Trauma and Injury Severity Score (TRISS) Coefficients 2009 Revision

Philip J. Schluter, PhD, Avery Nathens, MD, PhD, Melanie L. Neal, MSc, Sandra Goble, MSc, Cate M. Cameron, PhD, Tamzyn M. Davey, MPH, and Roderick J. McClure, MBBS, PhD

Background: Currently used Trauma and Injury Severity Score (TRISS) coefficients, which measure probability of survival (P_S), were derived from the Major Trauma Outcome Study (MTOS) in 1995 and are now unlikely to be optimal. This study aims to estimate new TRISS coefficients using a contemporary database of injured patients presenting to emergency departments in the United States; and to compare these against the MTOS coefficients.

Methods: Data were obtained from the National Trauma Data Bank (NTDB) and the NTDB National Sample Project (NSP). TRISS coefficients were estimated using logistic regression. Separate coefficients were derived from complete case and multistage multiple imputation analyses for each NTDB and NSP dataset. Associated P_S over Injury Severity Score values were graphed and compared by age (adult ≥15 years; pediatric <15 years) and injury mechanism (blunt; penetrating) groups. Area under the Receiver Operating Characteristic curves was used to assess coefficients' predictive performance.

Results: Overall 1,072,033 NTDB and 1,278,563 weighted NSP injury events were included, compared with 23,177 used in the original MTOS analyses. Large differences were seen between results from complete case and imputed analyses. For blunt mechanism and adult penetrating mechanism injuries, there were similarities between coefficients estimated on imputed samples, and marked divergences between associated P_S estimates and those from the MTOS. However, negligible differences existed between area under the receiver operating characteristic curves estimates because the overwhelming majority of patients had minor trauma and survived. For pediatric penetrating mechanism injuries, variability in coefficients was large and P_S estimates unreliable.

Conclusions: Imputed NTDB coefficients are recommended as the TRISS coefficients 2009 revision for blunt mechanism and adult penetrating mechanism injuries. Coefficients for pediatric penetrating mechanism injuries could not be reliably estimated.

Key Words: Trauma and injury severity score, TRISS, Adult, Pediatric, Revision.

(*J Trauma.* 2010;68: 761–770)

Submitted for publication June 24, 2009.
Accepted for publication January 7, 2010.

From the School of Public Health and Psychosocial Studies (P.J.S.), AUT University, Auckland, New Zealand; School of Nursing and Midwifery (P.J.S.), The University of Queensland, Brisbane, Australia; St. Michael's Hospital (A.N.), Toronto, Canada; National Trauma Data Bank (NTDB) (M.L.N., S.G.), American College of Surgeons, Chicago, Illinois; School of Medicine (C.M.C.), Griffith University, Logan, Australia; National Trauma Registry Consortium (T.M.D.), Royal Australasian College of Surgeons, Brisbane, Australia; and Accident Research Centre (R.J.M.), Monash University, Melbourne, Australia.
Address for reprints: Philip Schluter, PhD, Akoranga Campus, 90 Akoranga Drive, Auckland 0627, New Zealand; email: philip.schluter@aut.ac.nz.

DOI: 10.1097/TA.0b013e3181d3223b

The Trauma and Injury Severity Score (TRISS) is a weighted combination of patient age, Injury Severity Score (ISS), and Revised Trauma Score (RTS) variables developed to predict a patient's probability of survival (P_S). Despite its limitations,[1–5] TRISS continues to be the most commonly used tool for benchmarking trauma outcome.[1,5,6] TRISS coefficients, which are used to give the variable weights, were estimated from ordinary logistic regression models originally in 1987,[7] and then revised in 1995,[2] using the American College of Surgeons Committee on Trauma coordinated Major Trauma Outcome Study (MTOS) database. In the intervening 14 years, no further revised coefficients have been published, although TRISS coefficient revisions have been presented in Reference Manuals appearing on the National Trauma Data Bank (NTDB) website (http://www.ntdb.org) and distributed with the NTDB data in previous years.[5]

The original authors noted in 1987 that "As improvements in trauma care over time result in decreased mortality, these [TRISS] coefficients can be expected to change."[7] With the advances in trauma management since the most recent revision in 1995, together with changes in the distribution of injury types presenting to trauma centers, it is probable that the TRISS coefficients estimated in 1995 may no longer reflect optimal performance benchmarks for contemporary trauma systems. Moreover, while the MTOS was the largest database of injury information in the United States at that time, it was not population based and demonstrated to be biased and unrepresentative of the traumatic injury population.[8] Additionally, all previously published TRISS coefficients have only used complete cases; derived on those patients with valid non-missing data for all predictor variables. However, key covariate data can often be missing, and misleading conclusions can result if the incomplete data are ignored or the missing data mechanism is ignored or misspecified.[9] As such, coefficients estimated from the MTOS database may not be as accurate as those derived from larger, appropriately imputed, more representative datasets that are currently available.[4,9]

The aim of this study is to estimate TRISS coefficients on complete case and multiply imputed data from current national databases of emergency department admissions to trauma centers in the United States, and compare predictive performances of these estimated coefficients against those derived in 1995 from the MTOS.[2]

MATERIALS AND METHODS

Data Sources

The National Trauma Data Bank

The American College of Surgeons Committee on Trauma established the NTDB in 1997.[10] Currently, the NTDB contains detailed data on more than 3 million cases from more than 900 United States trauma centers.[10] However, like the MTOS database, the NTDB is not population based and consists solely of data submitted by participating trauma centers. It includes a disproportionate number of larger hospitals with younger and more severely injured patients.[10,11]

The NTDB National Sample Project

The National Sample Project (NSP) is a nationally representative sample based on NTDB data of traumatic injuries treated at Level I and II trauma centers in the United States. The NSP consists of a stratified sample of 100 hospitals (90 hospitals that have contributed data to the NTDB and 10 that have not contributed data to the NTDB before 2003).[12] Strata used for sampling were (i) NTDB participation (NTDB, non-NTDB); (ii) trauma level (I or II); and (iii) region (Northeast, Midwest, West, South).

