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Trauma Severity Scoring to Predict Mortality

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The evaluation of the care of the multiple trauma patient requires indices that predict survival or death and that reveal the presence or absence of complications. This article reviews briefly the different scales that have been developed. It is concluded that both anatomic and physiologic injury scores are required. A methodology of patient care evaluation is then developed based upon preliminary method (PRE), a state transition screen (STS), and a definitive method (DEF). The preliminary method is illustrated by use of the Trauma Score and the Injury Severity Score to predict patient outcome. This is then compared with the actual patient outcome. The STS methodology reveals patients who are better or worse than expected in their course in the hospital. The DEF method is used for comparison between institutions or for different time periods at a given institution.

Methods for the measurement of injury severity are essential for the appropriate allocation of therapeutic resources, prediction of outcome, and quantitative and qualitative evaluation of trauma care in different facilities or systems over time. Characterization of traumatic injury is complex, especially for multiorgan, multisystem injuries. Many trauma severity scales have been developed. The scales differ widely in their intended use, in the way they were derived, and in their statistical and face validity. To date, no one scale has been able to meet all varied needs of a trauma system since emergency medical service (EMS) administrators, physicians, and hospitals have different perspectives concerning the trauma patient, many of which can influence treatment and outcome.

Thus, one approach to categorizing indices of severity is by application. Those developed for patient triage, epidemiological studies, patient tracking and management, and evaluation of care will be reviewed. This review of trauma severity scales will briefly identify those indices generally considered to be the most advanced in their category. Indices that relate to aspects of morbidity and cost of care remain somewhat rudimentary. Other scales designed for use in non-trauma patients are beyond the scope of this review.

Triage

In battle or disaster circumstances, the term *triage* refers to the process of sorting patients into treatment or logistical hierarchies. In the day-to-day operations of a health care system, the term refers more broadly to the steps that must be taken to identify the patient at risk and to match existing resources to patient needs. An estimate of injury severity in terms of the patient's probability of survival is the essential underpinning of the triage process. Consequently, a severity index used for triage should have a high correlation with patient survival.

The Glasgow Coma Scale [1] provides a practical definition of coma for assessing the severity of brain function, brain damage, and the progress of the patient. The scale examines 3 behavioral responses: eye opening, best motor response, and best verbal response. Each response is assessed and scored independently of the others. The total score represents the severity of the patient's condition and has

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Table 1. The Trauma Score: Variable definitions, methods of assessment and codes.

		Rate	Codes	Score
A. Respiratory rate		10–24	4	
Number of respirations in 15 seconds; multiply by 4		25–35	3	
		>35	2	
		<10	1	
		0	0	A. ___
B. Respiratory Effort				
Retractive: Use of accessory muscles or intercostal retraction		Normal	1	
		Retractive	0	B. ___
C. Systolic blood pressure		≥90	4	
Systolic cuff pressure: either arm, auscultate or palpate		70–89	3	
		50–69	2	
		<50	1	
No carotid pulse		0	0	C. ___
D. Capillary refill				
Normal: Forehead or lip mucosa color refill in 2 seconds		Normal	2	
Delayed: More than 2 seconds capillary refill		Delayed	1	
None: No capillary refill		None	0	D. ___
E. Glasgow Coma Scale		Total GCS points	Score	
1. Eye opening				
Spontaneous	___ 4	14–15	5	
To voice	___ 3	11–13	4	
To pain	___ 2	8–10	3	
None	___ 1	5–7	2	
		3–4	1	E. ___
2. Verbal response				
Oriented	___ 5			
Confused	___ 4			
Inappropriate words	___ 3			
Incomprehensible sounds	___ 2			
None	___ 1			
3. Motor response				
Obeys commands	___ 6			
Purposeful movements (pain)	___ 5			
Withdraw (pain)	___ 4			
Flexion (pain)	___ 3			
Extension (pain)	___ 2			
None	___ 1			
Total GCS points (1 + 2 + 3) ___			Trauma Score ___ (Total points A + B + C + D + E)	

been correlated with the Glasgow Outcome Scale [2], which grades the level of ultimate brain function.

The Glasgow Coma Scale has been used for triage by paramedics in the field and by nurses and physicians in hospital settings. The scale has limitations in terms of the precise evaluation of coma, in that there are insufficient intervals for many applications. However, its simplicity and reliability in unskilled hands make it ideal for many applications.

