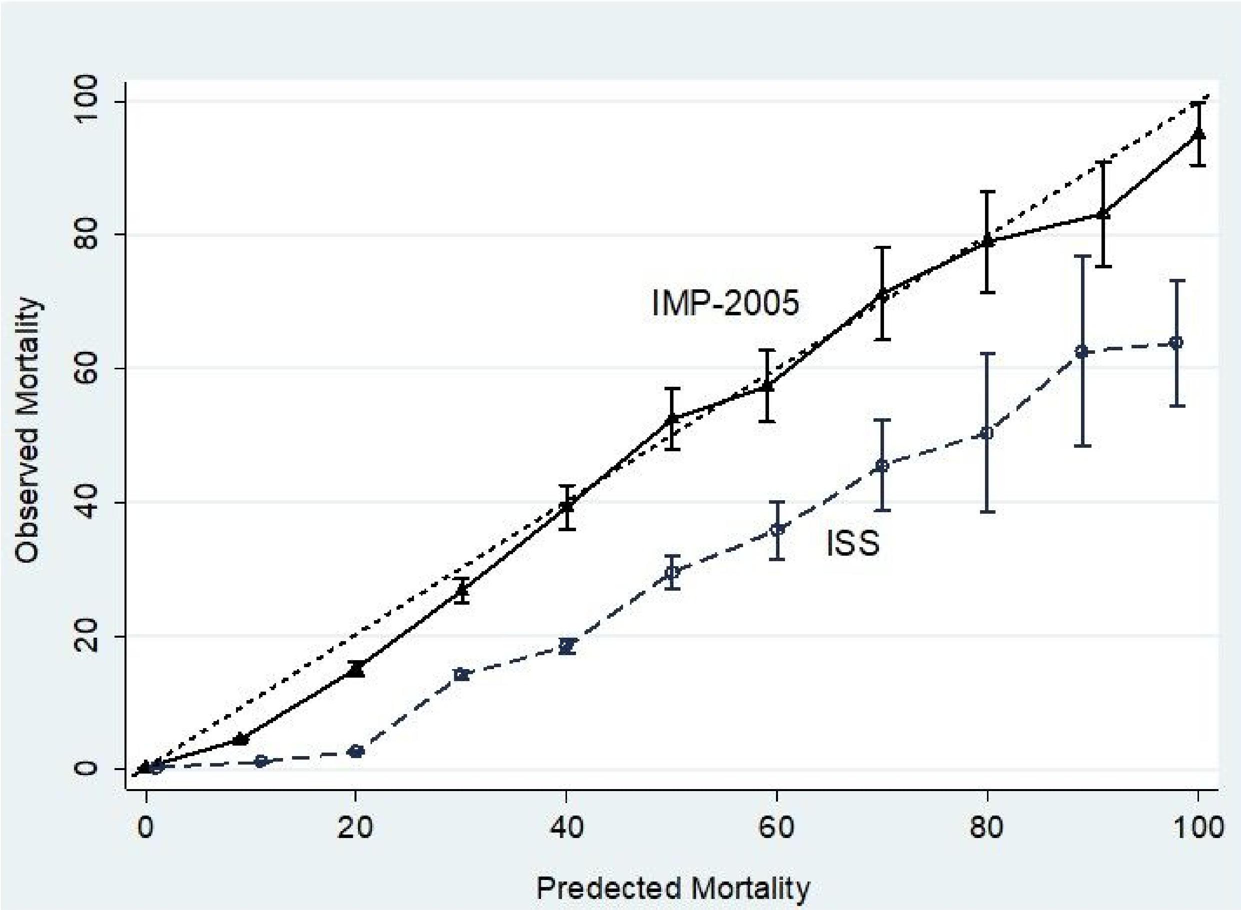

Figure 3

Calibration curves for IMP-2005 and ISS. The dotted reference lines represent perfect calibration. The 95% binomial confidence intervals for both models are based on the same validation dataset of 200,017 patients.

Supplementary Files

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