Study Sample

Two samples were used in this study: NTDB version 7.1 with admission years 2002 to 2006, including all traumatic injuries from both verified and designated trauma centers and unverified or non-designated centers; and NSP with admission year 2003 to 2006, including all traumatic injuries from a stratified sample of 100 hospitals. Traumatic injuries were defined as all admitted patients with ICD-9-CM discharge diagnosis 800.0-959.9, except those with (i) 905-909 (late effects of injury); (ii) 910-924 (blisters, contusions, abrasions, and insect bites); (iii) 930-939 (foreign bodies). Patients who died before receiving any evaluation or treatment or who were dead on arrival were excluded.[10,12] Cases where the mechanism of injury was burns or unknown were also excluded.

The TRISS Model

The TRISS model has two separate specifications for adults ($\geq$15 years of age); (i) for injuries sustained from a blunt mechanism, and (ii) for injures sustained from a penetrating mechanism. Specification (i) is also universally applied to children ($<$15 years of age), regardless of the mechanism of injury. TRISS coefficients give the P_S rather than the probability of death (P_D); naturally $P_D = 1 - P_S$. The P_S for any one patient can be estimated from:

$$P_S = 1/(1 + e^{-b})$$

where, for adults with blunt mechanism trauma,

$$b = -0.4499 + (0.8085 \times \text{RTS}) - (0.0835 \times \text{ISS}) - (1.7430 \times \text{age}), \quad (1)$$

for adults with penetrating mechanism trauma,

$$b = -2.5355 + (0.9934 \times \text{RTS}) - (0.0651 \times \text{ISS}) - (1.1360 \times \text{age}), \quad (2)$$

ISS has values from 0 to 75; age is coded: 0 if patient age is 15 years to 54 years, and 1 if patient age is $\geq$55 years; and the RTS is given by

$$\text{RTS} = (0.2908 \times \text{RR}) + (0.7326 \times \text{SBP}) + (0.9368 \times \text{GCS}). \quad (3)$$

The ISS is an anatomic scoring system that provides an overall score for patients with multiple injuries. Each injury is assigned an Abbreviated Injury Scale (AIS) score according to its relative importance on a six-point ordinal scale (1, minor; 2, moderate; 3, serious; 4, severe; 5, critical; 6, unsurvivable) and is allocated to one of six body regions: head and neck; face; thorax; abdomen; extremities (including pelvis); and external. Only the highest AIS score in each body region is used. The three most severely injured body regions have their score squared and added together to produce the ISS. An AIS of 6 in any anatomic region represents a fatal injury and automatically scores an ISS of 75, regardless of other injuries. Respiratory rate (RR), systolic blood pressure (SBP), and Glasgow Coma Score (GCS) each have values assigned to them as included in Table 1. If the expression for the RTS is directly substituted into above TRISS Eqs. 1 and 2, then it is convenient to re-write the equation for blunt mechanism trauma as

$$b = -0.4499 + (0.2351 \times \text{RR}) + (0.5923 \times \text{SBP}) + (0.7574 \times \text{GCS}) - (0.0835 \times \text{ISS}) - (1.7430 \times \text{age}) \quad (4)$$

and the equation for penetrating mechanism trauma as

$$b = -2.5355 + (0.2889 \times \text{RR}) + (0.7278 \times \text{SBP}) + (0.93 \times \text{GCS}) - (0.0651 \times \text{ISS}) - (1.1360 \times \text{age}). \quad (5)$$

Statistical Analyses

Once approval was obtained, NTDB and NSP data were downloaded and imported into SAS (SAS Institute, Cary, NC) for all subsequent analyses. Consistent with NTDB definitions, valid variable value ranges included $0 \leq \text{RR} \leq 99$; $0 \leq \text{SBP} \leq 300$; $3 \leq \text{GCS} \leq 15$; $0 \leq \text{ISS} \leq 75$; and $0 \leq$ age (years) ≤ 120; otherwise the variable values were set to missing. Medians, quartiles (Q_1, Q_3), frequencies, and percentages were reported for the NTDB and weighted NSP samples (using the SurveyFreq and SurveyMeans procedures). Comparisons between categorical variables were made using the χ^2 test for the NTDB sample and the Rao-Scott χ^2 test for the NSP sample (which accounts for the stratification, clustering, and probabilistic weightings).

TRISS coefficients for the P_S were estimated using maximum likelihood methods from ordinary logistic regression analyses. Again, analyses involving the NSP sample were weighted, accounting for the stratification, clustering, and probabilistic weightings (using the SurveyLogistic pro-

TABLE 1. Values Associated With RR, SBP, and GCS Used in the Calculation of the RTS and When Considered in Regression Models Separately

Value	RR (Breaths/min)	SBP (mm Hg)	GCS
0	0	0	3
1	1–5	1–49	4–5
2	6–9	50–75	6–8
3	>29	76–89	9–12
4	10–29	>89	13–15

cedure). Initially, analyses were conducted on complete cases; namely, for only those patients with valid non-missing data for all covariates listed in Table 1. Next, analyses were repeated for all patients, using imputed data for those covariates with invalid or missing data. A multistage multiple imputation method was used (using the MI procedure), with the first multiple imputation stage using a Markov chain Monte Carlo method to impute the dataset so that it has a monotonic missing pattern, and the second multiple imputation stage using the nonparametric propensity score method.[13] For analyses involving imputed data, $m = 5$ datasets were generated, analyzed, and results reported (using the MIANALYZE procedure). Assigning all predictor variables except ISS to their modal value, P_S over ISS values was then graphed and compared for each set of coefficients by age and injury mechanism groups. Finally, the predictive ability of each derived TRISS model was then assessed on the original and imputed NTDB and unweighted NSP samples using area under the Receiver Operating Characteristic curves (AUC). AUC 95% confidence intervals (CI) were calculated using exact binomial methods. A difference was considered important if the 95% CIs did not overlap.