The Trauma Score [3] (Table 1) contains the Glasgow Coma Scale variables as well as assessments of systolic blood pressure, respiratory rate, respiratory effort, and capillary refill. The Trauma Score (TS) was devised by modifying the mathematically derived Triage Index [4]. Weighted values assigned for the factors are summed to obtain the Trauma Score. The weights were selected by consensus of the participants of a conference on injury severity scoring systems [5]. The Trauma Score values range from 1 (worst prognosis) to 16 (best prognosis).

The performance of the Trauma Score as a predictor of survival was evaluated on a set of 1,820 blunt injured patients. The evaluation was completed using the misclassification rate, sensitivity, specificity, and relative information gain measures. This latter value, denoted as R, is a measure of the predictive power of an index. R takes on values from 0 to 1. High R values imply that an index has high predictive power relative to a perfect index (see Appendix). Results showed that the R value for the Trauma Score was 0.75, a relatively high value. The TS proved to be even more powerful for patients with penetrating injuries, achieving relative information gains of 0.90 for both a general set and a critical set of patients.

Other indices developed for triage have proven less useful than those discussed here. They include the Trauma Index [6], the Illness-Injury Severity Index [7], and the CRAMS Scale [8]. While these indices are simple to apply, they suffer from excessive or unknown misclassification rates, lack of information on inter-rater or intra-rater reliability, or unknown correlations with mortality or other outcomes.

Epidemiological Studies

Indices that scale or score anatomic injury severity have been applied in epidemiological studies of injury and in tracking patients or tracer groups through various echelons of treatment intensity. When used alone, they provide only limited correlation with outcome. When combined with measures of physiologic state, anatomic scales can be used for evaluation of regional, subregional, or institutional levels of care and for identification of patients who have exceptional outcomes.

The Abbreviated Injury Scale (AIS) rates and compares injuries in road vehicle accidents [9]. However, the AIS does not account for multiple injuries, a major drawback. The Injury Severity Score (ISS) was developed as a modification of the AIS [10, 11]. The ISS uses the AIS scores for the 3 most significant injuries suffered in different body regions. Many researchers have found the ISS to be a valuable tool for assessment of injury severity [12–14].

The Anatomic Index (AI) [15] is a set of survival probabilities attached to HICDA-8 codes based on data from blunt trauma patients. A comparison of the ISS and the AI was made to determine if there were significant differences in the usefulness of one index over another. Results showed that their performance as predictors of mortality were comparable based on sensitivity, specificity, misclassification rate, and relative information gain values. The R values for both AI and ISS were near 0.60.

The PEBL Code [16] was developed at the United States Army Armament and Development Command. PEBL codes are constructed by appending additional digits to HICDA codes. PEBL attains greater specificity by accounting for injury size, bone injury characteristics, and partial organ damage, and by distinguishing peripheral blood vessels and nerves. The probability of lethality estimates for penetrating injuries were obtained for PEBL codes based on wound data available on 3,600 combat casualties from Vietnam [17].

Patient Tracking and Management Indices

Patient tracking and management indices are valuable in representing the patient state transitions that follow traumatic injury. They are also useful for defining morbidity and cost-related outcome. They have wide application in directing patient care in early diagnosis and therapeutics. Many severity scales have been developed for use in the intensive care setting, including TISS [18], APACHE [19], and methods by Cullen et al. [20] and Shoemaker et al. [21]. These scales are used principally to characterize non-trauma patients and will not be discussed here.

Siegel and colleagues pioneered the development of sophisticated techniques for the tracking and management of the critically ill and injured patients in the ICU [22–27]. The techniques are currently implemented on a computer-based Clinical Assessment, Research and Education (CARE) system [28–30].

The system permits interactive entry of clinical information, fluid intake and output data, and biochemical, immunologic, and metabolic profiles as related to the cardiophysiologic data. The patient's cardiovascular and metabolic abnormalities can be compared over time to prototype patterns obtained from previously studied patients. From this physiologic state "trajectory," the physician can infer pathophysiologic mechanisms and make the appropriate therapeutic decisions.

Sacco and colleagues developed a broad class of trauma indices, covering a range of patient conditions. The Respiratory Index [31] was developed to measure post-traumatic pulmonary problems and can be used as a simple guide for respiratory therapy. The Renal Index [32] evaluates renal function and indications for hemodialysis. The CHOP Index [33] is used as a more general inhospital predictor of critical patient outcome. The Global Score is a dynamic (time dependent), overall predictor of patient severity derived from the statistically most powerful measurements among respiratory, renal, hepatic, central nervous system, and cardiovascular variables. The Global Score can be used to track patients [34], as a mortality and morbidity index, and for evaluation of patient care.

