A comparison of the Injury Severity Score and the Trauma Mortality Prediction Model

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BACKGROUND: Performance benchmarking requires accurate measurement of injury severity. Despite its shortcomings, the Injury Severity Score (ISS) remains the industry standard 40 years after its creation. A new severity measure, the Trauma Mortality Prediction Model (TMPM), uses either the Abbreviated Injury Scale (AIS) or DRG International Classification of Diseases—9th Rev. (ICD-9) lexicons and may better quantify injury severity compared with ISS. We compared the performance of TMPM with ISS and other measures of injury severity in a single cohort of patients.

METHODS: We included 337,359 patient records with injuries reliably described in both the AIS and the ICD-9 lexicons from the National Trauma Data Bank. Five injury severity measures (ISS, maximum AIS score, New Injury Severity Score [NISS], ICD-9–Based Injury Severity Score [ICISS], TMPM) were computed using either the AIS or ICD-9 codes. These measures were compared for discrimination (area under the receiver operating characteristic curve), an estimate of proximity to a model that perfectly predicts the outcome (Akaike information criterion), and model calibration curves.

RESULTS: TMPM demonstrated superior receiver operating characteristic curve, Akaike information criterion, and calibration using either the AIS or ICD-9 lexicons. Calibration plots demonstrate the monotonic characteristics of the TMPM models contrasted by the nonmonotonic features of the other prediction models.

CONCLUSION: Severity measures were more accurate with the AIS lexicon rather than ICD-9. NISS proved superior to ISS in either lexicon. Since NISS is simpler to compute, it should replace ISS when a quick estimate of injury severity is required for AIS-coded injuries. Calibration curves suggest that the nonmonotonic nature of ISS may undermine its performance. TMPM demonstrated superior overall mortality prediction compared with all other models including ISS whether the AIS or ICD-9 lexicons were used. Because TMPM provides an absolute probability of death, it may allow clinicians to communicate more precisely with one another and with patients and families. (*J Trauma Acute Care Surg*. 2014;76: 47–53. Copyright © 2014 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Disagnostic study, level I; prognostic study, level II.

KEY WORDS: ISS; TMPM; NISS; mortality prediction.

Since its inception in 1922 as the Committee on Fractures, the American College of Surgeons' Committee on Trauma has embraced quality improvement as a core value. Its publication, "Resources for Optimal Care of the Injured Patient" states, "...the multidisciplinary trauma program continuously evaluates its processes and *outcomes* to ensure optimal and timely care."[1] More recently, the American College of Surgeons' Committee on Trauma created and implemented a quality improvement program, the Trauma Quality Improvement Program, which takes into account each patient's predicted risk of dying exclusive of the care received at any particular hospital.[2] A measure of the severity of anatomic injury or the "dose of trauma" is perhaps the most fundamental input for any risk adjustment model that might be used to predict outcomes following injury. Such predicted outcomes can then be used in the context of basic research to compare treatments or, in the realm of quality assurance, to compare hospitals' performance.

In the last four decades, numerous approaches have attempted measuring the severity of anatomic injury.[3–7] Interestingly, the most durable model for this task was the first one proposed. The Injury Severity Score (ISS)[8] has served as a summary measure of anatomic injury since 1974 and has been incorporated in many trauma risk adjustment models to quantify the severity of an injury. The great strength of the ISS is its familiarity. However, during the last 40 years, several shortcomings of the ISS have emerged. First, the ISS relies on the severity codes of the Abbreviated Injury Scale (AIS), and unfortunately, many trauma centers do not record patients'

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The routines for the calculation of the TMPM probabilities are available via e-mail from the authors of each routine: Stata: Alan Cook, MD, adcookmd@gmail.com; SAS: Lee Friedman, PhD, lfried1@uic.edu; Excel: Turner Osler, MD, MSc, tosler@uvm.edu.