RESULTS

From the NTDB, 1,115,389 patients had valid eligible trauma codes. However, the mechanism of injury was burns for 22,813 (2.0%) or unknown for 20,543 (1.8%), leaving 1,072,033 (96.1%) patients from 665 trauma centers for analysis. For the NSP, 280,129 patients had valid eligible trauma codes. In these, the mechanism of injury was burns for 4,854 (1.7%) or unknown for 5,194 (1.9%), leaving 270,081 (96.4%) for analysis, and a weighted estimate number of 1,278,563. Henceforth, only weighted estimates will be reported for data description and specification of regression coefficients for the NSP sample. Table 2 includes the demo-

TABLE 2. Distribution of Patient Socio-Demographic and Injury Characteristics for the NTDB, Weighted NSP, and the MTOS[8]

	NTDB (N = 1,072,033) n (%)	NSP (N = 1,278,563) n (%)	MTOS (N = 80,544) n (%)
Gender			
Male	704,151 (65.7)	850,920 (66.6)	57,231 (71.1)
Female	365,469 (34.1)	421,641 (33.0)	22,599 (28.1)
Unknown	2,413 (0.2)	6,002 (0.5)	714 (0.9)
Age (years)			
<15	115,347 (10.8)	103,288 (8.1)	8,713 (10.8)
15–54	648,863 (60.5)	819,573 (64.1)	59,179 (73.5)
≥55	254,404 (23.7)	330,267 (25.8)	12,451 (15.5)
Unknown	53,419 (5.0)	25,435 (2.0)	201 (0.2)
Ethnicity			
White, not Hispanic	660,936 (61.7)	745,587 (58.3)	*
Black, not Hispanic	140,817 (13.1)	147,778 (11.6)	*
Hispanic	114,005 (10.6)	162,936 (12.7)	*
Asian/Pacific Islander	16,126 (1.5)	17,034 (1.3)	*
Native American/Alaska Native	7,311 (0.7)	4,999 (0.4)	*
Other	56,926 (5.3)	129,338 (10.1)	*
Unknown	75,912 (7.1)	70,892 (5.5)	*
Discharge status			
Alive	1,013,892 (94.6)	1,200,345 (93.9)	73,282 (91.0)
Dead	53,356 (5.0)	67,296 (5.3)	7,427 (9.0)
Unknown	4,785 (0.5)	10,923 (0.9)	15 (0.0)
Mechanism of injury			
Blunt	944,706 (88.1)	1,120,843 (87.7)	63,555 (78.9)
Penetrating	127,327 (11.9)	157,721 (12.3)	16,989 (21.1)
RTS on admission			
Defined	869,819 (81.1)	1,016,692 (79.5)	71,625 (88.9)
Incomplete	202,214 (18.9)	261,872 (20.5)	8,919 (11.1)
ISS			
Defined	1,056,325 (98.5)	1,265,239 (99.0)	80,538 (100.0)
Incomplete	15,708 (1.5)	13,324 (1.0)	6 (0.0)
Completeness of TRISS predictor variables			
All TRISS variables defined	822,266 (76.7)	992,044 (77.6)	71,431 (88.7)
Incomplete	249,767 (23.3)	286,520 (22.4)	9,113 (11.3)

* Denotes that the information was not reported.

graphic and injury profile of the NTDB and NSP samples, together with the full MTOS sample of 80,544 trauma patients from 139 United States and Canadian trauma centers, submitted from October 1982 through to 1987.[8]

Table 2 shows that there has been a shift in injury profiles since 1982–1987, but that the profiles for the NTDB and NSP samples are similar. Since the 1982–1987 MTOS study, more women, more older (≥55 years of age) patients, more blunt mechanism injuries, and fewer deaths at discharge were recorded. The NTDB and NSP samples had lower rates of data completeness for the RTS and ISS components compared with the MTOS sample. Completeness of information was age-dependent, with fewer TRISS variables completely defined for pediatric injuries (NTDB: 73.9% blunt mechanism, 73.6% penetrating mechanism; NSP: 70.7% blunt mechanism, 68.4% penetrating mechanism) than adult injuries (NTDB: 81.4% blunt mechanism, 83.0% penetrating mechanism; NSP: 79.7% blunt mechanism, 81.4% penetrating mechanism). Those with incomplete TRISS variables information in the NTDB sample were more likely to have died, 17,672 (7.1%), compared with those with complete information, 35,684 (4.4%), χ^2 test $p < 0.001$. Similarly, those with incomplete TRISS variables information in the NSP sample were more likely to have died, 20,571 (7.3%), compared with those with complete information, 46,724 (4.7%), Rao-Scott χ^2 test $p = 0.045$.

TRISS Variable Distributions

For patients with known discharge status, Table 3 presents the empirical distribution of the total numbers (N) and the numbers of those who survived (n) over all levels of each predictor variable used in the derivation of TRISS partitioned by age groups (pediatric and adult), injury mechanism (blunt and penetrating), and database (NTDB and NSP). From Table 3, it can be seen that available sample numbers are small for some pediatric variable levels, especially for the NSP sample that reports weighted estimates. This is because the NSP sample was designed to capture adult rather than pediatric trauma centers. For both NTDB and NSP samples, the distribution of survival over the TRISS variables varies markedly between the age and injury mechanism groups. Comparatively, the difference between NTDB and NSP samples within these age and injury mechanism groups is generally smaller.

TRISS Coefficients

Maximum likelihood estimated coefficients and associated standard errors (SE) for each age and injury mechanism combination appear separately for the complete case and imputed NTDB and NSP samples in Table 4. Also included in Table 4, are the revised and currently used TRISS coefficient estimates, first reported in 1995.[2]

To visually assess the impact of the revised coefficients included in Table 4, Figures 1 and 2 depict graphs of the P_S over all possible ISS values for each set of coefficients (MTOS, NTDB, and NSP) by injury mechanism groups for adult (≥15 years) and pediatric (<15 years) age groups. In these figures, the other component variables were assigned their modal value: RR = 10 to 29, SBP > 89, GCS = 13 to 15 and age <55 years. Additionally, Figure 3 presents an area graph of the 95% CI for the penetrating mechanism P_S estimated from TRISS coefficients derived from the imputed NTDB and NSP samples, as included in Table 4, by adult (≥15 years) and pediatric (<15 years) age groups.

