The Revised Estimated Survival Probability Index of Trauma Severity

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OVER THE PAST DECADE, THE MEASUREMENT of injury severity has been recognized as an important component of any study that attempts to evaluate the effectiveness of medical care among victims of traumatic injuries. Indices for measuring severity are usually based either on physiological variables (for example, blood pressure, capillary return, respiratory rate, response to stimuli) or on variables pertaining to the anatomic sites of the injuries. In retrospective studies based on examination of patient records, it is often not possible to use the indices based on physiological variables, since the needed information is frequently missing from the record or not reliable. In contrast, information on the anatomic sites of the injuries can often be found, albeit with some difficulty, on the hospital medical record; for this reason any measurement of injury severity done retrospectively from a medical record is likely to be based on anatomic information.

Of the anatomic indices that have been developed, the most widely used is the Injury Severity Score (ISS) (*1,2*). This index is a modification of an earlier index, the Abbreviated Injury Scale (AIS) which was originally developed for motor vehicle injuries. The AIS-ISS system of grading severity has undergone considerable evolution as experience in its use has accumulated, and an updated version appeared in 1980 (*3*).

An important limitation of the AIS-ISS system is that it entails a thorough examination of the body of the medical record to obtain the information on which severity is graded. The time required for such a thorough examination of records could make the costs of large multihospital studies prohibitively high and could seriously affect their feasibility. As an alternative to the AIS-ISS system of grading severity, we are proposing an index based on the International Classification of Diseases, Adapted (ICDA) conditions listed on the face sheet of virtually every medical record. Since it is based entirely on face-sheet information and hence does not require lengthy examination of the medical record, severity can be graded according to this index in a fraction of the time needed to obtain AIS-ISS scores. However, since the ICDA-8 system for categorizing traumatic injuries (ICDA 800–996) was not constructed for the specific purpose of scoring severity, several caveats (to be discussed subsequently) should be kept in mind when this index is used.

The index that we propose is called the Revised Estimated Survival Probability Index or RESP index. It is a modification of an earlier index called the Estimated Survival Probability Index or ESP index. Details on the development and validation of the ESP index have been published (*4*). We have used the ESP index in a large study evaluating the Illinois Trauma System (*5,6*).

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Methods

Conceptual model. The conceptual model for the RESP index is that the severity of multiple injuries with respect to "threat to life" can be expressed as a function of the severity of the individual injuries in terms of the threat to life existent if each injury were present as a single condition. In particular we used the following model:

$$P_{ijk\ldots l} = P_i \times P_j \times P_k \ldots \times P_l \qquad (1)$$

where

$P_{ijk\ldots l}$ = the probability of a patient surviving if he or she is admitted to the hospital with trauma conditions: $i, j, k, \ldots, l$ (expressed as ICDA codes)

P_i = the probability of a patient surviving if he or she is admitted to the hospital with trauma condition i (expressed as an ICDA code) and no other trauma condition (P_i is called the single condition survival rate)

and

$P_j, P_k, \ldots, P_l$ are defined similarly to P_i.

The basis of this model lies in the multiplicative law of probability; that is, if each trauma condition were acting independently of the other trauma conditions present with respect to threat to life, then the probability of a patient with multiple traumas surviving hospitalization would be equal to the product of the individual single condition survival rates, P_i, just described.

The model expressed in equation 1 is likely to be an oversimplification of the effects of multiple traumas, especially if several organ systems are involved in the injury. However, the rationale for this approach is that the product of the single condition survival rates might be a good enough approximation to stratify patients into groups.

With this conceptual model, our strategy was to obtain estimates of these single condition survival rates from an appropriate data source and to evaluate the utility of this model on a set of patients having multiple injuries.

Data source. The data used in constructing the Revised Estimated Survival Probability (RESP) Index are from the Hospital Discharge Survey (HDS), a nationwide probability survey conducted by the National Center for Health Statistics (NCHS) (7). In particular, we used standardized microdata tapes from the HDS covering the years 1971–75 for a total of 1,106,011 records. From this data set, a working tape was compiled consisting of all patients hospitalized with one or more trauma conditions (defined as ICDA-8 codes 800.0–939.0, 950.0–959.9, and 991.0–996.9). We did not include burns (940–949), adverse effects of chemical substances (960–989), effects of radiation (990), and complications of surgery or medical care (997–999) in our set of trauma conditions. If a patient had trauma diagnoses in both the inclusion range (800.0–939.0, 950.0–959.9, and 991.0–996.9) and the exclusion range (940–949, 960–989, 990, 997–999), that case was excluded from the working tape.