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injuries in the AIS lexicon. In these circumstances, the ISS cannot be computed without recourse to an DRG International Classification of Diseases—9th Rev.—Clinical Modification (ICD-9-CM) to AIS conversion process, a procedure that necessarily reduces the accuracy of individual injury descriptions.[9] Second, the AIS severity values were developed by expert consensus rather than empiric calculation from data, an approach that is certain to underestimate or overestimate the severity of many injuries. Third, because the ISS includes at most a single injury from each of the three most severely injured body regions, the ISS necessarily considers at most three injuries and often fewer. Perhaps, more problematically, the three injuries included in the ISS are often not the three most severe injuries that a patient has sustained. Finally, in practice, the ISS is nonmonotonic with respect to observed mortality as pointed out by Kilgo et al.,[10] "The ISS is ... characterized by (occasional) large spikes in mortality for successive ISS values."

The advent of large trauma data sets and powerful desktop computers has allowed injury severity modeling to overcome some of the constraints of the last century. One example of this evolution is the Trauma Mortality Prediction Model (TMPM).[11] The TMPM-AIS relies on empiric estimates of the severity of each of the 1,322 unique AIS codes rather than the expert assigned "post dot severity" codes used in the ISS. The TMPM-AIS uses these empiric severities of a patient's five worst injuries as predictors in a conventional logistic regression equation to estimate a patient's probability of dying. Because the methodology to develop TMPM-AIS is completely general, it was straightforward to develop a second version of TMPM, TMPM–ICD-9 that predicts mortality based on injuries described in the ICD-9 lexicon.[12] TMPM is thus accessible to those using the AIS lexicon and investigators using administrative data sets that capture injury diagnoses as ICD-9-CM codes.

Recently, Haider et al.[11] compared the ISS, the New Injury Severity Score (NISS), and TMPM–ICD-9. They concluded that the NISS and TMPM–ICD-9 were superior predictors of mortality when compared with ISS. Of note, however, their analysis compared trauma scoring systems based on different lexicons instead of comparing AIS-based models with other AIS-based models as well as ICD-9–based models with other ICD-9–based models.

We undertook an objective examination of the performance of currently available measures of anatomic injury severity to determine which, if any, could be recommended as a