Predictive Ability of the TRISS Models

AUC for each regression model is presented in Table 5. This AUC analysis was conducted separately on the complete case and imputed NTDB and unweighted NSP samples, respectively. Estimated AUC values were high, exceeding 0.9, for all age, injury mechanism, complete case and imputed coefficient analyses except one. Further, negligible differences in AUC estimates between the five sets of regression coefficients were seen for the NTDB and NSP samples over all age or injury mechanism groups, apart from those observed in the adult blunt mechanism on the NSP sample. Here, the NSP coefficient estimates yielded AUC values that are importantly higher (complete case NSP sample: complete case NSP coefficients AUC 0.921, 95% CI: 0.919–0.922; imputed NSP coefficients AUC 0.922, 95% CI: 0.921–0.924; imputed NSP sample: complete case NSP coefficients AUC 0.908, 95% CI: 0.907–0.909; imputed NSP coefficients AUC 0.911, 95% CI: 0.909–0.912) than those associated with the NTDB and MTOS models, and the NTDB coefficient estimates yielded AUC values that are importantly higher (complete case NSP sample: complete case NTDB coefficients AUC 0.917, 95% CI: 0.916–0.918; imputed NTDB coefficients AUC 0.919, 95% CI: 0.918–0.920; imputed NSP sample: complete case NTDB coefficients AUC 0.903, 95% CI: 0.902–0.905; imputed NTDB coefficients AUC 0.906, 95% CI: 0.905–0.907) than those derived from the MTOS model (complete case NSP sample: MTOS coefficients AUC 0.911, 95% CI: 0.916–0.918; imputed NSP sample: MTOS coefficients AUC 0.896, 95% CI: 0.895–0.898).

DISCUSSION

As previously recognized with trauma care data, one main finding of this article is that ignoring patients with any invalid or missing data in the derivation of TRISS coefficients can have a profound effect on the resultant estimates.[9] Figures 1 and 2 graphically demonstrate the difference between P_S estimates derived from complete case and imputed datasets. Increasingly, it is recognized that complete case analyses produce biased results[14] whereas appropriate imputation techniques yield valid results.[15] This study has a significant percentage of patients with incomplete information to analyze a P_S estimate (23.3% in the NTDB and 22.4% in the NSP compared with 11.3% in the MTOS), and data were not missing completely at random; being age-dependent and those with incomplete information being more likely to die. These dependences will almost certainly yield biased TRISS coefficients should complete case analysis alone be undertaken and reported. Having superior properties to single imputation,[15] we used multistage multiple imputation combined with logistic regression to estimate the TRISS coefficients.[13] In these imputations we assumed that the data were missing at random (MAR) which implies that the probability

TABLE 3. Total Numbers (N) and the Number Who Survived (n) with Associated Percentage (%) Over All Levels of the TRISS Predictor Variables by Adult (≥15 yrs) and Pediatric (<15 yrs) Age-Groups and Blunt and Penetrating Injury Mechanism Types for the NTDB and the Weighted NSP Samples

	Pediatric (<15 yr)						Adult (≥15 yr)					
	Blunt			Penetrating			Blunt			Penetrating		
	N	n	%	N	n	%	N	n	%	N	n	%
NTDB												
SBP (mm Hg)												
0	3,037	2,564	84.4	264	183	69.3	26,894	20,609	76.6	6,640	2,411	36.3
1–49	154	124	80.5	15	12	80.0	1,148	808	70.4	358	210	58.7
50–75	838	654	78.0	58	45	77.6	5,817	3,842	66.0	2,187	1,563	71.5
76–89	2,378	2,224	93.5	160	147	91.9	10,595	8,509	80.3	2,988	2,482	83.1
>89	87,098	86,241	99.0	5,721	5,636	98.5	707,926	683,658	96.6	95,384	91,729	96.2
RR (breaths/min)												
0	4,797	3,877	80.8	344	231	67.2	47,358	35,426	74.8	9,025	3,822	42.3
1–5	139	102	73.4	17	5	29.4	1,581	827	52.3	887	176	19.8
6–9	103	91	88.3	8	8	100.0	1,725	1,410	81.7	388	255	65.7
>29	14,459	14,296	98.9	691	672	97.3	20,591	18,924	91.9	4,698	4,283	91.2
10–29	77,519	77,211	99.6	5,463	5,431	99.4	655,455	639,153	97.5	88,919	86,842	97.7
GCS												
3	4,407	2,930	66.5	313	123	39.3	45,685	27,076	59.3	11,212	3,008	26.8
4–5	553	453	81.9	18	10	55.6	4,332	3,031	70.0	534	228	42.7
6–8	1,686	1,588	94.2	33	26	78.8	12,466	10,498	84.2	1,185	882	74.4
9–12	2,768	2,735	98.8	70	65	92.9	19,791	17,892	90.4	1,936	1,624	83.9
13–15	81,911	81,844	99.9	5,692	5,685	99.9	623,486	613,320	98.4	88,844	87,796	98.8
Age (years)												
<55	107,701	105,735	98.2	7,199	6,967	96.8	539,250	520,908	96.6	106,452	96,797	90.9
≥55							267,394	247,674	92.6	8,054	6,799	84.4
ISS—median (Q1, Q3)												
	8 (4, 10)	8 (4, 10)		4 (1, 8)	2 (1, 5)		9 (4, 14)	9 (4, 14)		5 (1, 12)	4 (1, 10)	
NSP												
SBP (mm Hg)												
0	6,300	5,820	92.4	460	391	85.0	81,325	72,452	89.1	9,108	5,954	65.4
1–49	69	51	73.9	12	9	75.0	925	587	63.5	393	169	43.0
50–75	661	506	76.6	43	40	93.0	6,957	4,204	60.4	2,268	1,660	73.2
76–89	1,947	1,843	94.7	123	113	91.9	12,122	9,520	78.5	2,685	2,157	80.3
>89	69,622	68,930	99.0	3,970	3,898	98.2	813,591	778,777	95.7	100,149	96,341	96.2
RR (breaths/min)												
0	7,377	6,586	89.3	557	418	75.0	98,525	84,327	85.6	11,452	7,198	62.9
1–5	98	87	88.8	3	3	100.0	935	650	69.5	398	249	62.6
6–9	89	83	93.3	2	2	100.0	2,027	1,658	81.8	492	398	80.9
>29	10,356	10,230	98.8	410	402	98.0	22,773	20,775	91.2	4,915	4,554	92.7
10–29	63,738	63,422	99.5	3,803	3,780	99.4	763,353	737,078	96.6	93,265	90,879	97.4
GCS												
3	3,214	2,074	64.5	295	111	37.6	49,833	28,115	56.4	10,322	3,986	38.6
4–5	364	309	84.9	4	0	0.0	5,133	3,440	67.0	615	232	37.7
6–8	1,441	1,376	95.5	31	27	87.1	15,363	12,379	80.6	1,258	982	78.1
9–12	2,251	2,233	99.2	71	69	97.2	23,227	20,822	89.6	2,131	1,774	83.2
13–15	70,076	69,947	99.8	4,173	4,171	99.9	759,762	743,650	97.9	96,150	94,964	98.8
age (years)												
<55	95,727	94,021	98.2	5,999	5,786	96.5	678,851	654,272	96.4	118,477	110,473	93.2
≥55							318,400	289,902	91.0	8,274	7,062	85.4
ISS—median (Q1, Q3)												
	6 (4, 10)	5 (4, 10)		3 (1, 9)	2 (1, 9)		9 (4, 14)	9 (4, 13)		4 (1, 10)	4 (1, 9)	