Evaluation of Care

Probably the greatest need in emergency medical service systems and particularly for trauma victims is a method for evaluating patient care. The ability to determine the appropriateness of outcome and the effectiveness of treatment is fundamental to documenting the validity of the systematic approach to regional trauma care.

Many scales have been developed with the intent of meeting this need. The Wisconsin Trauma Index [35] classifies severity of patient states at specific times during the acute phase of the injury (such as upon hospital admission, in the emergency room, just prior to surgery, or just prior to transfer to another hospital). It includes variables associated with the central nervous system, brain stem, cardiovascular system, pulmonary system, abdomen, and burns, as well as other factors, such as age.

Many other indices claim to be targeted to evaluation of trauma care. This is best accomplished through the incorporation of the patient's anatomical and physiological information into the evaluative mechanism. Toward this end, a 3-step approach has been developed that provides both a qualitative and a quantitative assessment of patient severity and outcome, in terms of both mortality and morbidity. The framework of this 3-step approach is briefly described.

The first level, called PRE (from *preliminary*), identifies trauma patients whose outcomes appear to be anomalous, such as "unexpected" deaths or survivals. PRE is essentially a qualitative evaluation [36]. The State Transition Screen (STS) is an extension of PRE and identifies cases for audit that would not be selected by PRE. Such cases include: (a) survivors who were "expected" to survive, yet who experience substantially poorer clinical states during their hospital stay than was expected based on their condition at admission; or (b) nonsurvivors who were "expected" to die, yet who experience substantially better clinical states during their hospital stay than would be expected based on condition at admission.

The third level, called DEF (from *definitive*) provides a quantitative comparison of care between 2 trauma services or systems [36]. DEF accounts explicitly for the differences in patient mix, the "predictive power" of the indices, and the statistical significance of the comparison. Each level will be discussed briefly.

PREliminary Method

The PRE methodology uses an anatomical measure of injury severity and a physiological measure of severity to identify anomalous outcomes. Here, PRE is illustrated in terms of the Trauma Score (TS) and the Injury Severity Score (ISS). Other combinations of indices may be used, such as TS, ISS and age. Each trauma patient in the population under study is assigned a value for the TS and for the ISS. The values are plotted on a simple 2-dimensional graph in terms of survival or death and examined in relation to a line delineating a 50% chance of survival. This line is called the S50 Isobar and is determined mathematically. Combinations of TS and ISS that are below the S50 isobar have chances of survival greater than 50%. Combinations above the S50 isobar have less than a 50% chance of survival. The set, S_A, of survivors whose points are above the line and the set, N_B, of nonsurvivors below the line, constitute a set of patients whose outcome was unexpected based on the TS/ISS scores.

Figure 1 displays TS/ISS combinations from 208 consecutive severe blunt trauma patients. The dots are associated with survivors; the *X*'s represent nonsurvivors. Some patients have the same TS/ISS pair, indicated by a number near the symbol. The patient outcomes are examined in relation to the S50 isobar. Of the 208 patients, there were 14 unexpected outcomes: 6 patients in S_A (survivors above the S50 isobar) and 8 patients in N_B (nonsurvivors below the S50 isobar). These 14 patients, then, would become the focus of a quality of care audit to determine the reasons for the unexpected outcomes.

The PRE filter rapidly identifies outcome anomalies but will not pick up patients with non-linear trajectories of course of illness between arrival and discharge. These patients comprise 2 groups: (a) those expected to die but who improve before dying; (b) those expected to live but who get worse before ultimately surviving. This latter group may be a group with significant morbidity. Both groups demand close scrutiny and the STS methodology allows this.