Table 1. Selected age-specific regression adjusted single condition survival rates

ICDA codes	Estimated single condition survival rates (P_{ia})		
	Under 45 years	45–64 years	65 years and older
Closed fracture of base of skull (801.0)	.9898	.9466	.9225
Closed fracture of pelvis (808.0)	1.0000	.9568	.9320
Fracture and fracture dislocation of vertebral column with spinal cord lesion (806.0, 806.2, 806.4, and 806.6)	.9587	.8304	.7590
Closed fracture of scapula (811.0)	1.0000	1.0000	1.0000
Cerebral laceration and contusion (851.0)	.9350	.8852	.8575
Injury to spleen without mention of open wound into cavity (865.0)	1.0000	.8359	.7423
Injury to other and unspecified intra-abdominal organs with open wound into cavity (868.1)	.9839	.6182	.4145

From our resulting trauma set (103,517 patients), a 75 percent systematic sample was taken. This data set, (77,600 patients) contains 61,419 patients with only 1 trauma condition and is the base we used to estimate the single condition survival rates.

Estimation of single condition survival rates. For each of 3 age groups (under 45 years, 45–64 years, and 65 years and older) estimated single condition survival rates, P_{ia}, were obtained from 61,419 records for each 4-digit trauma code (for example, 803.1). The subscripts i and a in the symbol P_{ia} specify ICDA condition and age respectively. Because of the large number of 4-digit trauma codes, some codes representing similar conditions or contiguous anatomic sites were grouped (for example, patients hospitalized with the condition 806.0, 806.2, 806.4, or 806.6 were grouped together) and the preliminary single condition survival rates were computed for the grouped codes. The algorithms used in estimating the rates follow; they represent standard methodology for obtaining unbiased estimates from complex sample surveys (*8*).

$$P_{ia} = \sum_{j=1}^{n_{ia}} W_{aij} X_{aij} \div \sum_{j=1}^{n_{ia}} W_{aij}$$

where

P_{ia} = the preliminary single condition survival rate for individuals in age group a for the group of patients having trauma condition i

X_{iaj} = 1 if the jth record among patients who are in group a and have trauma condition i has discharge status "alive"
0 if the discharge status is "dead"

W_{aij} = the HDS weight associated with the jth record among patients who are in age group a and trauma condition i. This weight signifies the number of discharges represented by a particular record selected in the HDS sample.

and

n_{ia} = the number of persons who are in age group a and have a trauma condition i.

It should be noted that NCHS provides a uniform set of instructions to hospitals for determining whether a case is included within the scope of the HDS sampling frame. In particular, patients must be admitted to the hospital to be considered eligible for the survey. This condition is especially important for patients who are discharged dead. Patients who die in the emergency department are strictly excluded from the HDS (*9*).

Use of regression to improve the reliability of the age-specific single condition survival rates. In computing the final survival rates, several steps were taken.

1. For each ICDA condition or group of conditions, 3 estimated preliminary age-specific single condition survival rates, P_{ia}, were computed as described previously, one for each age group (under 45, 45–64, 65 or older). These three rates served as the dependent variable.

2. The midpoints, 22.5 years and 55 years, of the age groups under 45 years and 45–64 years were chosen to represent these groups; the mean 73.1 years of those who were 65 years or older was chosen to represent this age group. These three points served as the independent variable.

3. The number n_{ia} of persons in age group a having trauma condition i served as weights in the calculation of weighted regression coefficients.

4. If the sum of all 3 age groups of the n_{ia} was less than 20 for a trauma condition, that condition was deleted from the group of trauma conditions.

5. With n_{ia} as weights, the P_{ia} as dependent variables, and the ages 22.5, 55, and 73.1 as independent variables, a slope and intercept were estimated by

weighted least squares for those ICDA codes for which

$$\sum_{a=1}^{3} n_{ia} \geq 20.$$

6. Final single condition survival rates P_{ia} were obtained for each of the 3 age groups by computing from the regression line, values at the points 22.5, 55, and 73.1. In those few cases where values above 1.00 were obtained, they were truncated to 1.00.