TABLE 4. Estimated Coefficients (est.) and Standard Errors (SE) of the TRISS Predictor Variables From the MTOS[2], NTDB, and NSP Samples by Adult (≥15 yr) and Pediatric (<15 yr) Age-Groups and Blunt and Penetrating Injury Mechanism Types

Data	Intercept est. (SE)	RR est. (SE)	SBP est. (SE)	GCS est. (SE)	ISS est. (SE)	Age est. (SE)
Pediatric (<15 yr): blunt mechanism						
MTOS	−0.4499	0.2351	0.5923	0.7574	−0.0835	
NTDB—complete case	0.1742 (0.1252)	0.0494 (0.0240)	0.7585 (0.0307)	1.1000 (0.0312)	−0.0750 (0.0031)	
NTDB—imputed	1.3809 (0.0825)	0.0546 (0.0201)	0.5852 (0.0255)	0.8533 (0.0207)	−0.0930 (0.0023)	
NSP—complete case	0.4540 (0.5109)	0.0299 (0.0747)	0.6754 (0.1108)	1.0578 (0.1851)	−0.0746 (0.0080)	
NSP—imputed	1.6982 (0.3448)	0.1076 (0.0724)	0.4500 (0.0962)	0.8348 (0.1124)	−0.0930 (0.0072)	
Pediatric (<15 yr): penetrating mechanism						
MTOS	−0.4499	0.2351	0.5923	0.7574	−0.0835	
NTDB—complete case	−1.1690 (0.3986)	−0.0150 (0.0914)	0.7146 (0.1033)	1.3273 (0.1053)	−0.0593 (0.0107)	
NTDB—imputed	0.1178 (0.2462)	0.0619 (0.0790)	0.4847 (0.0833)	1.0708 (0.0710)	−0.0810 (0.0072)	
NSP—complete case	−0.9512 (0.8567)	0.1559 (0.2222)	0.4492 (0.2198)	1.6060 (0.3293)	−0.0433 (0.0433)	
NSP—imputed	1.5995 (0.7460)	0.1286 (0.2886)	0.2001 (0.2816)	1.1270 (0.3485)	−0.1300 (0.0464)	
Adult (≥15 yr): blunt mechanism						
MTOS	−0.4499	0.2351	0.5923	0.7574	−0.0835	−1.7430
NTDB—complete case	1.1323 (0.0301)	−0.0657 (0.0062)	0.5649 (0.0076)	0.7485 (0.0057)	−0.0760 (0.0006)	−1.8465 (0.0174)
NTDB—imputed	1.6494 (0.0246)	0.0095 (0.0056)	0.4260 (0.0066)	0.6307 (0.0046)	−0.0795 (0.0005)	−1.6216 (0.0145)
NSP—complete case	1.4983 (0.2454)	−0.0852 (0.0308)	0.3918 (0.0737)	0.7562 (0.0541)	−0.0745 (0.0043)	−1.8157 (0.1180)
NSP—imputed	2.0281 (0.2142)	−0.0691 (0.0213)	0.2470 (0.0588)	0.6965 (0.0436)	−0.0748 (0.0052)	−1.6924 (0.0648)
Adult (≥15 yr): penetrating mechanism						
MTOS	−2.5355	0.2889	0.7278	0.9306	−0.0651	−1.1360
NTDB—complete case	−1.0110 (0.0565)	0.0670 (0.0148)	0.6757 (0.0160)	0.9691 (0.0135)	−0.0881 (0.0016)	−1.2014 (0.0680)
NTDB—imputed	−0.5757 (0.0472)	0.1517 (0.0179)	0.5237 (0.0165)	0.8310 (0.0116)	−0.0872 (0.0013)	−0.8714 (0.0545)
NSP—complete case	−0.8669 (0.3240)	0.0808 (0.0477)	0.6120 (0.0746)	0.9348 (0.0802)	−0.0824 (0.0059)	−1.5015 (0.1312)
NSP—imputed	0.3409 (0.4419)	0.0615 (0.0634)	0.3397 (0.0827)	0.8634 (0.1195)	−0.0805 (0.0075)	−1.2477 (0.1423)

RR, SBP, GCS, ISS and age variable classifications are those defined in Table 1 and equations 1–5.

that an observation is missing is dependent only on the observed data.

Another main finding is the similarity between imputed NTDB and NSP sample TRISS coefficients and their estimated P_S over the full range of ISS values for patients injured from a blunt mechanism. A marked divergence between these probabilities and those derived from MTOS coefficients as ISS increased was also seen, with patients now appearing to have improved P_S. A natural question is whether the P_S has actually changed over the intervening years. For adults injured by blunt mechanism, the original MTOS coefficients were based on 15,754 patients with around 260 (1.6%) having ISS ≥50.[8] (No sample size numbers were given for the revised MTOS coefficients.[2]) By comparison, the NTDB and weighted NSP samples have 796,843 and 986,312 injury events with valid ISS values, respectively, with 7,183 and 5,929 having ISS ≥50. Improved P_S is plausible because of improvements in medical care and technology and reductions in traffic-related fatalities.[16,17] However, the improvement may also partly result from a statistical artifice inherent within the MTOS estimates, because of the reliance on a relatively small sample size (especially at the higher ISS levels) in the derivation of the coefficient estimates. If the improvement in P_S is largely a clinical effect, resulting from improved trauma management, then future revisions of TRISS coefficients using sufficiently large patient numbers will confirm this improvement through the replication of our results.

Given the striking similarity between P_S estimates for blunt mechanism injuries derived from the imputed NTDB and NSP sample TRISS coefficients, it might be argued here that a truly representative sample is not required to formulate these coefficients.[18] Instead, capturing adequate patient numbers over the full range of the TRISS component variables to minimize associated sampling variability may be more important. However, as 55% to 67% of all Level I and 37% to 56% of all Level II centers are included in the NTDB sample,[19] it might also be argued that the similarity between the P_S estimates is expected. Nonetheless, further research explicitly investigating whether sample representation is needed to produce generalizable TRISS coefficients. If patient representation is not required to estimate valid TRISS coefficients, then this has important implications for estimating and revising population-based coefficients here and in other epidemiologic areas.