State Transition Screen Method

The State Transition Screen is based on the concepts of Global Score, Morbidity Transition (MT), and Minimum Morbidity. The Global Score is a function of the Respiratory Score [Respiratory Index + (Peep/5)], serum creatinine, serum bilirubin, and the Glasgow Coma Scale. The lower the score, the higher the patient's probability of survival. It is computed as follows:

$$\text{Global Score} = R_n + C_n + B_n + G_n$$

where R_n = 1.5 × Respiratory Score; C_n = 2.0 × Serum Creatinine; B_n = 0.5 × Serum Bilirubin; G_n

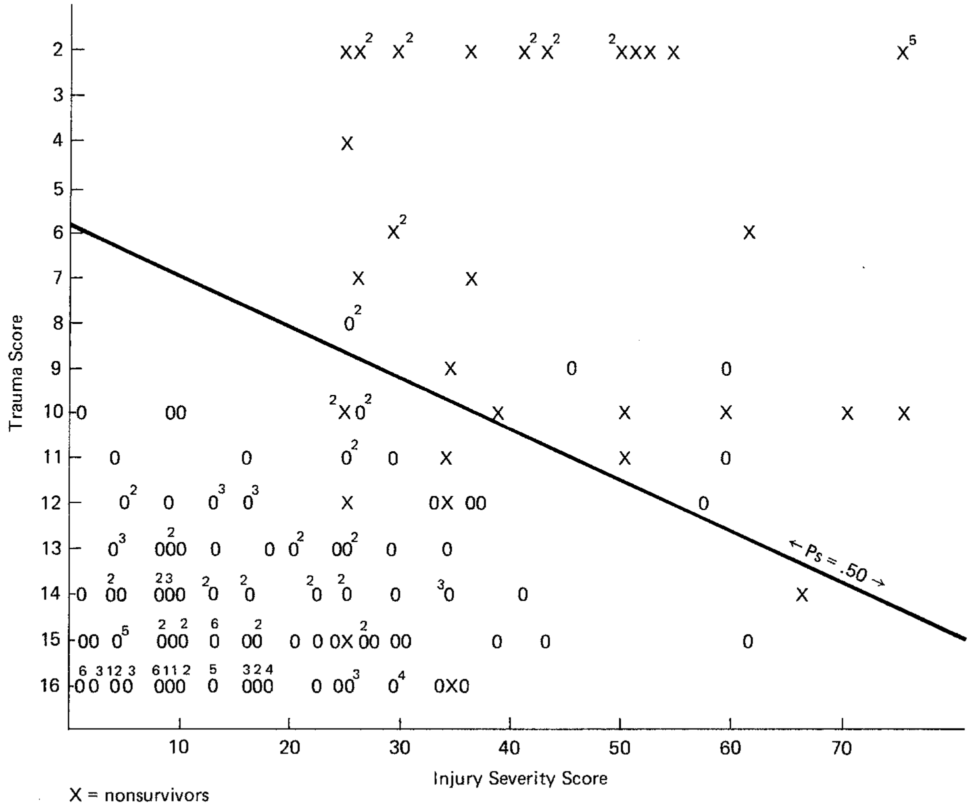

Fig. 1. Trauma Score and Injury Severity Score on 208 blunt major trauma patients from Washington Hospital Center.

= 15.0 − Glasgow Coma Scale. Morbidity Transition (MT) is defined as follows:

$$MT = \begin{matrix} P_L - P_A \text{ if } P_A > P_L \\ 1 - P_A \text{ if } P_L = P_A \end{matrix}$$

where P_L is the least probability of survival attained during a patient's stay, and P_A is the probability of survival based on admission state. This measure can be obtained for survivors and nonsurvivors. For nonsurvivors $P_L = 0$ and $MT = -P_A$. For survivors whose least probability of survival occurs at admission, $P_L = P_A$ and $MT = 1 - P_A$.

MT ranges from −1.00 to 1.00. A positive MT means that the patient's condition is never worse than at admission, and thus is a desirable therapeutic goal. Conversely, a negative MT means that the patient's condition at some time during the hospital stay was poorer than at admission. This is undesirable. Survivors with substantial negative MT values who are not identified by PRE provide additional interesting cases for audit. Such patients are defined as those for whom $P_A > 0.50$ and for whom $MT \leq -0.25$. P_A is based on Trauma Score, Injury Severity Score, and patient age combinations.

Minimum Morbidity (MM) is defined for *nonsurvivors only* as follows: MM = Minimum Global Score experienced by the patient during the hospital stay. Important cases for audit are nonsurvivors, not cited by PRE, who have small values of MM and small values of P_A. These are patients whose condition seems to improve substantially, yet they do not survive. Specifically, such nonsurvivors are defined as those with $P_A < 0.50$ and for whom the minimum Global Score ≤ 10.