The rationale for the procedure just outlined is that, for many of these trauma conditions, fatality increases with age. Thus, a fitted regression line making use of this relationship is likely to increase the reliability of the estimated single condition survival rates. The number of cases in each age group was used as weights so that preliminary single condition survival rates based on small n_{ia}'s would not unduly influence the estimated regression line. It should be emphasized that the primary reason for computing the linear regression model was to increase the reliability of the P_{ia}'s. More complex nonlinear relationships between age and the P_{ia}'s could not be explored with three data points. Increasing the number of age-specific single condition survival probabilities beyond three would have led to decreases in the reliability of the initially estimated P_{ia}'s.

A total of 531 single condition survival rates, P_{ia}, were computed (177 codes by 3 age groups), and a sample of these is shown in table 1. The complete set is available on request from the authors. Again, these regression-adjusted single condition survival rates are the building blocks of which the RESP index is constructed.

Of the 177 trauma conditions for which regression lines were calculated, only 24 (13.5 percent) involved fewer than 30 persons over the 3 age groups (that is, $\sum_{a=1}^{3} n_{ia} < 30$). The median number of persons on which the regression lines were based was 90, and the regression line for 57 (32 percent) of the 177 conditions was based on 200 or more cases. The distribution of these 177 P_{ia} is shown for each age group in table 2.

Computation of the RESP index. For each patient in the entire trauma set having one or more trauma conditions for which the estimated single condition survival rates, P_{ia}, have been computed, the RESP index was obtained by taking the product of the P_{ia} over all trauma conditions listed for the patient. For example, if patient j in age group a had trauma conditions i, k, and m, then the RESP score S_j for this patient is computed:

$$S_j = P_{ia} P_{ka} P_{ma}$$

Table 2. Distribution of ICDA codes from source group in ranges of regression-adjusted estimated single condition survival rates, by age group

Range of rates P_{ia}	*Under 45 years*	*45–64 years*	*65 years or older*
.0000–.8000	1	5	9
.8001–.9000	3	11	15
.9001–.9800	15	36	38
.9801–.9959	29	21	11
.9960–.9985	12	10	3
.9986–.9999	9	9	0
1.000	108	85	101
Total	177	177	177

Validation methodology for the RESP index. The conceptual model for the RESP was tested by examining the linear relationship between RESP and mortality. The data set used for validation consisted of all multiple trauma patients in the 75 percent sample of HDS. This sample is equal to 14,824 persons with more than one trauma ICDA code listed.

One method for examining the relationship between a dichotomous dependent variable (such as mortality) and a continuous independent variable (such as RESP) is the logistic model. The specific logistic model examined takes the form:

$$\text{Logit } P_i = \alpha + \beta X_i$$

where

P_i = the probability of death from multiple trauma
X_i = RESP index for patient i

and

$$\text{Logit } P_i = ln \frac{P_i}{1-P_i} = \text{the natural logarithm of the odds of death from multiple trauma}$$

The α and β regression parameters are estimated by maximum likelihood methods using standard computer programs (*10*). The focus of the validation is on the β parameter; if this parameter is negative and significant, it will indicate that there is a linear relationship between RESP and mortality.

In addition to the logistic regression fit to the continuous values of RESP, the *ln* odds for seven categories of RESP was obtained by a simple cross-classification. The seven categories are defined as follows: $\leq .5000$, .5001–.6000, .6001–.7000, .7001–

.8000, .8001–.9000, .9001–.9500, .9501–1.0000. The classes selected represent deciles except for the ≤ .5000 group, where there are few cases, and the .9001–.9500, .9501–1.0000 groupings, where the greatest number of trauma patients are found.

Graphs of the *ln* odds against RESP values are then obtained for both the logistic model and the categorical data. For the logistic model the relationship between the *ln* odds and RESP is constrained to be linear. However, plots of the *ln* odds from the categorical data (plotted at the mean RESP value for each category) are not forced to be linear. By comparing the graph from the logistic model with that obtained from the categorical data, departures from linearity can be identified. A close "fit" between the two graphs would be interpreted as strong evidence of the linear relationship between RESP and mortality.

The logistic model between RESP and mortality is analyzed for selected groups of patients. Models are fit for all multiple traumas, separately for patients with two, three, four, and five trauma conditions, patients with intracranial injuries (ICDA 850.0–854.9), and patients with cerebral lacerations and contusions, without mention of open intracranial wound (ICDA 851.0). The objective of these separate analyses is to determine the ability of RESP to discriminate among groups of patients even when matched on the number or type of traumatic conditions.

Results

Table 3 presents the results of seven logistic regressions between RESP and mortality. For each analysis the number of records, the beta coefficient, and the standard error are presented. The beta coefficients are large and negative for all models. Likewise, the *P* values are highly significant for each logistic model.