TABLE 1. Characteristics of 337,283 NTDB Trauma Patients 2009 to 2010

	Surviving Patients	Nonsurviving Patients	All Patients
Age, mean (95% CI)*	47.1 (47.0–47.2)	57.3 (56.9–57.7)	47.5 (47.4–47.5)
Sex, Male, % (95% CI)*	65.2 (65.0–65.3)	68.6 (67.8–69.5)	65.3 (65.1–65.5)
Race *			
White, non-Hispanic, % (95% CI)	68.6 (68.5–68.8)	70.9 (70.1–71.7)	68.7 (68.6–68.9)
Black, non-Hispanic, % (95% CI)	13.7 (13.5–13.7)	12.3 (11.6–13.0)	13.6 (13.5–13.7)
Hispanic/Latino, % (95% CI)	12.0 (11.9–12.1)	10.5 (9.9–11.1)	11.9 (11.8–12.0)
Race/other, % (95% CI)	5.7 (5.7–5.8)	6.3 (5.8–6.7)	5.8 (5.7–5.8)
Alcohol present, % (95% CI)*	17.3 (17.2–17.5)	15.9 (15.2–16.6)	17.3 (17.2–17.4)
Mechanism of Injury*			
Blunt, % (95% CI)	58.3 (58.1–58.5)	61.4 (60.5–62.3)	58.4 (58.3–58.6)
Penetrating, % (95% CI)	7.6 (7.5–7.7)	7.7 (7.2–8.2)	7.6 (7.6–7.7)
Other mechanism, % (95 CI)	34.1 (33.9–34.2)	30.9 (30.1–31.8)	34.0 (33.8–34.1)
Payor status*			
Medicare/Medicaid, % (95% CI)	28.5 (28.4–28.7)	40.9 (40.0–41.7)	28.9 (28.8)
Private insurance, % (95% CI)	45.7 (45.5–45.8)	33.6 (32.7–34.4)	45.2 (45.1–45.4)
Uninsured, % (95% CI)	16.7 (16.6–16.9)	16.3 (15.6–17.0)	16.7 (16.6–16.8)
Insurance status unknown, % (95% CI)	9.1 (9.0–9.2)	9.3 (8.8–9.8)	9.1 (9.0–9.2)
Length of stay, mean (95% CI),* d	6.2 (6.2–6.3)	6.6 (6.4–6.8)	6.3 (6.2–6.3)
Required ICU admission, % (95% CI)*	29.3 (29.1–29.4)	82.5 (81.8–83.1)	31.1 (31.0–31.3)
ICU length of stay, mean (95% CI),* d	5.2 (5.1–5.2)	5.5 (5.4–5.7)	5.2 (5.2–5.3)
Days of mechanical ventilation, mean (95% CI)*	2.4 (2.4–2.4)	4.2 (4.1–4.4)	2.6 (2.5–2.6)
Mortality prediction model values, median (interquartile range)			
ISS by AIS	9 (11)	25 (17)	9 (11)
NISS	10 (13)	41 (25)	11 (15)
Maximum AIS mortality risk ratio	1.6 (1.2)	32.9 (27.0)	1.6 (1.2)
TMPM pDeath for AIS, %	1.4 (2.7)	28.6 (5.6)	1.4 (3.0)
ISS by ICD-9	9 (10)	20 (13)	9 (10)
ICISS survival risk ratio, %	89.0 (15.9)	57.8 (54.7)	88.6 (16.9)
Maximum ICD-9 mortality risk ratio	2.6 (2.7)	4.0 (3.1)	2.6 (2.7)
TMPM pDeath for ICD-9, %	1.6 (2.8)	21.5 (32.2)	1.7 (3.2)
Died, % (95% CI)			3.5 (3.5–3.6)

*$p < 0.001$.

standard to replace ISS. Because the lexicon of injury description may influence the accuracy of outcome prediction, we felt that it is important to revisit the accuracy of several trauma outcome prediction models while carefully controlling for the effect of lexicon.

PATIENTS AND METHODS

Data Source

This study was conducted using data from the National Trauma Data Bank (NTDB) for the years 2009 and 2010. Available information included patient demographics, AIS codes (version 1998), ISS, mechanism of injury (based on ICD-9-CM Ecodes), encrypted trauma center identifiers, and the outcome "survival to hospital discharge." The NTDB data have been deidentified (i.e., all identifying information has been removed) to ensure confidentiality for patients, physicians, and hospitals participating in the NTDB. Approval was granted by the institutional review board of the Baylor University Medical Center, Dallas.

Because we wished to compare the effect of AIS coding of injuries with that of ICD-9 coding, we required that all patients in this study have their injuries described in both lexicons. Initial inspection of the NTDB disclosed that while all centers described their patients' injuries using ICD-9 codes, many centers did not submit any AIS codes. Furthermore, among centers submitting AIS codes, we observed that many centers used only a few different AIS codes, suggesting that these centers were not carefully assigning AIS codes to individual patients or perhaps were using AIS codes mapped from available ICD-9 codes. We believe that we have successfully excluded almost all centers that are reporting AIS codes that are actually mapped from ICD-9 codes rather than ab initio AIS codes. We did this by constructing graphs of the percentage of available AIS codes used by each hospital as a function of the number of patients admitted to that hospital (with individual hospital as the unit of analysis). Using this approach, we were able to forensically investigate the NTDB's AIS source for individual hospitals. For example, note that as the number of patients admitted increases, the percentage of available (2,011) ICD-9 codes used increases in a logarithmic manner (Supplemental Digital Content 1A [SDC 1A], http://links.lww.com/TA/A339). However, the same graph for the 1,322 possible AIS codes looks quite different, displaying both the logarithmic pattern and a second pattern of centers clinging to the *x* (horizontal) axis (SDC 1B, http://links.lww.com/TA/A339).