Both PRE and STS can be used effectively for intrahospital evaluations. For interhospital evaluation or intersystem comparison of outcome, a quantitative methodology is fundamental to assure that the evaluation is based on truly objective indicators and that the veneer of "opinion" does not enter into the methodological equation. The DEF methodology assures this.

DEFinitive Method

DEF provides a definitive quantitative comparison of survival rates either among institutions or for a given institution over different periods of time. This method requires the computation of 2 quantities: a statistic, *z*, proposed by Flora [37] for the comparison of a "test" institution and a "standard" (baseline) institution; and a quantity called the C-factor, which is an explicit measure of the credibility of the comparison. The quantity *z* measures the disparity between the actual number of survivors in the test institution population and the number of survivors expected from the baseline results.

DEF is intended to approach an "ideal" comparison of patient outcomes between a test institution and a standard institution. Such a comparison would be realized, with respect to an index, or combination of indices, if the following criteria were met:

1. The index values were obtained objectively and accurately in both institutions.
2. The comparisons were based on the same "severity mix" of patients from each institution.
3. The index discriminates perfectly between survivors and nonsurvivors in the standard institution.

Clearly, the severity mix will vary from one institution to another, and it is unlikely that an index or combination of indices will discriminate perfectly between survivors and nonsurvivors, even when it is applied to the patient set from which it is derived. Thus, in practice, the second and third criteria are never satisfied. DEF quantifies the disparities and provides a numeric indicator of the validity of the comparison.

Conclusion

The establishment of trauma systems has been controversial among physicians, hospital administrators, and political activists. Hospital administrators and physicians have been wary that certain patients would bypass their hospitals or would have to be transferred to trauma centers based on preestablished criteria. Clear specifications for patients who warrant care at a trauma center versus those who can be adequately cared for elsewhere have not emerged. Few studies "documenting" the value of trauma centers have withstood rigorous scientific scrutiny.

There is a general conviction that state of the art methods exist to correlate trauma patient severity with outcome. Widespread testing currently underway may identify areas for refinement, so that such indices can be incorporated into trauma care systems, such as trauma registries to monitor epidemiology, quality of care, and system needs.

Injury severity scales of proven reliability and validity are clearly essential to ensure accuracy in prediction of outcome, to complete evaluations of trauma care, and ultimately to determine program impact. Only when such scales have been incorporated into prediction of outcome studies can truly meaningful statements be made regarding: the role of physician extenders in pre-hospital care; the impact of time to definitive treatment; the impact of trauma centers within a given region; the change in quality of care in a given trauma center over time; and strategies to reduce trauma mortality and morbidity rates.

Appendix. Relative Information Gain (*R*) and the PER Method. The relative information gain, *R*, is a measure of the predictive power of an index, relative to a perfect index. It is derived from the following expression:

$$R = \frac{E}{2P(1 - P)};$$

where

$$E = \sum_x \left| P - P_s(x) \right| f(x)$$

In these expressions, *P* is the a priori probability of survival (the survival rate) for all patients in the population being analyzed; $P_s(x)$ is the probability of survival given *x;* and *f(x)* is the fraction of patients with index value *x*.

The quantity *E,* which is called the information gain, is the average change (from *P*) in the estimation of the probability of survival based on the index. The average change (from *P*) for a perfect index is 2P(1 − P).

R takes on values from 0 to 1. High *R* values imply that an index has high predictive power relative to a perfect index. We refer to this method of measuring an index as the PER method, as the 3 quantities *P, E,* and *R* are involved.

Résumé

L'appréciation exacte du traitement des polytraumatisés nécessite la définition de repères indicatifs qui permettent de prédire la survie ou le décès et qui révèlent la présence ou l'absence de complications.

Cet article fasse en revue les différentes méthodes d'évaluation qui ont été retenues. Leur étude a conduit à la conclusion que des éléments anatomiques aussi bien que des éléments physiologiques sont à prendre en considération.

L'évaluation de ces facteurs répond à trois étapes: étape préliminaire (PRE), étape de transition (STS), étape définitive (DEF).

L'évaluation préliminaire repose sur l'emploi d'une échelle de gravité traumatique. Pour une blessure donnée elle repose sur les données obtenues en prenant en compte l'état général du blessé. L'évaluation intermédiaire permet de préjuger de l'évolution différente que celle envisagée initialement que ce soit dans un sens favorable ou défavorable.

Cette méthode permet de comparer les résultats obtenus par les différents centres de soins et pour une même institution de connaître l'évolution des résultats.

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