For the four separate strata based on the number of trauma conditions, the beta coefficients exhibit a trend of decrease with the increasing number of trauma diagnoses. For example, the beta coefficient for the continuous RESP model with patients having 2 trauma conditions is —11.5 while that for patients with 5 trauma conditions is —7.6. This pattern in the individual beta coefficients makes intuitive sense because differences between RESP scores for deaths and survivors among patients sustaining two or three injuries is apt to be more pronounced than in the group of patients with five trauma conditions. Further support is given to the RESP index by examining the beta coefficients for the subset of patients with intracranial injury and cerebral lacerations and contusions. Again, the relatively large negative values of the coefficients indicate the linear relationship between RESP and mortality even within these two intrinsically severe subsets of patients.

Table 3. Logistic regression analysis of mortality and RESP for the 75 percent sample of multiple trauma patients and separately for patients with two, three, four, and five trauma conditions, patients with intracranial injuries, and cerebral lacerations and contusions

Data set analyzed	*Number of patients*	*Beta*	*Standard error*
All multiple trauma	14,824	−10.8097	.4810
2 trauma conditions	10,591	−11.5004	.7015
3 trauma conditions	3,011	−9.2010	.8934
4 trauma conditions	909	−9.4708	1.2582
5 trauma conditions	313	−7.5716	1.6274
Intracranial injury	4,801	−8.9037	.5825
Cerebral lacerations and contusions	528	−7.7249	1.5778

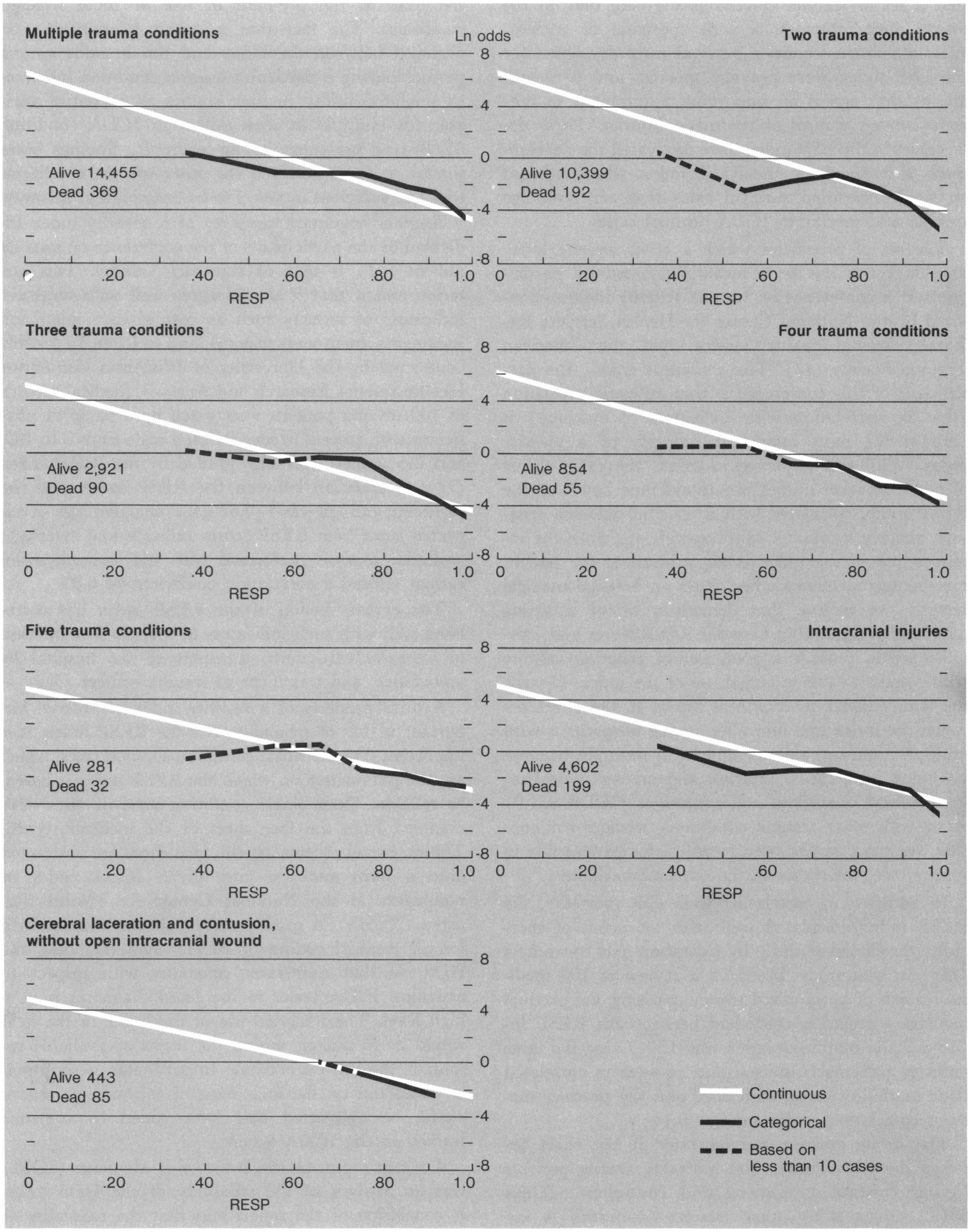
NOTE: *P* values for all betas are < .0001.