The hospitals (highlighted in red, SDC 1B, http://links.lww.com/TA/A339) along the *x* (horizontal) axis that used only 0% or a few percentage of possible AIS codes stand out as unusual. It is simply not plausible that any hospital might admit 5,000 patients, all of whom had the same injury, and it is almost as implausible that a hospital could admit 5,000 patients and catalog only 100 different injuries. We thus chose to exclude hospitals that clung to the *x*-axis, and using an abundance of caution, we further excluded any hospital that used fewer than 20% of the available AIS codes. Furthermore, because low-volume hospitals naturally use only a relative paucity of different AIS codes, we were unable to assert with authority that such centers hand-coded AIS codes.

TABLE 2. Comparison of Mortality Prediction Scores

	Area Under the ROC Curve		AIC*	
	Median	95% CI	Median	95% CI
AIS				
ISS	0.851	(0.848–0.853)	0.821	(0.813–0.830)
Maximum AIS	0.854	(0.852–0.857)	0.760	(0.751–0.769)
NISS	0.856	(0.853–0.859)	0.754	(0.745–0.763)
TMPM for AIS	0.888	(0.886–0.891)	0.682	(0.673–0.690)
ICD-9				
ISS for ICD-9	0.83	(0.828–0.833)	0.885	(0.877–0.894)
ICISS	0.838	(0.835–0.841)	0.758	(0.747–0.767)
Maximum ICD-9	0.864	(0.86–0.866)	0.761	(0.750–0.770)
TMPM for ICD-9	0.872	(0.869–0.874)	0.756	(0.747–0.763)

*Rescaled to yield values on the same order as the ROC (AIC/100,000).

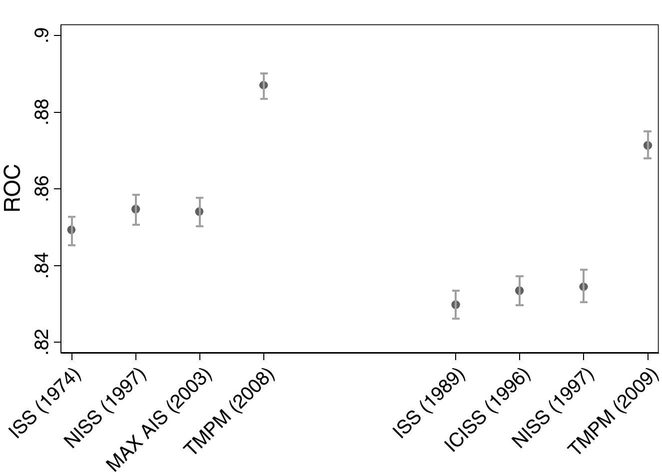

Figure 1. Medians and 95% CIs for ROC values for candidate models.

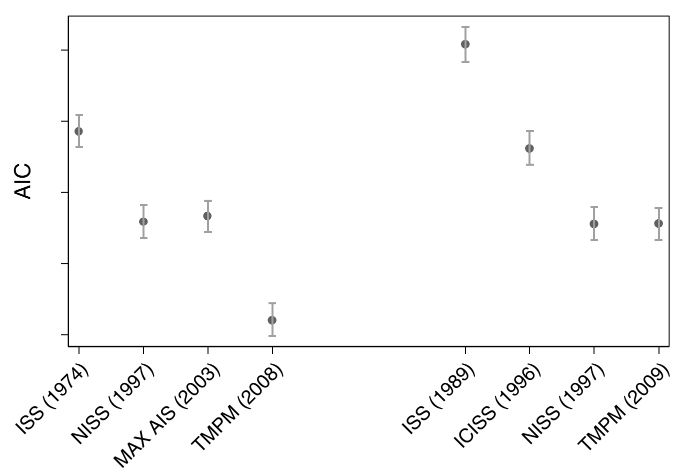

Figure 2. Medians and 95% CIs for AIC values for candidate models.