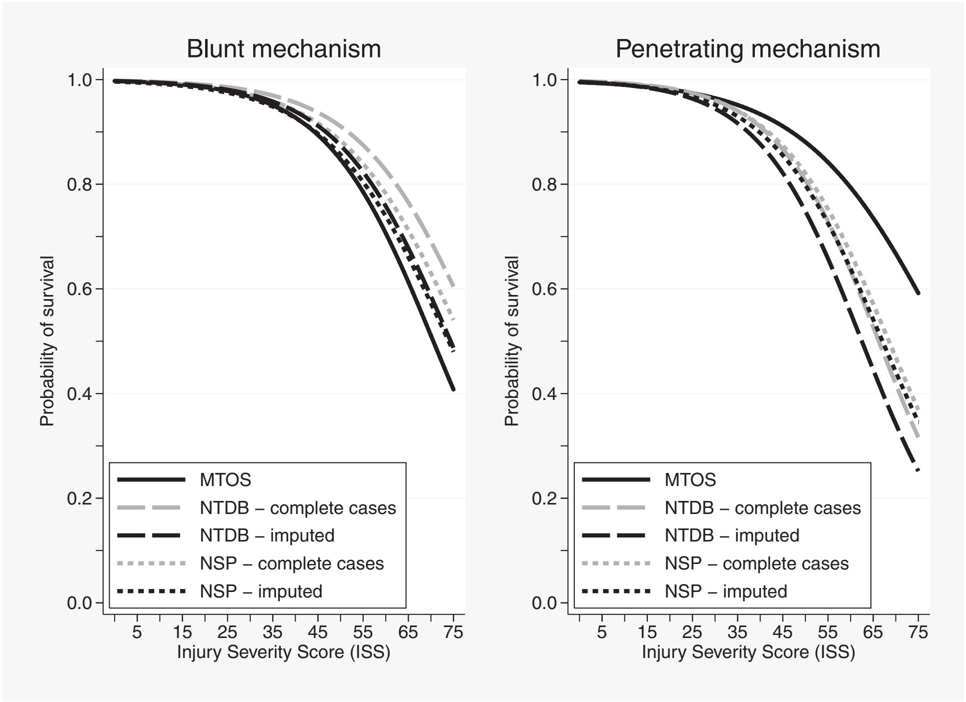

Figure 1. Graph of the predicted P_S for adult patients (≥15 years of age) over ISS from the estimated coefficients of TRISS from the MTOS,[2] NTDB and NSP presented in Table 4 by blunt and penetrating injury mechanism types. All other component variables had values assigned to their modal value.

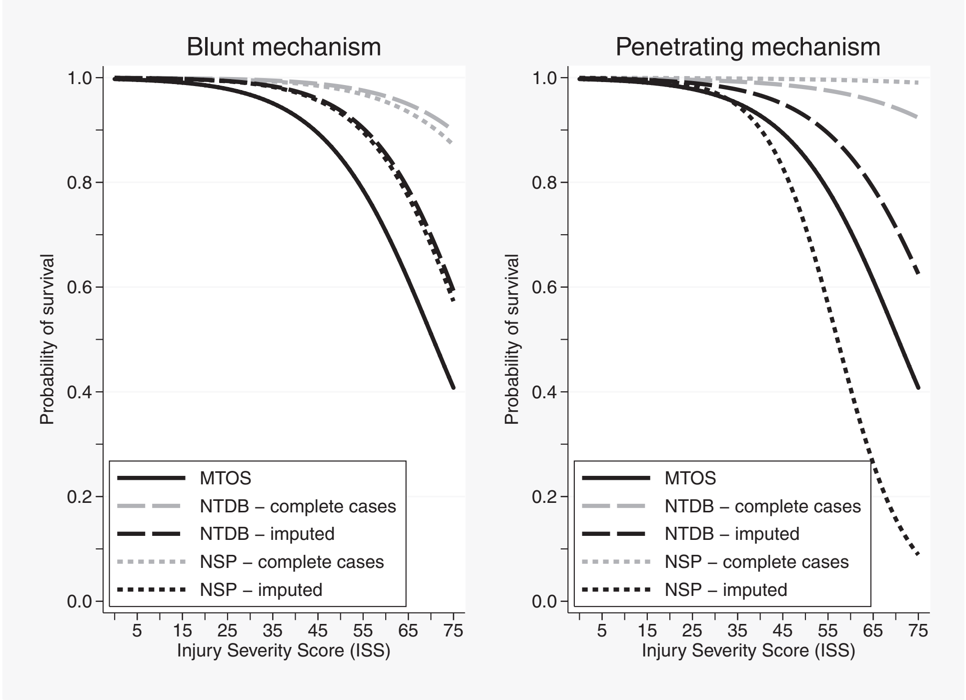

Figure 2. Graph of the predicted P_S for pediatric patients (<15 years of age) over ISS from the estimated coefficients of TRISS from the MTOS,[2] NTDB and NSP presented in Table 4 by blunt and penetrating injury mechanism types. All other component variables had values assigned to their modal value.