The chart portrays the relationship between RESP and *ln* odds for both the continuous and grouped data. For the total multiple trauma data set, there is a close parallel between the grouped and continuous models at all levels of RESP; the only divergence observed is at RESP values of less than .60 where the continuous model predicts slightly higher values of the *ln* odds than the grouped data indicate. The plots for the subset of patients with two, three, four, and five trauma conditions (see chart), indicates a close fit between the logistic model and the categorical data. For the group with two conditions, some deviation from the linear fit is observed at RESP values of less than .70, where the logistic tends to overpredict the observed *ln* odds. It is especially interesting to note the close parallel between the logistic model and the categorical plots for patients with four and five trauma conditions. Finally, the graphs for intracranial injuries and cerebral lacerations and contusions demonstrate a remarkably close fit between the logistic model and grouped data. Even for the group with cerebral lacerations and contusions, a condition which has a 16.1 percent overall mortality rate, the RESP is clearly able to order patients according to severity. (Categorical plots for the two classes ≤ .5000 and .5001–.6000 could not be obtained since these classes contained one case each; likewise, no cases could occur in the .9501–1.0000 class because of the severity of cerebral lacerations and contusions).

Discussion

In the development of single condition survival rates for the earlier ESP index, decimal ICDA numbers were collapsed into integer codes (for example, 800.0

Ln odds against the continuous Revised Estimated Survival Probability and the RESP grouped into seven categories for patients with trauma conditions



and 800.1 into 800). It is often the case, however, that a set of trauma conditions differing only in the fourth digit represents a wide spectrum of severity. Also, the single condition survival rates developed for the ESP index were not age specific, and it is well known that age is an important determinant of outcome among victims of traumatic injuries. These deficiencies in the ESP index have motivated the development of its successor, the RESP index, which is based on single condition survival rates that are both age specific and specific to ICDA decimal codes.

The set of properties which a good severity index should possess has been recently debated by participants at a conference on trauma severity indices sponsored by the National Center for Health Services Research, Public Health Service, and the American Trauma Society (*11*). The consensus among the participants of this conference is that outcome prediction (that is, correlation with indicators of outcome) is perhaps the most important property of a severity index. With this objective in mind, the main thrust of our validation studies was to examine how well the RESP index correlates with a specific outcome measure, namely mortality. More specifically, since the intended use of the index is an adjustment for patient mix in retrospective studies based on hospital medical records, we believe that demonstration of a strong monotonic relationship between RESP scores and mortality would provide a good test of criterion validity with respect to this intended use of the index. Clearly, the strong linear relationships shown in the chart between the index and mortality among all patients with multiple traumas, among those with multiple traumas involving intracranial injuries, and among those having cerebral lacerations and contusions (ICDA 851.0) along with other trauma conditions provides evidence that the index can be used to adjust for patient mix in studies using mortality as the outcome variable.

In addition to correlating well with mortality, the RESP index correlated well with an index of morbidity developed recently by Gustafson and co-workers (*11*). In that study, based on a review of 100 medical records of hospitalized trauma patients, the product moment correlation coefficient between the RESP index and the morbidity index was 0.57. Using the same series of patients Gustafson and co-workers correlated their morbidity index with ISS, and the product moment correlation coefficient was 0.44.