Erring on side of caution, we also excluded these low-volume centers and established a cutoff of more than 1,000 patients per center for inclusion in our study. Because low-volume centers by definition admit few patients, this decision only slightly reduced the power of our data set. Finally, we excluded patients younger than 16 years.

Model Comparison

The values for ISS, NISS, and maximum AIS were taken directly from the NTDB data set. The survival risk ratios for the ICD-9–Based Injury Severity Score (ICISS) and maximum ICD-9 were computed using ICD-9-CM codes, as were TMPM–ICD-9 predicted probabilities of death. TMPM-AIS–predicted probabilities of death were computed for each patient using that patient's AIS "pre dot" codes available in the NTDB. Comparisons of surviving patients with those who expired were accomplished using the χ^2 and t test statistics where appropriate.

All severity measures were compared in terms of discrimination (area under the receiver operating characteristic [ROC] curve),[13] proximity to the true model (Akaike information criterion [AIC]).[14] Calibration curves were constructed for each model. All confidence intervals (CIs) were computed using 1,000 bootstraps of the data set.

RESULTS

We selected 337,359 patients in the NTDB admitted to 1 of 146 hospitals during 2009 and 2010 whose injuries had been described in both the AIS and ICD-9 lexicons for inclusion in this study. The mean age of our cohort was 47.5 years. Sixty-five percent were male, and 68.7% were white. Penetrating trauma accounted for 11.4% of our cohort's injuries. Medical expenses were paid by some type of insurance for 63.6% of the trauma patients in this study. Intensive care unit (ICU) admission was necessary for 105,030 (31.1%) of the study population. The median values for each of the eight injury severity measures are listed in Table 1. The overall mortality rate for the patients in this study was 3.5%.

The TMPM discriminated survivors from nonsurvivors more accurately than any other candidate measure using either AIS or ICD-9 lexicons (Fig. 1, Table 2). The TMPM also demonstrated superior proximity to the "true model" as determined using the AIC whether computed using AIS or ICD-9