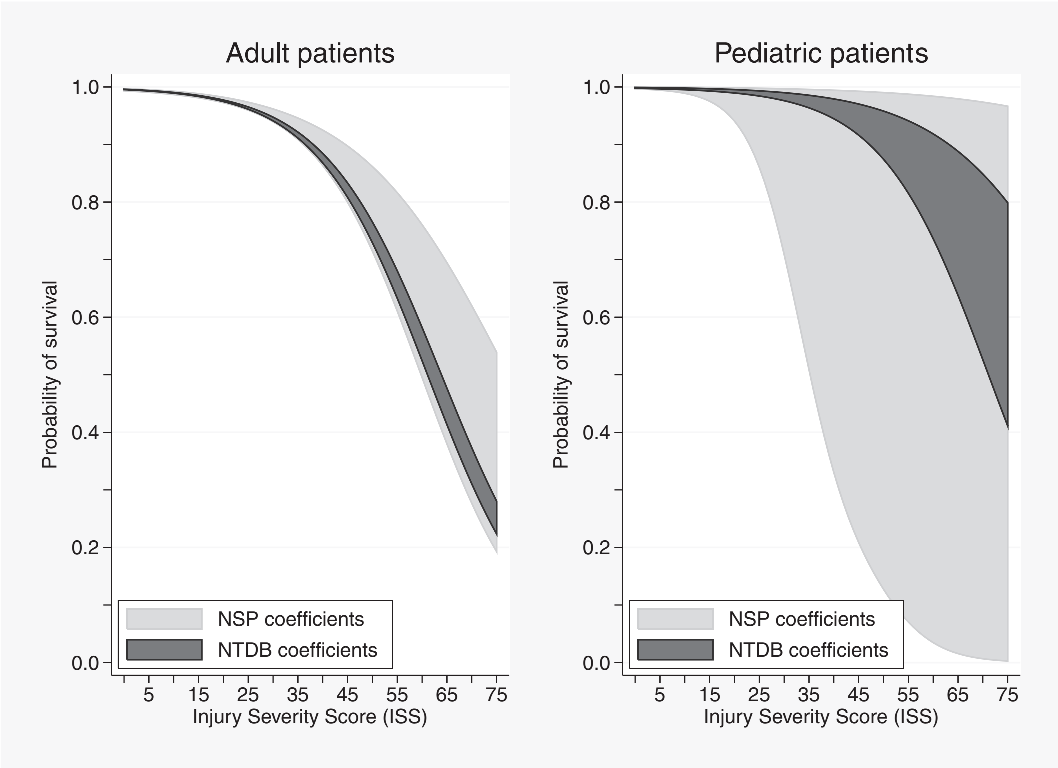

Figure 3. Area graph of the 95% CIs for a penetrating mechanism injury P_S estimated from TRISS coefficients derived from the imputed NTDB and NSP samples, as included in Table 4, by adult (≥15 years) and pediatric (<15 years) age groups. All other component variables had values assigned to their modal value.

Results for penetrating mechanism injuries with were less clear. For adults, results from the imputed NTDB and NSP regression analyses yielded coefficients that were generally similar and produced P_S estimates that diverged markedly from those derived from the MTOS coefficients with increasing ISS (Fig. 1). The original MTOS coefficients were based on 7,423 patients with around 169 (2.3%) having ISS ≥50.[8] (Again, no sample numbers were provided when the revised MTOS coefficients were published.[2]) By comparison, the NTDB and weighted NSP samples have 113,383 and 125,405 injury events with valid ISS values, respectively, with 1,666 and 1,333 having ISS ≥50. From Figure 1, it appears that the P_S for a given ISS has actually deteriorated since that observed during the MTOS period. In the context of the evidence previously discussed,[16,17] such deterioration is unlikely. Much more probable is that the change in P_S seen from the NTDB and NSP sample regression coefficients is due to the increased estimation precision from the greater available patient numbers in these samples compared with the MTOS estimates derived from the relatively small number of patients, especially at the higher ISS levels. However, the decrease in the proportion of penetrating injuries seen in the NTDB (11.9%) and NSP (12.3%) sample compared to that seen in the MTOS (21.1%) sample may also partly account for a deterioration in survival following penetrating injury as there may be less clinical experience in treating such trauma today, especially in smaller centers providing a lower level of surgical care. Future revisions of TRISS should confirm these corrected coefficients and P_S estimates through replication. In selecting between the imputed NTDB and NSP sample coefficients, Figure 3 demonstrates that there remains considerable variability in the P_S associated with NSP coefficients relative to those derived from the imputed NTDB sample. Given the similarity between coefficients on the larger blunt mechanism injury sample, together with this variability associated with the NSP coefficients, the imputed NTDB coefficients might be preferred.

Finally, the results for pediatric patients suffering a penetrating injury were erratic. The substantial differences in P_S estimates between all models considered (Fig. 2) and the large variability in 95% CIs associated with both imputed NTDB and NSP sample coefficients (Fig. 3) implies that insufficient data exists to model this injury mechanism in this patient group. None of the considered models, including MTOS, can be usefully applied to this population. Considerably, more cases with higher ISS values are required. Capturing current information from multiple large registries around the world may be the only means of determining reliable TRISS coefficients for pediatric penetrating mechanism injuries.

In terms of predictive performance, there were negligible differences in AUC estimates between the five sets of regression model coefficients within each injury mechanism, age, complete case, and imputed NTDB and unweighted NSP samples investigated. This was despite the considerable difference in patient profiles seen between the NTDB, NSP and

TABLE 5. AUC from Estimated Coefficients of TRISS From the MTOS[2], NTDB, and NSP Presented in Table 4 and Applied to the Complete Case and Imputed NTDB and Unweighted NSP Data by Adult (≥15 yr) and Pediatric (<15 yr) Age-Groups and Blunt and Penetrating Injury Mechanism Types

	NTDB Data		Unweighted NSP Data	
Model Coefficients	**Complete Case**	**Imputed**	**Complete Case**	**Imputed**
Pediatric (<15 yr): blunt mechanism				
MTOS	0.983	0.975	0.974	0.967
NTDB—complete case	0.983	0.974	0.974	0.966
NTDB—imputed	0.984	0.975	0.975	0.969
NSP—complete case	0.983	0.974	0.974	0.967
NSP—imputed	0.984	0.976	0.975	0.969
Pediatric (<15 yr): penetrating mechanism				
MTOS	0.991	0.982	0.996	0.987
NTDB—complete case	0.989	0.980	0.997	0.987
NTDB—imputed	0.991	0.983	0.998	0.990
NSP—complete case	0.992	0.982	0.997	0.988
NSP—imputed	0.990	0.983	0.997	0.991
Adult (≥15 yr): blunt mechanism				
MTOS	0.926	0.914	0.911	0.896
NTDB—complete case	0.927	0.914	0.917	0.903
NTDB—imputed	0.928	0.916	0.919	0.906
NSP—complete case	0.927	0.914	0.921	0.908
NSP—imputed	0.927	0.915	0.922	0.911
Adult (≥15 yr): penetrating mechanism				
MTOS	0.979	0.969	0.974	0.963
NTDB—complete case	0.980	0.971	0.976	0.967
NTDB—imputed	0.980	0.971	0.976	0.968
NSP—complete case	0.979	0.970	0.976	0.967
NSP—imputed	0.979	0.971	0.977	0.969

1982–1987 MTOS samples,[8] and that models calibrated on data they are then used to predict will generally have better diagnostics (which may explain the one important difference noted in the AUC results).[2] The general lack of model superiority in AUC statistics reflects the fact that the overwhelming majority of patients experienced relatively minor traumatic injuries and survived, and the penalty for incorrectly predicting survival in patients with relatively severe injuries became inconsequential.