The strong gradient demonstrated in the chart between the RESP index and mortality among patients having cerebral lacerations and contusions (ICDA 851.0) along with other trauma conditions is encouraging because of the intended use of this index in tracer studies. In such studies, ascertainment is on the basis of the presence of one or more selected conditions. The fact that a strong relationship was observed between the index and the *ln* odds among persons having a particular trauma condition indicates its potential utility in such studies as a control variable for multiple injuries. Although ICDA condition 851.0 was presented as an example, findings were similar to those observed for other specific conditions that had sufficient numbers to be examined in this way.

Another important property of a severity index indicated by the participants of the conference on severity indices (*11*) is that of construct validity. This criterion means that it should agree well with objective indicators of severity such as cost of care, physician judgments, treatments selected, and so forth. In a study conducted by the University of Wisconsin Center for Health Systems Research and Analysis, medical records of 100 trauma patients were rated by a panel of physicians with respect to severity on a scale from 0 to 100, and the records were also graded by the RESP index (*11*). Correlation between the RESP index and the physician ratings was —0.67 (the negative sign is expected since high RESP scores indicate low severity); a similar analysis performed with ISS and physician ratings yielded a correlation coefficient of 0.67.

The earlier version of the RESP index has correlated well with such indicators of severity as admission to intensive care units, transport to the hospital by ambulance, and treatment at trauma centers (*6*).

A third property of a severity index considered important is that of reliability. For the RESP index, it is important that the single condition survival rates, which are the parameters on which the RESP index is based, be reliable. These single condition survival rates were obtained from the face sheet of the medical record. The diagnoses written on the face sheet are abstracted onto a form and are later given ICDA codes by nosologists at the National Center for Health Statistics (NCHS). A quality control system is maintained for all medical coding of NCHS data including the HDS, so that inter-rater reliability with respect to assigning ICDA codes to the listed diagnoses is at a high level. The intended use of the index in the field would be to mirror, within the limits of available resources, the HDS procedure. In particular, descriptions of conditions on the face sheet of the medical record would be abstracted and later coded by someone trained in the ICDA system.

A recent report by the Institute of Medicine (IOM) was an analysis of the reliability of the HDS (*12*). A conclusion of the report was that the reliability of the HDS was not satisfactory. In particular, the IOM researchers found the reliability of nonmedical information above 90 percent; for diagnostic information, the HDS abstract and the IOM reabstract agreed on the principal diagnosis in 63.4 percent of the cases at the 4-digit level of ICDA-8 coding. Their principal recommendation was that a more complete review of the entire medical record (especially the narrative discharge summary) would improve HDS diagnostic reliability.

Does the IOM study impugn the validity of the RESP index? First, reliability in the IOM study included both ordering and coding errors; in the construction of the RESP index the ordering of primary, secondary, and tertiary diagnoses has no impact. Only cases with single trauma diagnostic codes, whether primary or not, were used in estimating the P_{ia}'s. Second, the reliability of the HDS should be examined in terms of its biasing impact on the RESP. That is, if the errors in ICDA trauma codes are random and not related to underlying injury severity, the effect on the calculation of the P_{ia} values and the subsequent RESP scores would be negligible.

To understand further the potential biasing impact of the unreliability of face-sheet information, we are currently conducting studies involving primary data collection. The results will be reported when the studies are completed.

Unlike the AIS system, which was developed with the specific objective of grading injury severity, trauma codes in the ICDA system do not always characterize the severity of an injury. Any index based on ICDA codes should therefore be considered a pragmatic tool and should be used primarily as a covariate in studies involving groups of patients rather than for prognosis, triage, or audit of individual patients. So long as the ICDA system remains as the "universal" system for categorizing disease including injuries, ICDA codes will be obtainable more readily than AIS codes. For this reason, an index based on ICDA codes is needed, and the RESP index, because it is easy to use and has demonstrated high association with fatality and morbidity in a variety of settings, is a potentially useful tool in trauma studies.

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SYNOPSIS

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The construction of a revised version of the Estimated Survival Probability Index (or ESP index) is described. The original index had been proposed as a tool that would be useful in grading from hospital medical records the severity of injuries sustained by patients hospitalized with trauma conditions. The revised index (RESP) is based on a data set of 61,419 records. Unlike the ESP, the RESP index is based upon parameters that are age specific and specific to decimal ICDA codes. The RESP is validated by correlating RESP scores with observed mortality by using an independent set of multiple-trauma patients. Overall, a strong monotonic relationship between the RESP index and increasing mortality was demonstrated. Also, the RESP index correlated with mortality in selected subsets of multiple trauma patients with extremely severe injuries. Some uses and limitations of this index are discussed.