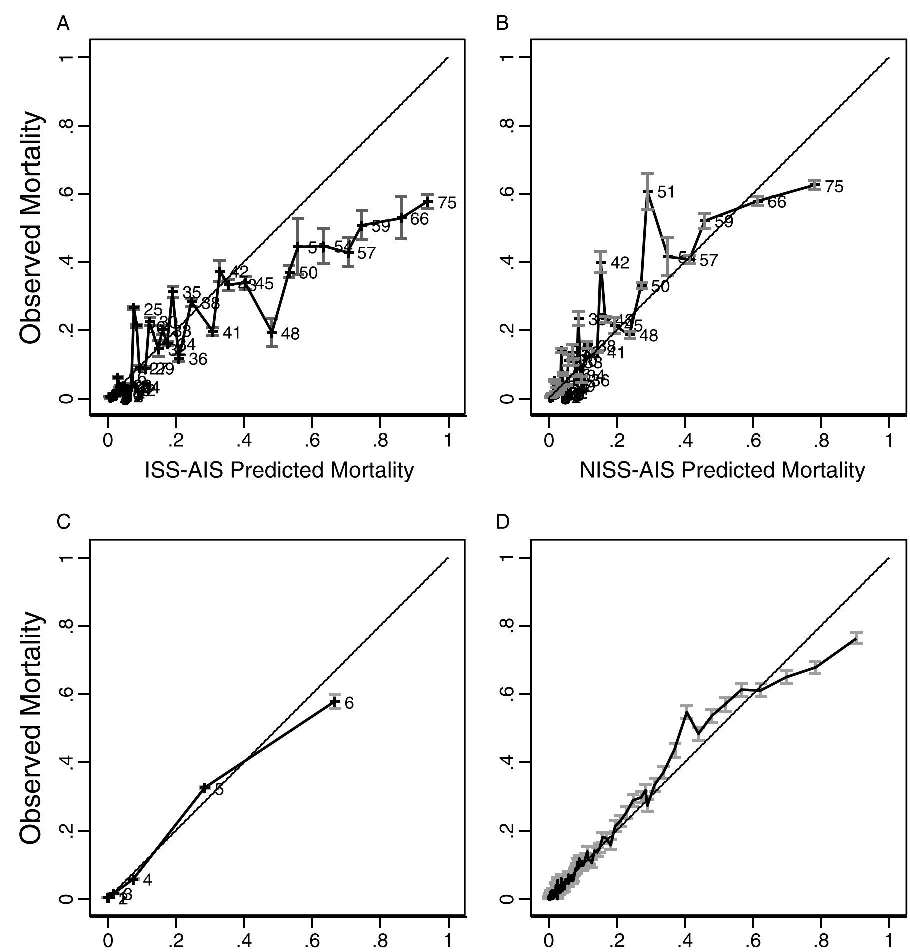

Figure 3. Calibration plots of the four AIS-based prediction models.

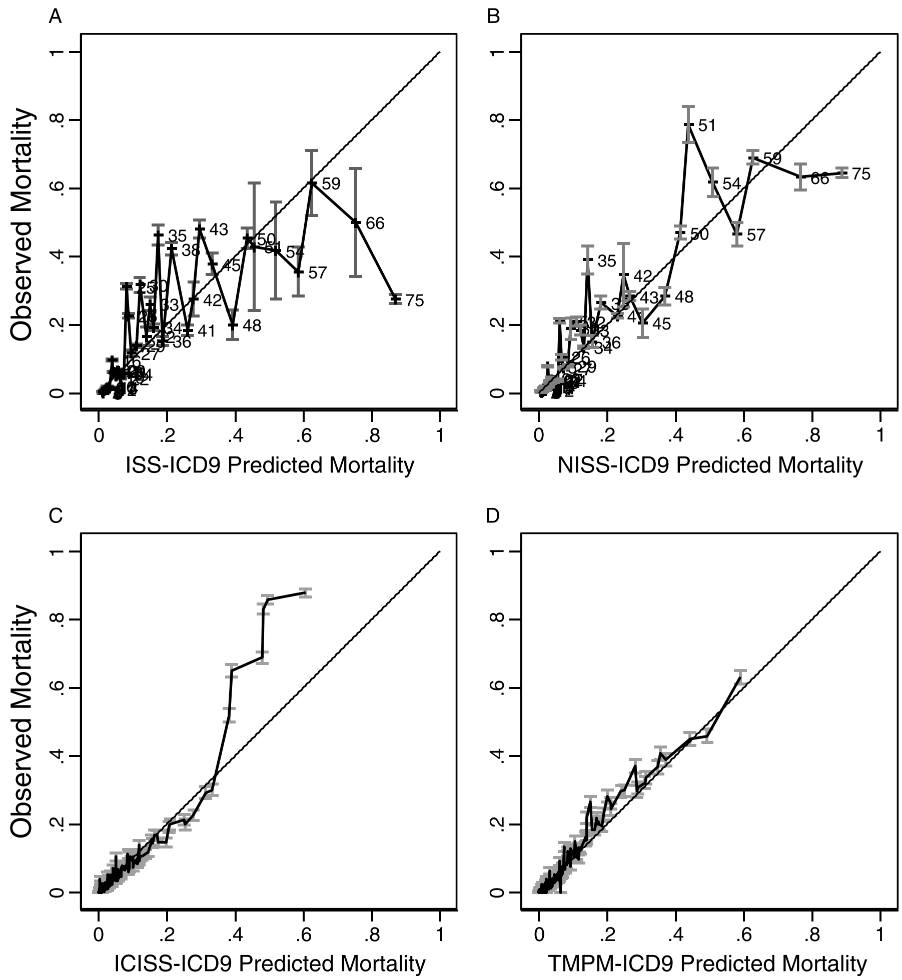

Figure 4. Calibration plots of the four ICD-9-based prediction models.

codes (Fig. 2, Table 2). Calibration plots show that the TMPM approximates the 45-degree line of perfect calibration more closely than any other model, whether TMPM is computed from AIS codes or ICD-9 codes. Scores based on the traditional "sum of squares" approach (ISS and NISS) are dramatically nonmonotonic. (Figs. 3 and 4).