A salient strength of the presented analyses has been the use of large, contemporary, national databases (one which is nationally representative), and a thorough statistical approach and analysis. Another salient strength is the specification, estimation, and reporting of pediatric-specific TRISS coefficients for blunt mechanism injuries. Because of the lack of pediatric injury data in the MTOS study for estimation of the original or revised TRISS coefficients, the current TRISS methodology simply applies adult blunt mechanism coefficients to pediatric patients, regardless of their injury mechanism. With the availability of the large NTDB and NSP samples, we are now in a position to derive TRISS coefficients directly for pediatric blunt mechanism injuries. Also, importantly, we have demonstrated that the MTOS coefficients applied to pediatric penetrating mechanism injuries are likely to be highly inaccurate and unreliable. Further data collection is required before reliable coefficients can be derived.

Arguably, the most important limitation of this study is the large level of missing data; substantially more than that observed in the MTOS database. Multistage multiple imputation assuming data are MAR and was used to minimize this limitation. However, the pattern of missing data may be even more complex, such as not missing at random (NMAR),[9,14,15] thereby introducing bias into our presented results. Unfortunately, NMAR imputation options are extremely difficult and time-consuming, do not exist in major specialist statistical packages and cannot be tested for.[15] However, no imputation scheme was used in the derivation of coefficients from the MTOS, despite the authors demonstrating significant differences between covariates for patients with and without complete information, and reporting dependencies between covariate completeness and outcome.[8] As such, important biases are almost certainly inherent within the currently used TRISS coefficients.[9,14,15]

Trauma scoring systems provide a means for benchmarking and monitoring trauma system performance over time, between hospitals and jurisdications.[20–22] TRISS has been the principle such scoring system for more than 20 years.[1,6] The analyses presented in this article confirm the robust predictive capabilities of the TRISS model for future use. The article adds to knowledge in the field by presenting a revised set of TRISS coefficients derived from a contemporary, large, national dataset. It is recommended that the coefficients derived from the imputed NTDB sample for adult and pediatric blunt mechanism and adult penetrating mechanism injuries be considered the TRISS coefficients 2009 Revision and Trauma Registry software updated accordingly. At this time, coefficients for pediatric penetrating mechanism injuries cannot be reliably estimated.

REFERENCES

1. Gabbe BJ, Cameron PA, Wolfe R. TRISS: does it get better than this? *Acad Emerg Med.* 2004;11:181–186.
2. Champion HR, Sacco WJ, Copes WS. Injury severity scoring again. *J Trauma.* 1995;38:94–95.
3. Kilgo PD, Meredith JW, Hensberry R, Osler TM. A note on the disjointed nature of the injury severity score. *J Trauma.* 2004;57:479–485.
4. Hannan EL, Mendeloff J, Farrell LS, Cayten CG, Murphy JG. Validation of TRISS and ASCOT using a non-MTOS trauma registry. *J Trauma.* 1995;38:83–88.
5. The American College of Surgeons. *National Trauma Data Bank Reference Manual: Background, Caveats, and Resources.* Chicago, IL: The American College of Surgeons; 2005.
6. Glance LG, Osler T. Beyond the major trauma outcome study: benchmarking performance using a national contemporary, population-based trauma registry. *J Trauma.* 2001;51:725–727.
7. Boyd CR, Tolson MA, Copes WS. Evaluating trauma care: the TRISS method. Trauma Score and the Injury Severity Score. *J Trauma.* 1987; 27:370–378.
8. Champion HR, Copes WS, Sacco WJ, et al. The Major Trauma Outcome Study: establishing national norms for trauma care. *J Trauma.* 1990;30: 1356–1365.
9. Kirkham JJ. A comparison of hospital performance with non-ignorable missing covariates: an application to trauma care data. *Stat Med.* 2008; 27:5725–5744.
10. The American College of Surgeons. *National Trauma Data Bank (NTDB) Research Data Set v. 7.1: User Manual.* Chicago, IL: The American College of Surgeons; 2008.
11. Clark DE, Winchell RJ. Risk adjustment for injured patients using administrative data. *J Trauma.* 2004;57:130–140.
12. The American College of Surgeons. *National Trauma Data Bank (NTDB) National Sample Project: ED Admission Years 2003–2006.* Chicago, IL: The American College of Surgeons; 2008.
13. SAS Institute Inc. *SAS Help and Documentation: The MI Procedure: Overview.* Cary, NC: SAS Institute Inc.; 2003.
14. Bennett DA. How can I deal with missing data in my study? *Aust N Z J Public Health.* 2001;25:464–469.
15. Donders AR, van der Heijden GJ, Stijnen T, Moons KG. Review: a gentle introduction to imputation of missing values. *J Clin Epidemiol.* 2006;59:1087–1091.
16. Noland RB, Quddus MA. Improvements in medical care and technology and reductions in traffic-related fatalities in Great Britain. *Accid Anal Prev.* 2004;36:103–113.
17. MacKenzie EJ, Rivara FP, Jurkovich GJ, et al. A national evaluation of the effect of trauma-center care on mortality. *N Engl J Med.* 2006;354:366–378.
18. Rothman KJ, Greenland S, Lash TL. *Modern Epidemiology.* 3rd ed. Philadelphia, PA: Lippincott Williams and Wilkins; 2008.
19. The American College of Surgeons. Trauma Programs: National Trauma Data Bank (NTDB) Reports and Publications. Available at: http://www.facs.org/trauma/ntdb/docpub.html. Accessed 13 June, 2009.
20. Senkowski CK, McKenney MG. Trauma scoring systems: a review. *J Am Coll Surg.* 1999;189:491–503.
21. Sugrue M, Caldwell E, D'Amours S, et al. Time for a change in injury and trauma care delivery: a trauma death review analysis. *ANZ J Surg.* 2008;78:949–954.
22. Traub M, Cass D. Trauma systems. In: McClure RJ, Stevenson M, McEvoy S, eds. *The Scientific Basis of Injury Prevention and Control.* East Hawthorn, Victoria: IP Communications;2004:233–245.