DISCUSSION

Although patients treated at trauma centers have better outcomes than those treated at nontrauma centers,[15] there is significant variability in outcomes even among trauma centers.[16] It is therefore important to compare outcomes among centers, both to determine best practices and to discover centers where improvement is possible. For such comparisons to be credible, however, it is important to use the best available adjustment for injury severity. A host of such models have been developed in the 40 years since Baker et al. originally constructed the ISS, made possible largely by the advent of ever larger data sets and the increasing power of desktop computing. Hundreds of articles have been published describing the merits and shortcomings of each of these models. Through this process of development and debate, substantial progress has been made over time. Yet, remarkably, the ISS is still the most used measure of injury severity.

We believe that the results of the current analysis make a strong case to adopt the TMPM as a measure of overall injury severity for several reasons: the TMPM performs better than any other model in terms of discrimination and calibration. In addition, versions of TMPM are available for data coded in either the AIS or the ICD-9 lexicon. Finally, software is available to allow TMPM to be easily computed in the Excel, Stata, or SAS computing environment.

CONCLUSION

We conclude that the TMPM is the best of the models considered in this report because it has significantly better discrimination and calibration than any of its predecessors. The NISS should continue the legacy of the ISS when rapid relative estimates of injury severity are required. However, when a computer is available, TMPM is preferred because of its superior discrimination and calibration. We also note that the AIS lexicon consistently outperformed the ICD-9 in our study, suggesting that the AIS better captures the diverse spectrum of injury and describes it more precisely than does ICD-9. Others with an interest in accurate outcome prediction have called for the use of the AIS lexicon. Specifically, Trauma Quality Improvement Program will soon require the use of the AIS-05 lexicon.[17] Our finding that outcome prediction based on AIS injury descriptors is superior to prediction based on ICD-9 descriptors supports this view. This is expected because AIS was specifically created as a measure of injury severity, while the ICD-9 was conceived as a complete taxonomy of all possible illnesses, without regard to severity. Moreover, the ICD-9 lexicon will become obsolete in 2014 with the implementation of the ICD-10 lexicon. Thus, widespread adoption of the AIS lexicon for mortality prediction is appropriate owing to its superior articulation of traumatic injuries and a matter of tangible urgency. Regardless of which lexicon used, the TMPM proved superior to the ISS, ICISS, and NISS.

The ISS has fought the good fight with distinction for 40 years, but the TMPM now more accurately measures the degree of anatomic injury and offers the further advantage of handling injuries described in either the AIS or the ICD-9 lexicons. We believe that the ISS should now be laid to rest and the TMPM be adopted as the standard measure of injury severity.

AUTHORSHIP

A.C. and J.W. conducted the literature search for this study, which L.G. and T.O. designed. A.C. performed data collection. A.C. and T.O. analyzed the data. A.C., D.H., and T.O. contributed to data interpretation. A.C., J.W., S.B., and T.O. wrote the manuscript. A.C., S.B., D.H., L.G., L.F., and T.O. contributed to critical revision.

DISCLOSURE

The authors declare no conflicts of interest.

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DISCUSSION

Dr. Howard R. Champion (Annapolis, Maryland): I always relish an opportunity to discuss a paper that has got Turner Osler's name on it. There are usually so many targets of opportunity.

However, today I want to stand up and compliment the presenter, the terse paper, and also to commend, highlight, and extol the statistical comparative methodology used in this manuscript.

The area under the ROC curve is frequently the only measure put forward as a comparative evaluation tool for various biometric and biological models. It is completely inadequate when we are looking for accuracy and precision in outcome prediction. And, therefore, the use of the Akaike Information Criterion and the calibration curves as put forward in this paper should be regarded as a standard and should always accompany such measures of discrimination as the AUROC when such comparisons are being made.

I have no qualms at all about supporting empirically based trauma scoring systems such as the TMPM. Indeed we actually developed one in the '80s ourselves, but traded it in in the Woodstock Conference. That was based on ICD-8.

However, the criticisms leveled at ISS do not seem to be equally transferred to a scrutiny of AIS and ICD. I think you've identified some of the shortcomings in the paper, but AIS is also somewhat obsolescent. It started off as 75 codes. It is now over 2,000 codes, the majority (about 60%) of which are not used by anybody in any trauma center.

The Germans have got a redacted version. And we are publishing, shortly, a combat injury scale which also ignores the vast amount of data that is there and never available for the analytic interests of those that are doing the coding.

Questions: How would you look forward to the modeling of this anatomic scale into the context of age, and concurrent disease states, that are going to be increasingly important, particularly in the U.S.?

You've raised the issue of ICD-10. There are conversions between ICD-9CM and ICD-10CM. And, as you note, ICD-10 is used worldwide. ICD-11 is already in final print. And so how rapidly are you moving to correct the almost instant obsolescence of TMPM as we speak today?

Finally, it occurs to me that, we have been criticizing ISS now for 25 years and it is still on the pedestal, as you noted.

There are a few places where logic and science are left at the door. One is Capitol Hill, with which I have a lot of acquaintances. But this one in the trauma community seems to be another example. I would ask you to comment as to why we have not been able to drive a stake through the heart of ISS.

I would refer you to a recent article by Atul Gawande in the New Yorker a couple of months ago where he looked at the rapid way certain things are adopted by the medical community, such as anesthesia, and the very tardy adoption of other things, such an antisepsis. Are we stuck in a rut because we don't understand the statistics? Or what excuse can you give for us still placing credence in ISS?

Thank you.

Dr. Stanislaw Stawicki (Columbus, Ohio): Have you considered putting this data through some self-learning models, neural network-based models to see whether or not you can dynamically adjust it as opposed to using a static model?

Dr. Alan Cook (Dallas, Texas): Thank you very much, Dr. Champion. I appreciate your comments and your review of our work.

In terms of its performance in a composite measure, that is absolutely of interest to us. TMPM is a measure of the dose of trauma. A composite mortality prediction model that includes the TMPM, age, comorbidities and such could perform better than the dose of trauma alone. That would be a logical next step.

I do not believe the TMPM is moving towards obsolescence. The TMPM-ICD-10 does not exist yet. To produce a TMPM-ICD-10 model, we will need a large, robust dataset that includes a sufficient number of fatalities to allow us to start over, essentially, and compute the MARC values or the model averaged regression coefficients for each injury. And obviously we don't have an ICD-10 dataset for the United States. Nonetheless, that point is well taken.

We are ready to develop TMPM-ICD-10 as soon as an ICD-10 dataset is available. In the mean time, we should continue using AIS.

The ISS has persisted because of familiarity and the simplicity of calculation.

One way to facilitate the adoption of TMPM would be to include a column containing the TMPM probability of death in the NTDB dataset. We would be happy to make our software available to the NTDB, as we do for all investigators, to perform the TMPM calculation.

Now, for neural networks, it's been a long time since nets were popular, probably because they perform no better than standard logistic regression. We looked at neural networks over a decade ago, but didn't pursue them for this reason. There is an editorial in the *Journal of Trauma* by Drs. Osler and Bedrick from 2000 addressing this very topic (*J Trauma*. 2000;49(2):221–223). My coauthors and I don't have any work going on in that area though.

Thank you very much for this opportunity and thank you for your questions.